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Johannes Schweitzer

13 April 2020

H01PS.01

H01PS - Climate and land surface changes in hydrology

Poster

Role of radiometric surface temperature for analytical estimation of surface energy balance states and fluxes

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We present a novel analytical solution of the terrestrial surface energy balance fluxes (sensible heat, H and latent heat, LE), conductances (boundary layer, gB and surface, gS), and soil moisture availability (M). This method, called the Land Surface temperature based Partitioned Evapotranspiration Model (LSPEM), is based on a set of five equations that combines the Penman-Monteith equation (PME), Priestley-Taylor equation, diffusion equations, and Bouchet's Complementary hypothesis, formulated such that explicit specification of the conductances is not needed, and hence retrieved. LSPEM is driven with radiometric surface temperature (Tsfc), net radiation (RN), ground heat flux (G), air temperature (Ta) and relative humidity (RH). Estimated LE and H were validated against eddy covariance observations at 17 semi-arid FLUXNET sites over 5 continents. We find a RMSE of 53 mm/yr on annual evapotranspiration (ET) with a correlation between observed and estimated ET to be 0.95. LSPEM is marginally sensitive to the uncertainties in Tsfc and efficiently captured the dry down period in the semi-arid landscapes where LE is strongly governed by the subsurface soil moisture and where LE models in general show poor results. A realistic response and modest correlation was found when the partitioned LE components (evaporation, E and transpiration T) were related to the observed soil moisture and rainfall. This study highlights the importance of Tsfc in finding the analytical solution of surface energy balance states and fluxes in the framework of PME closure. The initial promise of LSPEM over semi-arid landscape points to its potential to benefit from future NASA and NOAA missions having thermal sensors, such as HyspIRI, GeoSTAR and GOES-R for mapping multi-scale LE and drought.

H01PS.02

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Poster

Evaluation of Multiple Satellite-based Rainfall Products over Complex Topography

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Hydrological predictions in topographically complex regions are challenging due mainly to high spatial variability in hydrologic processes and fluxes. Difficulties in establishing ground-based observation networks exert further limitations in these regions. Rainfall, being the primary driver of the hydrologic cycle, is strongly controlled by the topography. Recent improvements in the ability of satellite-based rainfall retrieval algorithms to produce near-real time estimates at high space and time resolutions make them potentially attractive for hydrologic studies in watersheds with complex topography. This study evaluates three different satellite-based rainfall retrieval algorithms, namely, Tropical Rainfall Measuring Mission Multi-satellite Precipitation Analysis (TMPA), NOAA/Climate Prediction Center Morphing Method (CMORPH) and EUMETSAT's Multi-Sensor Precipitation Estimate (MPE) using a relatively dense rain gauge network within topographically complex Filyos Basin in Turkey. The evaluation is performed at multiple time and space scales using quantitative, categorical and graphical measures. Our results indicated that satellite-based products significantly underestimated the rainfall in regions characterized by orographic rainfall and overestimated the rainfall in the drier regions. The results also indicated that there exists a seasonal dependency in the degree of agreement between satellite-based rainfall products and the rain gauge network. We will present the details of the evaluation results and discuss potential implications of using satellite-based rainfall algorithms as input to hydrologic models in topographically complex regions.

H01PS.03

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Poster

Spatial and temporal relations between forest cover and low flow regime in Blue Nile Basin, Ethiopia

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Water scarcity during the dry season is a rising problem facing in the Blue Nile Basin of Ethiopia. Reestablishment of forests is regarded as an important tool for integrated water management strategies to improve the security of the food and water supplies in the region. But the effect of forest cover changes is hard to predict without data specific to the local catchments and climate information. Fortunately, the region is fortunate to have over a dozen gauging stations with records of daily water flow extending back almost half a century to proof the upper said hypotheses. Spatial and temporal relations between forest cover and low flow hydrology are investigated using the long term data records. The aims of this study are 1) to assemble and analyze the relationship between watershed characteristics, including forest cover, and low flow at spatial scale; 2) to document forest cover change and analyze its relation to low flow hydrology at temporal dimension using the time series data from 1960-2004. Multivariate analysis was used to see the spatial relation; while a combination of statistics, modeling and qualitative data analysis were used in analyzing the relationship along time series. The spatial analysis showed that woodland and grassland were positively correlated with low flow regime; while grazing land correlated negatively. Tuffs/Basalts are also showed strong negative correlation with low flow regime. Changes in the low flow hydrology were few whereas the change in forest cover was big along the temporal scale. In addition, relationship between forest cover change and low flow was little and inconsistent among the different watersheds. The few changes in the low flow regime were also watershed specific and not following general trend across the Basin. So, forest cover change relation to low flow hydrology is watershed specific and more pronounced in wet – lowland areas, where woodland and grassland are dominant. As these two land cover types were vulnera

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Poster

The impact of climate warming on the peak discharges time in the Greater Zab, Lesser Zab and Khazir rivers in Iraq

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The time of peak discharges in rivers is considered a good indicator in the climatological variation in the rivers basins reflecting their values for long periods. The water quantities of the melted snow during spring season is one of the main sources feeding rivers in the world like Tigris river and its tributaries in Turkey and Iraq. The climate variation on the rivers basin lead to variation in their hydrograph specially in the peak discharge values and its arrival time. The daily discharges data for three hydrological stations on the Greater Zab, Lesser Zab and Khazir rivers for forty years (1965-2004) was analyzed after the division into two periods (1965-1984) and (1985-2004). Some previous statistical criteria was applied in analyzing the time of peak discharges measured at each river like the annual center time of the discharges (CT). This is the time at which half of annual volume of flowing discharges is passed. However, the recorded air temperature criteria in the climatological stations have been also depended in this analysis.

An early arrival time of peak discharge as a result of an advancement in the melting snow was observed to be (6.2, 7.1,10.4) days for the Greater Zab, Lesser Zab and Khazir rivers stations respectively. This is due to 3.3°C increasing in the average maximum recorded air temperature in the climate stations during the previous forty years.

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Poster

Impacts of climate and land surface changes on urban catchment hydrology

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Rapid land use changes have changed the catchment hydrology and watershed responses. Climate change has also imposed a significant impact on hydrological behavior of the catchments. Extreme responses such as floods, landslides and water quality degradations are frequently reported in most of the urban catchments which experiences high rate of anthropogenic activities. Assessment of hydrological responses to these climate and land surface changes is very important in urban area. Numerical modeling is one of the best ways to evaluate such hydrological responses against land use changes. Model the urban hydrological process considering all those impacts is a complex process. Selecting and prioritizing the most sensitive parameters affecting to urban catchment hydrology is one of the main reasons that numerous urban hydrological models are distinguished from each other. In this study XPSWMM urban hydrological model has been used to model an urban catchment in Western Australia, taking its land surface changes and climate variation into account. The land use changes with recent urban developments within the catchment have been considered during the modeling process. Impacts of land use changes on peak runoff of several major and minor rainfall events have been evaluated with reference to present and future land developments in the catchment. It has been identified that surface roughness change can increase the post development peak runoff up to 10.3% and 15.5% in 1 year and 100 year ARI events respectively. Changing infiltration parameters caused to change the peak runoff up to 8.8%. Results of the study concluded that the overall land use change is more sensitive to runoff generation in the catchment.

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Poster

Assessment of vegetation change on actual evapotranspiration through hydrological model

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Land cover data classified from original Landsat images of different periods was first used to estimate the vegetation change in Laohahe basin since it could have direct effects on regional evapotranspiration (ET) regime and relevant hydrological processes. The variable infiltration capacity (VIC) macroscale hydrological model was then applied to calculate the corresponding changes in actual ET (AET). VIC model performs well in the simulation of monthly runoff over Laohahe basin, with a correlation coefficient, Nash-Sutcliffe efficiency criterion, and bias of 0.9, 0.88, and 2% during the calibration period of 1965-1971, and 0.8, 0.8, and 6% through the verification period of 1972-1976, respectively. The correlation coefficient of annual AET from VIC model simulation and empirical equation is up to 0.745, which indicates a good agreement. Results from VIC model showed that vegetation change has exerted an influence on AET both temporally and spatially within the studied area. For example, monthly and annual AET in the sub-basins varied a lot from 1965 to 2008 though no apparent temporal trend was actually found for the whole basin over the same time period. Moreover, annual AET had also changed in space, decreasing in the northeast and increasing in the west. Besides, the amount of precipitation could sway the degree of vegetation change affecting the AET, i.e., given the same extent of vegetation variation, large precipitation in wet years would induce great changes in AET while low precipitation has far less impact on AET.

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Poster

Modification of the standardized precipitation evapotranspiration index for drought evaluation

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Though incorporating effects of temperature in terms of potential evapotranspiration (PET), the standardized precipitation evapotranspiration index (SPEI) is not granted as perfect and has potential limitations. For example, the proposed water difference (precipitation minus PET) was found excessively dependent on temperature, yielding significantly increasing water deficit with increase of PET under high temperature, and this trend appears more apparent in some dry areas. But abnormally large water deficit due to large PET can be unreliable as actual evapotranspiration tends to be far less than the PET for low precipitation. Moreover, relationships of water deficit and temperature varied a lot for varying climates, which might undermine the consistency and spatial comparability of SPEI. In contrast, the moisture departure adopted by Palmer drought severity index (PDSI) is preferable and more robust, greatly reducing and homogenizing dependences of water deficit on temperature while retaining role of precipitation. We intended to conduct a new standardized water-balance-based index (SWBI) through a moisture departure probabilistic approach. Moisture deficit/surplus was calculated at different time scales and several techniques were used to adjust corresponding time series to appropriate probability distributions. Comparisons of SPEI, SWBI and self-calibrated PDSI (SC-PDSI) time series of observatories in diverse climatic regions showed that 1) SWBI is highly consistent and correlated with SPEI at all time scales of analysis and parallels it for detecting droughts involving changing climate, and 2) SWBI is also coincident with SC-PDSI and escapes complicated self-calibration to obtain site-dependent climatic parameters relatively. Overall, SWBI modifies sensitivities of SPEI to increase in temperature and PET, considering physical nature of water supply and demand relating to droughts, and could serve as a competent alternative in drought monitoring and assessment.

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Poster

Evaluating the water budget in the Amazon basin in a model intercomparison framework

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Several modeling attempts have been made trying to improve the simulation of water and energy cycles at different time and space scales worldwide. These attempts consider different modeling approaches and meteorological forcings, resulting in contrasting evapotranspiration and runoff rate estimates. Considering the restricted availability of observed data to fully evaluate LSM water balance at large scales, the use of discharge observations at gauging stations is found as a straightforward way to evaluate the water budget within a catchment. Taking advantage of the recent implementation of the Hydrological Modeling and Analysis Platform (HyMAP) in the Land Information System (LIS), this study presents the first results of a land surface model (LSM) intercomparison over the Amazon basin. LSM water budgets are evaluated by means of daily water discharge and monthly variation of total water storage (TWS). Discharges simulated by HyMAP from 1980 to 2008 are compared against observations at 146 gauging stations and simulated TWS at different catchments are compared against GRACE TWS estimates. The meteorological dataset used to force eleven LSMs is provided by the Princeton University on a 3-hourly time step and at a 1°; spatial resolution. Three precipitation datasets are also used in order to evaluate the uncertainty caused this variable. Results show that discharge and TWS simulations can vary significantly as a function of both the LSM used and the geographical location.

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Poster

Vegetation change and its responses to precipitation in southeastern Tibetan Plateau

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Due to the impact of climate change and human activities, vegetation covers on the Tibetan Plateau have experienced a significant change during the past decades. Investigation on the response of vegetation to precipitation regimes plays an important role in the projection of future ecosystem dynamics. In this study, Mann-Kendall and lag-time correlation methods were employed to investigate the spatial distribution and changes of vegetation, as well as its response to precipitation based on a monthly dataset of satellite-driven Normalized Difference Vegetation Index (NDVI) spanning a period from 1982 to 2002. Results show that greenness tendency is significant in the study area, with a magnitude of 0.009/10a under the confidence level of 1%. Trend of changes exhibits different characteristics on different segments and vegetation types along rivers. NDVI demonstrates a strong hysteresis effect for precipitation with the greatest lag-time (4 months) correlation coefficient of 0.55. Meanwhile, the spatial distribution of correlation shows a remarkable variation with a range from -0.54 to 0.67 in the Yarlung Zangbo River basin.

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Poster

Efficiency of reservoirs on Flood Mitigation in large scale watersheds with land use changes

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The reservoirs are which ones of the major factors in hydrology and flood trends around the large scale watersheds. Gorganrood river Basin in the North-East of Iran due to its high potential of flood source area and sufficient rainfall-runoff records was selected as the case study. The mountainous-forested watershed consists of three reservoirs contain Boostan, Golestan, and Voshmgir was constructed around the basin. In This research, the effects of reservoirs on the flood control and mitigation was quantified using WMS Package with GIS tools for calculating flow direction and accumulation. This work presents the effects of mentioned dams on flood control in the large scale watersheds which was estimated by calibrated CN. The integrated hydrologic model was run for scenarios such as, without and with the reservoirs during a big event in this area. SCS method was used to calculate the hydrograph at the outlet. The meteorological models are based on specific-storm with temporal and spatial distribution according to envelope curve and IDW interpolation methods, respectively. Integrating of remote sensing and geographic information system was applied to discover the change in land use by comparing with Land sat TM images taken in 1988 and 2002 with 28.5 m resolution used to assess the land use changes. The results reveal that the flood peaks at the outlet obviously was decreased after establishing of dams up to 35%, however noteworthy exchanging of land use was happen in watersheds, incessantly under cultivated lands caused the flash and heavy floods in recent years. Two regional climatic conditions including: semi-arid, semi-humid in the west and arid, cold semi-arid in the east cause a change in climate and flash floods in the middle of the basin.

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Poster

Prediction of water resources under changing environment in the Hai River Basin

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Considering environmental changes in the future including climate change and artificial water use as well as land use change, this study predicts and evaluates the quantities of water resources under different conditions through the application of a distributed hydrological model in the Hai River Basin, which is the political and cultural center of China. The results indicate that, comparing with the multi-year average during 1980-2005 in the basin, in the future 30 years (2021-2050), the precipitation may increase by 11.6%, the temperature may increase by 0.9¡æ, water use amount may increase by 10.2%, although the quantity of surface water resources may increase to some extent, the quantity of groundwater resources may decrease, both the special and generalized quantity of water resources may have little change, in other words, the changes will mainly occur in the composition of the quantity of water resources. Meanwhile, the change of surface runoff in the basin within a year may exacerbate. Specially, the quantity of surface water resources may increase by 38.4% due to the increase of precipitation and the reduction of groundwater exploitation, the quantity of groundwater resources may decrease by 9.7% due to the reduction of agricultural water consumption in the future which may recharge groundwater resources, the special quantity of water resources, which can be calculated as the sum of quantities of surface water resources and groundwater resources minus the overlap between them, may slightly increase by 2.6%, and the generalized quantity of water resources which refers to the effective use of precipitation may slightly increase by 5.1%. From the view of surface runoff variation within a year, surface runoff in July and August during flood season may increase by 28%, while surface runoff in the rest months may averagely decrease by 14%, thus the situation of water resources in the basin may still be severe.

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Poster

Dynamic modeling for assessing the impact of climate change on the hydrological regime of Chenab Basin, North Western Himalayas

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The projection of future climate variables from 2011-2040 was done by using General Circulation Model (GCM). In the Baglihar station, the projected temperature in 2020s indicates that average annual maximum temperature will rise by 0.4oC and 2040s, the increment will be 0.6 oC and 0.5 oC for A2 and B2 scenario respectively. In Dhyangarh station, the projected temperature in 2020s indicates that average annual maximum temperature will rise by 0.6oC and 2040s, the increment will be 0.7oC and 0.6 oC for A2 and B2 scenario respectively. The increment for A2 scenario is greater than B2 scenario because A2 scenario represents a medium high scenario, which produces more CO_2 concentration than B2 scenario. In 2020s the average annual minimum temperature will rise by 0.2oC in Baglihar and 2040s, the increment will be 0.3oC and 0.2oC for A2 and B2 scenario respectively. For Dhyangarh station, the average annual minimum temperature will be increased by 0.3oC in 2020s and in 2040s, the increment will be 0.4oC and 0.3oC for A2 and B2 scenario respectively. In both the stations B2 scenario shows the maximum precipitation during the month of February, July and august as compare to A2 scenario where the trend will shift towards the month of march, April, September and October from January, Feb., July and august. The results obtained from HBV model indicate that June, July, August there was reduction in discharge by 4.0%, 5.34% and 5.45% respectively according to A2 scenario and 2.78%, 4.42% and 5.21% respectively according to B2 scenario for period 2011 to 2040 (Baglihar station) and 4.2 %, 5.4% and 5.8% respectively according to A2 scenario and 3.9%, 5.1% and 5.47% respectively according to B2 scenario for period 2011 to 2040 (Dhyangarh station). Thus, the climate change shows the reduction of discharge in both the stations but the reduction is more in case of Dhyangarh station as compare to Baglihar station.

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Poster

Impacts of climate change on hydrology in the Srepok Watershed, Vietnam

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In this paper, the author investigated the impacts of climate change on hydrology in Srepok watershed located in the central highlands of Vietnam by using the SWAT (Soil and Water Assessment Tool) hydrological model. The model was calibrated and validated using daily streamflow records. The calibration and validation results indicated that the SWAT model was able to simulate the streamflow reasonably, with Nash-Sutcliffe efficiency exceeding 0.54 for the Duc Xuyen station, 0.68 for the Cau 14 station, and 0.72 for the Ban Don station, for both calibration and validation at daily and monthly steps. The hydrologic response to climate change was simulated based on the calibrated model. The climate change scenarios were built by using a downscaling method (delta change method) based on the outputs of MIROC 3.2 Hires GCM driven by A1B and B1 emission scenarios. Results indicated a 1.3-3.9°C increase in annual temperature and a 0.5 to 4.4% decreases in annual precipitation corresponded to a decrease in streamflow of about 2.8 to 7.6%. The large decrease in precipitation and runoff are observed in the dry season.

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Poster

Distributed hydrological modeling for estimation of hydrological dynamics in karst region

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Hydrological processes in karst basin, controlled by permeable multimedia, consisting of soil pores, epikarst fractures, and underground conduits, are very complex because of the special hydrogeological characteristics. Distributed modelling of hydrological dynamics in such heterogeneous hydrogeological conditions is a challenging task. Basing on the multilayer structure of the distributed hydrology-soil-vegetation model (DHSVM), a distributed hydrological model for a karts basin was developed. Infiltration and saturated flow movement within soil, epikarst zone and deep flow zone are expressed in this model. Specifically, underground stream flow is simulated as well as stream flow in surface at the same time. And a computation method for surface water concentrated by dolines recharges into ground water was developed. A small karst basin located in Guizhou province of southwest China was selected for this hydrological simulation. A GIS technique has been used to build surface and underground stream network and to identify influence areas of dolines. Based on this technology, a distributed hydrogeological structure of karstic watershed was developed. The model parameters were determined on the basis of field measurement and observed stream flow and underground channel flow from watershed outlet. The results show that this new model was able to capture the sharp increase and decrease of the underground streamflow hydrograph, and as such can be used to investigate hydrological effects in such area.

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Poster

Effect of climate change on flood events as a major driver of nutrient discharge from a suburban watershed, western Japan

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The objective of this study is to evaluate the combine effect of climate and land-use changes on nutrient fluxes from a suburban watershed in western Japan, using numerical simulations with the SWAT model. The study area is the Takaya River watershed which is located in western Japan has a catchment area of 141km2 and the mean annual precipitation of 1100 mm. It is mainly covered with forest in upper portion while rice paddy and urban in lower portion. Heavy rain occurs during the summer months (June to September) and this is mainly associated with monsoonal activity and several typhoons. To confirm the effect of extreme event on nutrient fluxes, we focused on the 1980s and the 2000s.

Nutrient loads have been increasing in the watershed while human activity is getting larger with land-use changing. However, although the amount of annual nitrogen flux in the 1980s is larger than that in the 2000s, amount of the flux at each event in the 2000s has larger than that in the 1980s. In spite of nearly same annual precipitation, the drought period is getting longer than before the 2000s. Therefore, the results suggested that nutrient comes from domestic waste water and agricultural sources were trapped in the stream channel in drought period, then those were released in the flood events. This trend is same with phosphorus flux. It is like the «first flush» phenomenon on urban hydrology. Finally, the mean N:P ratio of river discharge in the 2000s was estimated around 40 which is bigger than the 1980s. This result indicated the watershed is under nitrogen rich condition because the ratio is higher than 16 is known for the Redfield ratio. We conclude that the recent trend in nutrient flux in Japan has divided into two opposites, small flux in dry period and large flux in wet period, due to pattern of discharge has been changed by climate change.

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Poster

Building flood inundation modelling capability in river system models for water resources planning and accounting

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There are a large number of wetlands in many regulated river basins in Australia such as the Murray-Darling Basin (MDB). These wetlands vary in their hydrologic, geomorphic and vegetation characteristics and are very sensitive to changes in both water and land management. A detailed understanding of wetland hydrology and inundation characteristics is imperative for effective environmental management. The river system models used for water resources planning and managements of regulated rivers in Australia do not have explicit functionality to model flood inundation and account for water flux terms related to floodplains and wetlands.

In this study, we have developed two conceptual approaches for building flood inundation modelling capability in river system models. The first approach is a simple method suitable for data limited environment. In this approach during any flood event, flow in a river reach within a floodplain is partitioned into two components, in-stream and overbank flow, based on the in-stream capacity. A flood volume-area relationship derived from the inundation time series, generated by analysing daily MODIS satellite imagery, is used to estimate inundated area for the overbank flow. The losses due to evaporation and groundwater seepage from the floodplain are calculated using the estimated inundated area.

The second approach is more comprehensive and suitable for areas with high resolution data. LiDAR DEM is used to divide a floodplain into multiple storages based on pre-defined threshold of flood inundation heights. The storage characteristics including dead storage volume and hydraulic connectivity between floodplain storages and a river reach are derived from the LiDAR DEM using a spatial data processing technique developed within the GIS environment. This data is used to estimate inundated area for overbank flow.

This paper introduces the two approaches, demonstrated their applications and findings across several floodplains in the MDB.

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Poster

Effects of land-cover change on rainfall-runoff relationships: A case study of the Yarkon-Ayalon watershed, Israel

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The study of temporal changes and spatial patterns is often conducted by analyzing land cover changes (LCCs) using spaceborne images. LCC affects runoff regime within watersheds through processes such as urbanization, agriculture, and afforestation, especially when considering extreme rainfall events. This study focuses on the Yarkon-Ayalon watershed, located in central Israel. It drains an area of 1800 km2 and is characterized by a mean annual precipitation of about 600 mm. This watershed experiences rapid LCCs that affect runoff characteristics. The objective of this research is to estimate the effects of temporal and spatial changes in land cover on rainfall-runoff relations in an extreme rainfall event. A classification map of six land cover types was created for year 1989. It was used as an input for the Kinematic Runoff and Erosion (KINEROS2) hydrologic model along with precipitation data of an extreme rainfall event with a return period of fifty years that lasted five days and led to a total of 170 mm of rain. Model calibration and validation were performed by using total runoff volume and peak discharge data based on hydrometric measurements taken during this rainfall event. This procedure was then performed using a 2009 classification map as an input to KINEROS2 model, along with the same precipitation data and calibration parameters, in order to understand the possible outcomes of a similar rainfall event following 20 years of LCCs. The results show an increase in runoff volume and peak discharge values between the time periods under examination as a result of LCCs. A strong relationship is spotted between vegetation cover and runoff volume. The LCCs that have the most pronounced effects on runoff are related to urbanization and vegetation removal. Using a hydrologic model enables understanding runoff characteristics affected by land cover patterns and their changes through time.

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Poster

Impact assessment of climate change and human activities on flood-season streamflow in the middle of Loess Plateau, China

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The Yanhe River Basin (YRB) is the first-order tributary of the Yellow River, which is located at the middle of the Loess Plateau, China. The Yanhe River is the main river that causes floods and damages to the Yanan city. The YRB contributes significantly to the total sediment yield in the Yellow River. A great number of water and soil conservation measures including terracing, afforestation, and construction of sediment-trapping dams have been implemented since the 1960s. It is important to investigate the contributions of climate change and human activities affecting the changes of flood-season streamflow and to provide a scientific basis for future flood prevention. The data from six hydrological stations and 22 meteorological stations of YRB are used in this study. Two nonparametric methods, the Mann-Kendall test and the Pettitt test, are used to detect change trend and change point in the flood-season streamflow for the period of 1952 to 2003. The lumped conceptual daily hydrological model SIMHYD and one kind of sensitivity-based method are used to assess the impact of climate change and human activities to flood-season streamflow. The results show that the change point in flood-season streamflow occurred in 1972. The flood-season streamflow has decreased by 34.2% from 1972 to 2003 compared with the period from 1952 to 1971. The flood-season streamflow becomes more sensitive to change in precipitation than change in potential evapotranspiration (PET) in 1972-2003. The impact of human activites is greater than climate change after 1972. The effects of climate change and human activities on flood-season streamflow account for about 36% and 64% respectively.

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Poster

Detecting emerging patterns on water fluxes in Germany during the last 60yr

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Detecting changes and causality in water fluxes is a challenging task because of the nonlinear dynamics of the atmosphere-land-vegetation system. Noisy measurements as well as structural and parametric uncertainty of land surface models (LSM) complicate even further the detection of trends, feedbacks, and causation mechanisms. Trend analysis of extreme hydrometeorologic variables becomes particularly difficult under these conditions. Quite often, wrong conclusions have been drawn because uncorrelated variables were assumed to have no causal relationship with presupposed predictors.

The main goal of this study was to quantify the ``Granger causality'' (Granger 1969) of monthly soil moisture, runoff, and latent heat obtained with a mesoscale distributed hydrological model (mHM) (Samaniego et al. 2012) and large-scale circulation patterns. A particularly relevant research question in this study is to test whether large scale drought events in Germany can be assumed ``Granger caused'' by anomalies of geopotential height and atmospheric humidity over Europe.

mHM was forced with grided daily precipitation and temperature data at 4x4 km resolution from 1950 to 2011. Land cover changes during this period were also considered. mHM soil moisture and runoff has been evaluated with available observations. Potential predictors were acquired from ERA 40 reanalysis. A 100-member ensemble of daily soil moisture fields over Germany were obtained with parameters estimated for all large river basins in Germany.

Preliminary results indicated the existence of a negative trend (p-value 5%) in soil moisture during summer months which is the consequence of observed downward trend in precipitation and upward trend in temperature. On the contrary, soil moisture simulations in winter months did not exhibited significant trends. The application of the Granger causality test is under investigation.

H01PS.20

H01PS - Climate and land surface changes in hydrology

Poster

A real-time flood forecasting system by incorporating high-resolution NWP rainfall into rainfall-runoff modelling

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Mesoscale Numerical Weather Prediction (NWP) models are nowadays gaining more and more attention in providing high-resolution rainfall forecasts for real-time flood forecasting. In this study, the newest generation NWP model, Weather Research & Forecasting (WRF) model, is integrated with the rainfall-runoff model in real-time to generate accurate flow forecasts at the catchment scale. The rainfall-runoff model is chosen to be the Probability Distribution Model (PDM), which has been widely used for flood forecasting. Dual data assimilation is carried out for real-time updating of the flood forecasting system. The 3-Dimensional Variational (3DVar) data assimilation scheme is incorporated with WRF to assimilate meteorological observations and weather radar reflectivity data in order to improve the WRF rainfall forecasts; meanwhile real-time flow observations are assimilated by the Auto-Regressive Moving Average (ARMA) model to update the forecasted flow transformed by PDM.

The Brue catchment located in Southwest England with a drainage area of 135.2 km^2 is chosen to be the study area. A dense rain gauge network was set up during a project named HYREX (Hydrological radar experiment), which contains 49 rain gauges and a C-band weather radar, providing with sufficient data for NWP model verification and data assimilation in this study. Four 24 hr storm events are selected from the HYREX project with different characteristics regarding the storm formation and the rainfall-runoff responses. Flood forecasts are then carried out by the constructed forecasting system for the four storm events with a forecast lead time of 12 hours. The forecasting accuracy of the system is found to be largely improved by incorporating the WRF forecasted rainfall when the forecast lead time is beyond the catchment concentration time. The assimilation of real-time meteorological and radar data also show great advantage in improving the performance of the flood forecasting system.

H01PS.21

H01PS - Climate and land surface changes in hydrology

Poster

Impact of land use change on evapotranspiration: the case of the upper reaches of Huai River

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The study assesses the effect of land use and land cover changes (LULCC) on evapotranspiration in the upper reaches of Huai River basin located in the middle of China. First, some sensor images are taken to quantify LULCC in the basin. A knowledge-based decision tree (K-DT) classification technique is used to detect LUCC. The classification includes cropland, built-up area, barren land and forest. By comparison of post-classification change, analyses the results of changing. Subsequently, use Fu's formula derived from the Budyko hypothesis to estimate interannual evapotranspiration. Finally, the influence of LULCC on annual evapotranspiration is evaluated.

H01PS.23

H01PS - Climate and land surface changes in hydrology

Poster

Impact of climate change and land use change on stream flow in the upper reaches of Huai River

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This study used the sensitivity-based approach and hydrological approach evaluating Impact of climate change and land use and land cover change(LULCC) on stream flow in the upper reaches of Huai River. The sensitivity-based approach includes six(seven) Budyko framework based models, in which Fu's formula and Zhang's formula contain parameters which describes catchment characteristics. In order to improve accuracy ,we calibrate the parameters by the historical data. The hydrological approach ,we selected Xinanjiang Model which is suited humid and semi humid area to evaluate impact of LULCC on stream flow. The results from this study show that the estimates of LULCC impacts from the hydrological models are similar to those from the commonly used sensitivity-based approaches. The sensitivity-based approaches are only applicable where long term datasets are available and they only provide results at a mean annual time scale.

H01PS.24

H01PS - Climate and land surface changes in hydrology

Poster

Climate change and glacier lake outburst floods in Himachal Himalaya

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The paper deals with relationship between climate change and glacial lake outburst floods. To qualify this objective primarily meteorological data of temperature and rainfall of Bhuntar, Manali, Dharamsala and Mandi for a period of 30 years ranging from 1977 to 2007 has been obtained. A land surface temperature map has been derived using Landsat TM thermal band-6 to show surface temperature and change during year 1989 and 2011. Long-term mean annual temperature records from 1901 to 1982 over India detected an increasing trend in mean surface air temperatures. Mean minimum temperatures of all stations are showing increasing trend with varying degree ranging from 0.1°C at Dharamsala to 2°C at Mandi. In the Spiti valley, maximum surface temperature increase has been noticed between the heights of 4,000 to 5,000 m. The total annual rainfall for the state is 149 cm and the total annual number of rainy days is 65. Kangra district receives the maximum amount of rainfall (185cm) in a year. The average day with snow in a year is also decreasing. The decrease is of around 3.4 days in a period of 23 years. Glacial lakes are a common feature at altitudes of 4,500 to 5,500 m in many river basins of the Himalaya. At least between 3 to 10 years one GLOF event was recorded in Himalayan region. A few incidence of GLOF has been noticed by the people residing in the remote area but has not been documented. Parechu lake outburst in the Spiti river in June 2005 has been studied. High silt content in the river resulted in the temporary shutdown of hydroelectric projects in the area. The washing away of bridges on the Spiti and the Satluj rivers affected 2,400 people living in 23 villages. In order to identify potential GLOFs', the present paper uses technique adopted by Clague and Mathews (1973) for estimating maximum instantaneous discharge from a lake at the time of outburst. A total of 17 glacial lakes have been outburst. A total of 17 glacial lakes have been identified.

H01PS.25

H01PS - Climate and land surface changes in hydrology

Poster

Monitoring land cover change on the wadi Mina basin using multitemporal Landsat imagery

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Many studies have shown that the Wadi Mina basin as many regions in Algeria is impacted by drought since the 70s. In an attempt to see the impact of this drought on the land cover we used satellite imagery, which has been demonstrated to be the most effective method for land cover mapping. The processing of multi-temporal Landsat images allows for the monitoring of land cover change. Landsat satellite images of 1985 and 2009 were analyzed to detect land cover changes in the wadi Mina basin. Four different categories of land cover were used: dense vegetation (forest), sparse vegetation (cultivated lands and grasslands), water and bare soils. The images were first transformed into Normalized Difference Vegetation Index (NDVI) images and then we used a supervised classification to estimate the changes in the study area. Both positive and negative changes in the land cover were analyzed. The dense and sparse vegetation decreased respectively from 6,1% and 50,4% in 1985 to 2,4% and 49,5% in 2009.

H01PS.26

H01PS - Climate and land surface changes in hydrology

Poster

Modelling hydrologic effects of land-use change using an integrated approach combining SWAT and CLUE-s models

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Economic development and urbanization have affected both water quantity and quality in many regions of the world. Understanding and quantifying the hydrologic response to urbanization and land-use change have become a major focus in studies on the impact of human activities on hydrology. This study employs an integrated approach that combines the land-use change allocation model (CLUE-s) and a physically-based distributed hydrologic model (SWAT) for examining the impact of various land-use change scenarios in a region undergoing rapid change in land-use - the Xiangjiang River basin in China. Results indicate that various land-use policies, such as no change, dynamic change and simultaneous change, have different levels of impact on the simulation of spatial distributions of hydrologic components. Land-use change can lead to significant changes in the distributions of water resources and hydrologic processes. Results of this study will be helpful for land use planning and watershed management. The integrated modeling approach is shown to be a promising tool for land use impact studies.

H01PS.27

H01PS - Climate and land surface changes in hydrology

Poster

Evapotranspiration and heat fluxes over a patchy forest - studied using modelling and measurements

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Most forests in Europe are too small to fulfill strict fetch requirements associated with idealized flux observations. As a consequence of limited fetch, the flux measured above the canopy will often deviate from the source strength underlying the measurements, i.e. observations of sensible and latent heat flux above forest downwind of a forest edge show these fluxes to be larger than the available energy over the forest (Klaassen et al. 2002, Theor. Appl. Climatol. 72, 231-243). Because such flux measurements are very often used for calibration of forest parameters or model constants, further using these parameters without a proper interpretation in mesoscale or global circulation models can results in serious bias of estimates of modelled evapotranspiration or heat fluxes from given area.

Since representative measurements focused on heterogeneous effects are scarce numerical modelling can be used to interpret the measurements. Recently, the atmospheric boundary layer (ABL) model SCADIS (Sogachev et al., 2002, Tellus 54B, 784-819) has been successfully applied to analyze the mechanisms of CO_2 flux formation near a forest edge for neutrally stratified conditions (Sogachev et al., 2008, Ecological. Appl. 18, 1454-1459). In the present work, we apply the SCADIS with enhanced turbulence closure including buoyancy for investigation of the spatial distribution of latent and sensible heat vertical fluxes over patchy forested terrain in Denmark during selected days in the summer period. A closer look at the result shows that though the meteorological mast is located in the middle of a forest patch by size about 1x2 km^2, it is not free from uncertainties regarding energy balance closure. Comparing observed and SCADIS (1D and 3D) simulated data for the mast confirms that caution is needed when interpreting measured flux data. The approach used in this work can be utilized in interpretation of already existed experimental data and in the planning of future experiments.

H01PS.28

H01PS - Climate and land surface changes in hydrology

Poster

Observed variations in the Indian monsoon hydroclimate during recent decades

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Detection of anthropogenic influences on regional hydroclimate often tends to be obscured by internal variations within the climate system. Using observed climate records and twentieth-century reanalysis, we have examined the dominant modes of variability and trends in the Indian monsoon hydroclimate during recent decades. The present analysis extracts the internally-driven signals and the externally forced trends in the monsoon hydroclimate over the Indian subcontinent. It is seen that the internal variations in the precipitation minus evaporation over the Indian monsoon region are largely related to interannually varying patterns of sea surface temperature (SST) in the tropical Indo-Pacific basins. By separating the internal component of monsoon hydroclimate variability, it is seen that the emerging pattern of precipitation minus evaporation change reveals a significant contribution of the forced trends over the Indian subcontinent. To gain further insight into the forced changes in the precipitation minus evaporation history during recent decades, we have conducted a detailed integrated analysis of the three-dimensional moisture budget.

H01PS.29

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Poster

Évolution et régionalisation des précipitations au nord de L'Algérie (1936-2009)

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Une analyse de l'évolution du régime pluviométrique du nord de l'Algérie a été établie sur une période d'observation de 73 ans (1936-2009). Pour cela 102 postes pluviométriques répartis sur tout le Nord de l'Algérie, ont été sélectionnés. Les séries temporelles ont été soumises à cinq tests de stationnarité, dans le but de détecter une tendance ou un changement. Les tests de rupture, à savoir, le test de Pettitt, Kendall, Buishand, la méthode bayesienne de Lee et Heghinian et la segmentation d'Hubert, ont révélé une tendance à la baisse des précipitations, observée entre la fin des années 60 et le début des années 80. Toutefois, cette baisse ne concerne pas toute la zone d'étude; à l'Est, les séries pluviométriques sont homogènes et la méthode de segmentation d'Hubert indique même une augmentation considérable des précipitations à partir de 2002. À l'échelle saisonnière, la rupture est plus importante en hiver et s'avère influencer la tendance des pluies annuelles. L'indice pluviométrique standardisé a montré que les décennies 80 et 90 étaient les plus déficitaires particulièrement dans la région Ouest (déficit pluviométrique entre 13 et 30%). La régionalisation des précipitations par l'analyse en composantes principales a mis en évidence six régions homogènes. Ce découpage spatial montre aussi la vulnérabilité de chaque région au changement climatique. La forte variation du régime pluviométrique au Nord de l'Algérie, peut être expliquée par deux facteurs déterminants : climatique et géographique. D'une part, la circulation atmosphérique générale et particulièrement l'Oscillation Nord Atlantique qui influence le climat. D'autre part, les caractéristiques géomorphologiques qui jouent un rôle important dans la répartition des précipitations.

H01PS.30

H01PS - Climate and land surface changes in hydrology

Poster

Using remote sensing data to assess evapotranspiration modeling in a large scale hydrological model and associated uncertainty i

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Assessment of impacts of climate change on water resources normally involve forcing hydrological rainfall-runoff models with climate scenarios derived from global climate models. This kind of analysis has several sources of uncertainty, and normally the uncertainty in climate model outputs is recognized as the most important, at least in tropical regions. With few exceptions, uncertainty related to the hydrological models is normally considered to be less important. However, this lack of recognition of the role of hydrological modeling uncertainty in the whole process may be related to the narrow range of perceptual models on which hydrological models are based. We explored the case of a river basin in a seasonally dry tropical region in Brazil, the Carinhanha river, with a drainage area of nearly 20 thousand km2, where vegetation access to groundwater, if considered or not in the perceptual model, leads to different hydrological models, and may also lead to relatively large differences in the assessment of impacts of climate change on streamflow. We used a hydrological model that uses the hydrological response units approach and defined areas where plants have access to groundwater by applying the Height Above Nearest Drainage (HAND) method. Model results were assessed both in terms of calculated streamflow at three river gauging stations and in terms of evapotranspiration, with model results being compared to remote sensing estimates based on the SEBAL algorithm. Remote sensing evapotranspiration estimates confirmed that vegetation near water courses has access to the water table and is able to maintain higher evapotranspiration rates during the dry season. Results show that rivers in the Cerrado (South-American savannah) region may be more susceptible to climate change than normally recognized.

H01PS.31

H01PS - Climate and land surface changes in hydrology

Poster

Space-time variability of rainfall and hydrological trends in the Alto São Francisco River basin

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This study is directed to an analysis of the negative river streamflow trends detected in the Alto São Francisco River Basin series since 1978. This basin covers one of the most important hydrologic regions of Brazil and comprehends several States of Brazil. The waters of the Alto São Francisco River Basin supply the demands of almost 7 million people in mostly large cities, which depend primarily from this water supply. Any reduction in the volume of its waters may have large economic and social impacts, and the municipal governments suggest that the rainfall amounts are systematically decreasing. A detailed statistical analysis applied to the river streamflow and rainfall time series in several gauges in the valley detect negative streamflow trends. In addition, a wavelet transform analysis is applied. However, there are no signs of any significant rainfall reduction in the valley, and in fact, some rain gauges show a small rainfall increase during the recent decades. An autocorrelation analysis performed on the river streamflow time series shows a large autocorrelation in consecutive years, suggesting that regulation in the operation of reservoirs for water use (hydroelectric generation, irrigation, human consumption) are responsible for the negative streamflow trends, rather than a climate change of the rainfall regime within the basin.

H01PS.32

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Poster

Drought frequency analysis in China using a 55-year dataset of reconstructed soil moisture

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Drought is a recurring hydroclimatic event. According to the statistical data, there is a severe drought occurred almost every 2 years , and the drought-attacked areas, drought-inundated areas from 1949 to 2007 indicates an increasing trend in China. Study on spatiotemporal distribution feature of drought may have profound guiding significance for agriculture. Soil moisture is a key factor to reveal the whole process of occurrence, expanding and mitigation of a drought event. We used VIC (Variable Infiltration Capacity Model) to simulate the daily soil moisture with a 30km*30km resolution and established the soil moisture anomaly percentage index (SMAPI) to calculated drought frequency (1956 - 2010). This study focused on the spatial distribution of drought frequency and changing trend in China. The changing trend of drought occurrence was analyzed by using Mann-Kendall method. The results indicate that drought frequency in eastern China is higher than that in western China. The spring drought attacks the most extensive area while winter drought affects the greatest population which distribute in southern China and Hwang-Huai-Hai plain. Xinjiang and southern China mainly suffers spring and winter drought, whereas northeastern China often incurs summer drought. The middle and lower reaches of Yangzi River experiences various seasonal droughts with prominent spring, summer and autumn droughts. Analysis on MK trend of drought frequency reveals an aridified belt zone which stretches from Northeast Plain-Haihe River plain-Loess Plateau-Sichuan Basin-Yunnan-Guizhou Plateau. The MK trend of four seasons' drought frequency shares the same changing sign at national spatial scale, which is similar to that of annual drought.

H01PS.33

H01PS - Climate and land surface changes in hydrology

Poster

The contribution of Distributed Temperature Sensing (DTS) in streams to assess spatial runoff processes in a moraine dominated agricultural catchment

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Evaluating impacts of site-specific changes in land use and land cover on catchment processes is significantly complicated by spatial heterogeneity and the long and variable time lags between precipitation and the responses of streams and groundwater. In this study, a 1-D soil-plant-atmosphere model (Daisy) was used to calculate the water balance of a moraine dominated agricultural catchment (42 km^2) in Denmark, and a Distributed Temperature Sensing (DTS) system was installed in the stream Elverdam to assess the spatial variations in lateral inflows to the stream. The Daisy model was set up using a high spatial resolution (10-30 m) land use map which includes agricultural crops, forest, wetlands and inhabited areas, and spatial variations in soil types, geology and tile drainage were represented. The DTS system measured diurnal variations in water temperature each meter along a stream reach of 1800 m over 812 hours (≍ 34 days) in all four seasons of a full year. Data from two water level loggers quantified flow contributions over the study reach, and a climate mast provided local meteorological data. Multiple discrete locations with stream-groundwater interactions were identified, as indicated by low temperature amplitudes, but only some discrete groundwater inflow sources were large enough to allow quantification based on heat and mass flow conservation equations. The trend in downstream water temperatures at night was useful to quantify total groundwater inputs. The routing and flow accumulation of water from individual grids within the catchment to the stream was calculated using a Lidar based (1.6 m resolution) digital elevation model. Many locations with observed (DTS-based) discrete lateral inflows were in good agreement with stream locations receiving extra large inflows from the upland contributing land areas, but riparian land use, tile drains, geology and stream slope were also important determinants of reach-scale lateral inflow

H01PS.34

H01PS - Climate and land surface changes in hydrology

Poster

Estimating water table contribution to the water requirement of wheat in Huaibei plain, China

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A shallow water table can be considered as a valuable resource for supplying part of the crop water requirement. Capillary rise from the water table plays an important role in supplying water to the crops in the clay loam area in Huaibei plain, China. During rainless season in high-rainfall areas, subirrigation by regulating water table depth through drainage systems may serve as a means of supplementary irrigation. So estimating water table contribution to the water requirement of wheat, to the actual production is of great significance. The primary purpose of this study is to quantify water table contribution to the wheat water requirement. A field experiment with winter wheat was conducted on a non-saline clay loam soil and a fluctuating shallow water table in Bengbu, Huaibei plain. This experiment to determine water table supply through capillary rise to the crop water requirement involves two different approaches mainly. In the first approach developing a computer model based on Darcy's Law is to calculate the capillary upward flux. The model uses , as inputs ,the relationship between hydraulic conductivity and water content ,the depth of water table below the root zone , and the matric suction at the bottom of the root zone . The second method is based on soil water balance by taking the water table contribution as the difference between estimated evapotranspiration and soil water depletion in the field. Water table contribution was estimated from 10th October, 2004 planting to the 31st May, 2005 harvesting. Both methods estimated water table contribution to be in the range of 22-24 cm, which amounts to about 30% of the ET over the 230-day period.

H01PS.35

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Poster

Water resources analysis in in Southeast Asia with an index of potential food production

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It is one of the most important and urgent issue to understand the spatial and temporal variation of hydrological cycle including agricultural water usage and its response to climate variability. Hunukumbura and Tachikawa (2012) simulated river discharge change of whole Chaophraya river basin using river-routing model with GCM output provided from MRI-JMA. From their analysis, it was found that water resources in Pasak river basin, which is part of Chaophraya rier basin, decrease under the climate change projection. So, in this study, it is focused on water resources vulnerability in Pasak river basin.

Land surface scheme SiBUC (Simple Biosphere including Urban Canopy) is known as a few model which can treat irrigated paddy field or farm land as land use. SiBUC can be utilized as means to discuss water resources issues because it can deal with agricultural water usage including irrigation effect. It is important to assess crop growth state for future climate projection. To describe crop growth by numerical simulation, we developed and introduced crop growth model into our land surface scheme. Introduced crop growth model was original from crop growth scheme in SWIM (Soil and Water integrated Model). And it was able to estimate the state of crop growth and inter-annual crop production. Validation of our coupled model applying paddy field at Niigata prefecture, Japan, resulted in reasonable estimation of annual variation of food production. Therefore, coupled model was applied to Pasak river basin. Using observed meteoro-hydrological data which was derived by originally installed devices at Rama VI dam office, coupled model was tuned as well-reproducing rice crop state in Pasak river basin. After that, rice crop production changes were estimated by coupled model with GCM output data. As a result, it was assumed that rice crop production decrease about 5% under near future climate projection and it also decrease about 13% under future climate projection.

H01PS.36

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Poster

Automatic runoff forecasting under climate and land surface changes

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Climate and land surface changes have made many traditional forecasting approaches less efficient. These factors cause additional uncertainty in forecasting procedures and, therefore, they should be taken into account. In automatic runoff forecasting systems which are being developed in the Russian State Hydrometeorological University, global change and changes in land use are identified automatically and then they are reflected through systematic recalibration of the Multi-Layer Conceptual Model. The developed customer-oriented automatic forecasting systems usually include several tools, options and features which make automatic calibration and recalibration fast, efficient and reliable. The most important of them are a special optimization algorithm and a method of «natural» smoothing the response surface based on multi-scale objective functions. In our forecasting systems, model forcing data arrays are composed in near real time. For this purpose, satellite data, radar data (if available), output data of the Weather Research and Forecasting Model and quite scarce surface observations are integrated. This way allows issuing background hydrological forecasts aimed to detect increased risks of flooding in large areas, including ungauged and poorly gauged basins. After that, enhanced forecasting can be applied only for those basins where increased risks of flooding were predicted. All the developed systems as well as their particular elements are available for authorized customers through the Internet (as any «cloud» technologies) and can be used for operational or training purposes.

H01PS.37

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Poster

The impact of land use change on regional climate in Tokyo metropolitan area

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Because regional responses of surface hydrological and biogeochemical changes are particularly complex, it is necessary to develop assessment tools for regional scale adaptation to climate. We developed a dynamical downscaling method using the regional climate model (NIED-RAMS) which incorporated the urban canopy scheme dealing with three-dimensional structures of urban buildings in the Tokyo Metropolitan area to add spatial resolution to accurately assess critical interactions within the regional climate system for vulnerability assessments to climate change for regional scale adaptation. We digitalized a regional planning atlas (land use in the past) from 1888 that formerly existed only on paper into GIS data. It quantified information on the reduction of green spaces and the expansion of urban areas in the Tokyo metropolitan area. The impacts of land use and land cover (LULC) change in the past were assessed by including this land use information into the regional climate model. We conducted regional climate sensitivity experiments of land use and land cover (LULC) change from 1888 to 1975 in the Tokyo Metropolitan area by using the NIED-RAMS with horizontal grid spacing of 5 km. The lateral boundary condition is the 2001 Japanese 25-year ReAnalysis (JRA-25). The experiments show good accuracy in reproducing the surface air temperature and precipitation. The experiments indicate the distinct change of hydrological cycles due to anthropogeninc LULC change. The LULC change from the past increased 2 m air temperature (about 1 K) and sensible heat flux, decreased latent heat flux, enhanced turbulent mixing, and changed spatial distribution of precipitation.

H01PS.38

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Poster

Projected impact of climate change on groundwater system of an inland river basin in the western China

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Bayin River is originated from a branch of Arjin Mountain and ended in Keluke Lake -- an inland fresh water lake. The middle and lower reaches of the river flows along the edge of a series of alluvial fans and is mostly fed by groundwater from snow melt, which is highly sensitive to climate change in such region. In this paper, climate change impact on natural recharge to Bayin groundwater basin has been investigated for the year 2050. Projection data including temperature and precipitation etc. are generated by a high-resolution regional climate model CCLM (COSMO model in Climate Mode) and are coupled to a groundwater model established by Visual Modflow. The regional groundwater flow model is first calibrated and verified by observation data from May 2008 to April 2009. Simulation results show that infiltration from river into the aquifer is 0.69 $\times 10^6 m^3/d$ and takes 69% of total recharge; while precipitation takes 26%. Evapotranspiration and discharge to the river are two main sinks of groundwater system. Then, the assessment of the impact of climate change on regional groundwater cycle is carried out under SRES A2 (medium-high) and B2(medium-low) scenarios of CCLM by estimating groundwater level, groundwater recharge, regional groundwater budget and flow rate of springs discharging from the aquifer into Keluke Lake. The greatest reduction in surface water recharge is observed in scenario A2 and remains relatively stable in scenario B2. The spring discharge to the lake is may fail the threshold of 0.28 $\times 10^8 m^3/a$ after 2040s in scenario A2. Climate change adaptation measures are highly suggested in this region to mitigate its impact.

H01PS.39

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Poster

Modeling evapotranspiration in the Amazon Basin using MOD16 algorithm

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Evapotranspiration (ET), including water loss from plant transpiration and land evaporation, is of vital importance for understanding hydrological processes and climate dynamics and remote sensing is considered as the most important tool for estimate ET over large areas. The Moderate Resolution Imaging Spectroradiometer (MODIS) offers an interesting opportunity to estimate 8-day and monthly ET with 1 km spatial resolution. The MODIS global evapotranspiration algorithm (MOD16) considers both surface energy fluxes and climatic constraints on ET (water or temperature stress) to predict plant transpiration and soil evaporation based on Penman-Monteith approach. The algorithm is driven by MODIS remotely sensed data and reanalysis meteorological inputs. In this study, MOD16 algorithm was applied to the Amazon Basin, a crucial area to regional and continental climatic and hydrologic processes due to the large extent and flux magnitude. Model performance was assessed across the Amazon, at 8 eddy-covariance sites, ranging from tropical rainforest, selective logged forest, tropical dry forest, seasonal flooded forest, savanna to pasture and agriculture. We also computed a seven-year mean ET against a water balance over the Amazon Basin (gauge location at Óbidos, with and upstream area of 4.618.700 km2). The results show that monthly and annual ET are in consistent with observations of eddy covariance sites, with monthly root mean square error (RMSE) ranging from 20% in tropical rainforest, seasonal flooded forest and savanna, 52% in tropical dry forest up to 94% in pasture and cropland. Comparison of the six-year average annual ET over the Amazon basin resulted in a mean error of 11 ±6% or 118 ±60 mm yr-1. MOD16 estimated an Amazonian wide-basin evapotranspiration of 1181 mm yr-1. Our results indicate significant potential for regional mapping and monitoring evapotranspiration using MODIS remote-sensed information.

H01PS.40

H01PS - Climate and land surface changes in hydrology

Poster

Climate changes and their major impacts in environmental conditions of a freshwater Brazilian wetland

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Actually the impact of climate changes has been widely studied searching for answers about the hydrological behaviour due to alterations on the temperature and precipitation regime. One special issue of interest is how these alterations may affect environmental conditions. Alterations in the wetlands' water levels, for instance, are known to promote changes in biological communities that depend on specific habitat conditions to thrive or survive. If the stress promoted by water level changes exceed certain limits there is the probability of reduction of specimen numbers and biodiversity or even elimination of some key species in ecosystems such as wetlands. In this study is presented an assessment of how climate changes can affect the hydrological regime and biodiversity of a coastal Brazilian freshwater wetland (Taim Wetland) with approximately 315 km2. The analyses were based on predictions of twenty Atmospheric/Ocean General Circulation Models (AOGCMs), considering two climate change scenarios from the Intergovernmental Panel on Climate Change (IPCC) and two 30 years-time intervals, centered at 2030 and 2070 (1920 simulations). Values taken from these projections were used as input in a 2-D full hydrodynamic cell model previously calibrated and validated for the local study, allowing the generation of a monthly time series. In a raster environment, the regions considered as habitat for some specific key species were superimposed with the spatial distribution of monthly water levels and depths prediction. Results showed that for this wetland the water levels will increase in both sceneries as consequence of climate changes, and a great number of key species considered in this study should be directly affected due to reduction or even elimination of areas used as habitats. It suggests that hydrological alterations are really important for these wetland´s characteristics and further studies should be carried out to evaluate mitigations measures for these impacts.

H01PS.41

H01PS - Climate and land surface changes in hydrology

Poster

More effective policy for climate change induced impacts on water systems in India

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The distribution of water resources potential in the country shows that the national per capita annual availability of water at 1820 cu. m in 2001 is estimated at 1588 in 2010. Regional climate models, driven by output from the global models, provide information on scales of 25 km or 50 km over limited geographical regions, suitable for national climate impact assessments and planning adaptation. Climate change is likely to impact most hydro-logic processes and impacts need to be assessed at regional/river basin and smaller scales. Global climate models (GCMs) are the most credible tools available today for impact assessment and results from the studies are useful in developing adaptive responses (e.g., long term reservoir operating policies; modifications in hydro-logic designs; change in cropping patterns; water use adjustments etc.). Climate Change Projections (precipitation, temperature, radiation, humidity) are inter-related and are dependent on stream-flow, evapotranspiration, soil moisture, infiltration, groundwater recharge etc. Due to the fact that current water security problems are likely to increase and substantial impacts on agriculture and forestry are very likely by 2050. Predictors in hydro-logic cycle include stream flow (result of rainfall, evaporation and infiltration), monsoon (insignificant infiltration compared to stream flow), rainfall (consequence of mean sea level pressure or MSLP, geo-potential height & specific humidity) and evaporation (mainly guided by temperature and humidity). Climate change is affecting all the predictors in hydrologic cycle directly or indirectly. There is a need for more effective climate change policy for mitigation approach.

H01PS.42

H01PS - Climate and land surface changes in hydrology

Poster

Updated vegetation information in high resolution regional climate simulations using WRF

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Climate studies show that the frequency of heat wave events and above-average high temperatures during the summer months over Europe will increase in the coming decades. Such climatic changes and long-term meteorological conditions will impact the seasonal development of vegetation and ultimately modify the energy distribution at the land surface. In weather and climate models it is important to represent the vegetation variability accurately to obtain reliable results.

The weather research and forecasting (WRF) model uses a green vegetation fraction (GVF) climatology to represent the seasonal variation of vegetation parameters. The climatology describes the fractional vegetation cover within each grid cell but is additionally used to scale other parameters such as LAI, roughness, emissivity and albedo within predefined intervals. The climatology does not reflect recent climatic changes or changes in management practice since it is derived more than twenty years ago.

In this study, a new high resolution, high quality GVF product is applied in a WRF climate simulation over Denmark during the 2006 heat wave year. The new GVF product reflects the year 2006 and it was previously tested in a climate run at low spatial resolution showing good performance. The new simulations are carried out at higher resolution and the performance is quantified against (1) a control run using the default GVF data and (2) two gridded data sets (E-OBS and DMI Climate grid) at lower resolution for which the simulations are aggregated to match the resolutions of the gridded data. The comparison include temperature, wind and precipitation.

H01PS.43

H01PS - Climate and land surface changes in hydrology

Poster

Monitoring drought occurrences using evapotranspiration data and vegetation indices

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Drought is a chronic potential natural disaster characterized by an extended period of time in which less water is available than expected, typically classified as meteorological, agricultural, hydrological and socioeconomic. With human-induced climate change, increases in the frequency, duration and severity of droughts are expected, leading to negative impacts in several sectors, such as agriculture, energy, transportation, urban water supply, water quality, among others. The current drought indicators are primarily based on precipitation. However, only a few indicators incorporate evapotranspiration (ET), soil moisture and water-based vegetation indices. ET and soil moisture play an important role in the assessment of drought severity as sensitive indicators of land drought status. In this context, our objective is to evaluate the drought occurrences in Southern Brazil using MODIS remotely sensed data to retrieve evaporative drought index (EDI) and normalized difference water index (NDWI) from 2000 to 2012. The EDI, defined as 1 minus the ratio of actual ET to potential ET, is one of the most important indices denoting the soil moisture response to surface dryness, while the NDWI, that uses near infra-red (NIR) and short wave infra-red (SWIR), is sensitive to vegetation conditions, soil moisture and leaf water content. These indexes were calculated to better understand the relationship between vegetation and soil moisture. Results showed that both indices captured major regional droughts (2005, 2010 and 2012) with similar wetting and drying patterns compared to the standardized precipitation index (SPI). Overall, the MODIS remotely sensed drought indices reveal the efficacy and effectiveness for near-real time drought monitoring.

H01PS.45

H01PS - Climate and land surface changes in hydrology

Poster

Impact of climate change and land use on runoff : case of Dakar Suburbs (Senegal)

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Climate change and climate variability have been identified in West and Central Africa in the 90s. Climate change leads to a drastic reduction in rainfall, lower of static level of the water table and changes in land use. Climate change has also a social factor impact, with the influx of rural populations to the suburbs of large cities. In Dakar, capital of Senegal, lower static level of the water table has fostered a strong urbanization in the suburbs. Return to normal rainfall which seems to announce from the year 1999 combined with the change in land use has resulted in this suburb of inundations which has dramatic consequences for populations and high costs for the Government. In this paper we study the impact of climate change and changing land use on runoff. SWMM software was used. Three remote sensing images corresponding to periods of different land use in the suburbs of Dakar (1954, 1978, 2003) were used. The year 2003 was chosen as the reference year for rainfall. SWMM model showed that for the same daily rainfall, the change of land use has resulted in reduced infiltration, increased runoff, surface storage and runoff coefficient.

H01PS.46

H01PS - Climate and land surface changes in hydrology

Poster

Climate Prediction and hydrological sensitivity in part of Lower Niger Basin

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The need to manage the consequences of the current and projected stress on water resources and ensure sufficient, perennial water supply needs among others call for the need to accurately assess the impact of projected climate change on hydrological system. The need to address potential climate change impacts through better understanding and accurate forecasts of climate conditions over time periods of weeks to a few years at a finer climate information scale through downscaled dataset and information, is therefore necessary due to increasing per capita water demand and the need to accurately estimate the sensitivities and uncertainty of hydrological system to climate variability and change at local scale. Water resources issues in Lower Niger River Basin include poor water resource usage and inappropriate management policies, marked decrease in flow as a result of issues relating to varied climatic dynamics and river regulation through dams operations which has reduced average discharge

In this paper, a statistical downscaling regional climate model was developed for lower Niger Basin from the global climate scenario using the dual field synoptic-scale circulation fields and neural analysis. The seasonal climate forecasting method involved the use of the Canonical Correlation Analysis (CCA), Principal Components Regression (PCR) and Multiple Linear Regression (MLR) methods with probabilistic retroactive forecasts been verified using a range of graphical techniques . From the derivable regional climate index, projected climate change impact on localized hydraulic structure design and available water resources sensitivities was estimated with better understanding of the varied threats, linkages and feedbacks between the regional climate change and the water system components within the river system.

H01PS.47

H01PS - Climate and land surface changes in hydrology

Poster

Climatic warming and water temperature in rivers draining from Alpine glaciers

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Distinctive diurnal and seasonal patterns of water temperature occur in rivers draining from large Alpine glaciers. Such temperature regimes have been recorded alongside discharge at hourly resolution in the Findelenbach, and Gornera and Massa rivers, within a few kilometres of the receding termini of Findelengletscher, Gornergletscher and Grosser Aletschgletscher respectively in Wallis, Switzerland, in spring and summer between 2003 and 2012. Water temperatures rise to a seasonal maximum in April and May, as discharge slowly increases from the onset of melt. Discharge continues to increase as the transient snowline rises up glacier and air temperatures rise to seasonal maxima, but water temperature decreases to levels lower than those observed in spring. At the diurnal level, water temperature first increases with increasing radiation and warming air temperatures in early morning before meltwaters from the glacier surface reach the portal enhancing river flow to daily maxima in late afternoon. Water temperature declines during daily discharge peaks as energy availability is insufficient to offset larger volumes of water flowing. By evening, declining flow accompanies decreased energy input and water temperature remains subdued. Meltwaters emerging from portals of Alpine glaciers are generally around 1 degree Celsius, but warming with distance downstream is influenced by volume of water flowing, velocity of flow and stream surface area as well as energy availability. Warmer conditions leading to greater energy availability also generate enhanced meltwater runoff volumes. A paradox arises in that when solar radiation and air temperatures are high, stream water temperatures are often reduced. As air temperatures continue to warm, water temperatures in large glacier-fed rivers will first cool before warming, as runoff initially increases, before declining glacier surface area leads to reduced melt.

H01PS.48

H01PS - Climate and land surface changes in hydrology

Poster

Hydrological response to vegetation changes in semi-arid region, China

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Evaluating the impact of land use change on water is a major challenge in hydrological research. Changes in land surface properties ultimately modify the energy and water exchange of the soil «vegetation» atmosphere system. In recent years, the runoff of Laohahe shows a dramatic decrease and discontinuous flow as the result of climate change, human activities, or both. The objective of this work is to document significant streamflow hydrology changes induced by human activities and to quantify the impacts of observed changes on regional hydrologic regimes. In the area of study, the observed discharge had been influenced by human activities such as land use changes, bans, irrigation from rivers, and industry usage. Most importantly, land use changed acutely with forest and farmland increasing while grassland decreased starting in 2000 based on former studies. The statistics method and Variable Infiltration Capacity (VIC) hydrological model were used to estimate the effect of land use changes on runoff and evaportranspiration (ET) of Laohahe basin. Firstly, the runoff of study area was divided into «the natural period» and «the human-induced period» according to the analyses of long-term monthly and yearly discharge records using Pettitt test method. Then the hydrological process was simulated by the VIC hydrological model using observed and reconstructed monthly discharge. Furthermore, the simulated results were compared based on land use scenario in 1989, 1999, and 2007, respectively. This method is used to explore the effect of land use change on streamflow of Laohahe basin. The result shows that land use change and human intake water appeared to be the most likely culprit contributing to the significant reduction in streamflow from 1999 to 2008 in the Laohahe basin by 70%.

H01PS.49

H01PS - Climate and land surface changes in hydrology

Poster

The future changes projection of precipitation and temperature in the Yangtze River Basin, China

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The performance of reproducing the precipitation and temperature in the Yangtze River Basin in 1970-1999 by the regional climate model-RegCM4 at a spatial resolution of 50*50 km was analyzed based on the observed precipitation and temperature data of 250 meteorological stations in the Yangtze River Basin. The annual average, seasonal changes, inter-annual changes and the extreme climate indices of the temperature and precipitation were used to validate the model. The RegCM4 could simulate the temperature quite well, but the model is more capable of simulating precipitation in humid regions and wet seasons and tends to overestimate precipitation for regions and seasons with small amount of precipitation. The model simulates most extreme climate indices quite well except the significant overestimates of the consecutive dry day. The future climate was projected by RegCM4 coupled with the European-Hamburg general climate model (ECHAM5) at A1B emission scenario. At the end of the 21st century (2070-2099), compared with the historical period the predicted increase of temperature is large than 3 degrees, the extreme hot events will increase and the extreme cold events will decrease, precipitation is predicted to increase over most areas of North China and decrease over South China, and with the increase of the heavy rainfall events and serious drought events.

H01PS.50

H01PS - Climate and land surface changes in hydrology

Poster

Impact of initial soil moisture anomalies on climate extremes over East Asia based on a regional climate model

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This paper aims to investigate the impact of initial soil moisture anomalies on subsequent climate extremes (e.g. hot days, heat wave) over East Asia based on one recently published regional climate version model, RegCM4-CLM3.5. A series of numerical experiments are designed to test the mechanism of initial soil moisture anomalies feedback in spring, summer and autumn seasons with prescribed soil moisture on March 1st, June 1st and September 1st. The results show that both the dry and wet initial soil moisture anomalies can reinforce the very severe flood extreme in the three seasons; in addition, the initial soil moisture anomalies have cerrtain relationship with the changes of climate extremes, the wet (dry) initial soil moisture anomalies would increase (decrease) the precipitation climate extremes and reduce (increase) the hot extremes over most part of the study area except the boundary area along the ocean. But for the cold extremes, the wet (dry) initial soil moisture anomalies act a role as the greenhouse gases and the wet (dry) soil moisture condition would decrease (increase) the cold extremes.

H01PS.51

H01PS - Climate and land surface changes in hydrology

Poster

Characteristics and scenarios projection of climate change on the Tibetan Plateau

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The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4) presents twenty-two global climate models (GCMs). In this paper, we evaluate the ability of 22 GCMs to reproduce temperature and precipitation over the Tibetan Plateau by comparing with ground observations for 1961¡»1900. The results suggest that all the GCMs under estimate surface air temperature and most models over estimate precipitation in most regions on the Tibetan Plateau. Only a few models (each 5 models for precipitation and temperature) show roughly consistent with the observations in annual temperature and precipitation variations. Comparatively, GFCM21 and CGMR are able to better reproduce the observed annual temperature and precipitation variability over the Tibetan Plateau.

H01PS.52

H01PS - Climate and land surface changes in hydrology

Poster

Rainwater harvesting under multi recorded scenarios at semi-arid of eastern Sinjar mountain, Iraq

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Macro Rainwater Harvesting (RWH) has been tested with a catchment area of four basins at Eastern Sinjar District-Iraq, using three recorded rainfall scenarios (S1, S2, and S3) that represent rainfall seasons of the maximum, minimum and average of weekly rainfall during the study period 1990-2011, that help to offer a better understanding about the factors that governing hydrologic processes in a semi-dry region. This region is facing a severe water shortage problem and the scarcity of sufficient hydrologic studies. The estimated harvested runoff volumes for the above scenarios based on United State Department of Agriculture Natural Resources Conservation Service Curve Number method (USDA-NRCS-CN) using the watershed modeling system (WMS) to estimate the runoff volumes for the selected catchments' area. The harvested runoff water could be stored in four separated reservoirs, then their water to be used later by supplemental irrigation of 100% of total irrigation requirement in order to maximize the irrigated area of the rain-fed farms of semi-arid Eastern Sinjar. The irrigated area for individual reservoir has been calculated. Excess water volume from reservoirs' capacity was calculated, which represents the water release from the spillways. These amounts of water release might be used to recharge ground water aquifers, although they are limited with their volumes instead of loss in vain without interest. The implementation of water harvesting in this area seems to be a very effective and large area can be used for agricultural practices.

H01PS.53

H01PS - Climate and land surface changes in hydrology

Poster

Climate change impacts on water resources in Haryana state, India

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Climate change is one of the most serious phenomena and one of the most crucial issues of our times.Climatic variables such as precipitation and temperature are essential inputs to water resources. Different combinations and seasonal pattern have direct consequences on the water regime of a region. Understanding rainfall variability, shifts and trends are of primary importance when considering the potentials of biophysical, social and economic impacts of climate change. An increase in mean rainfall could enhance agricultural production and water supply. However, if this increase is associated with more extreme rainfall events, it can enhance flood frequency and intensity. Conversely, decrease in mean rainfall can lead to drought and greater drought risk. Given such a heavy dependence on rainfall, it should be no surprise that climate extremes such as droughts or floods can pose significant water threats to the entire region.

The short rainy season is succeeded by long dry season. The distribution of rainfall is irregular in both time and space and water deficiency is a problem everywhere. In the present Study, time- series analysis is used to observe the specific trends in rainfall and temperature. Simply stated, time-series analysis is defined as analysis of data in which time is an independent variable. A time series is analysed for the purpose of formulating and calibrating a model that can be used both to describe the time- dependent characteristics of a climatic variable and to predict future values of the time-dependent variable. It is observed that water resources of the State are heavily dependent on the climatic variables.

H01PS.54

H01PS - Climate and land surface changes in hydrology

Poster

Adapting to the impacts of climate change in the water sector - case of a small island

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Mauritius, situated off east of Madagascar, is a small isolated island covering a surface area of about 2000km^2. The water sector is heavily dependent on rainfall, annual average being 2100, making about 3700Mm^3. With the current existing facilities, only 33% of this volume can be harnessed annually. The level of satisfaction of water supply is high in the domestic sector, 99.6% of the population having access to piped supply, but is lower in the agricultural sector, with only 62% of the demand being satisfied. Because of its steep topography, and increasing build up area, high volumes of surface runoff are generated, reaching up to 60% of the total rainwater. Overall water demand is increasing at the rate of 1% per year, putting more and more pressure on the water sector. Losses in terms of defective pipes and unaccounted for water reach up to 50% in the distribution network. In addition to these constraints, the island has been recording the impacts of climate change on the water sector over the last few years' extreme climate events in the form of long dry periods, flood type rainfall events and increasing surrounding temperature. Diseases related to poor quality water are almost negligible, but occur to some extent during the wet season after prolonged heavy rainfall. As per the IHDP rating, Mauritius falls under the category of water stress countries and may even shift to water scarce country category in the near future. Recently investments in the water sector have significantly increased with the objectives of achieving water security. This should be supplemented though a number of initiatives linked to water resource protection, geophysical studies, isotope studies, desalination technology, artificial recharge and water demand management. The country has few local experts in geophysical studies, isotope studies and artificial recharge. Both research and training are required in order to ensure water security.

H01S1.01

H01S1 - Climate and land surface changes in hydrology

Oral

Seamless forecasting of floods and droughts and other extreme events

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Early warning systems of floods, droughts and other extreme events at a global scale are now essential due to the combined threat of increased population settlement in vulnerable areas, such as those prone to flooding or water shortage, and the possible risk of an increase of the intensity of extreme weather due to climate change.

The recent availability of long-term global gridded datasets of precipitation and temperature alongside improvements in skill of weather prediction provides an unique opportunity to develop systems for early detection of extremes on a global scale. The European Weather Centre for Medium Range Weather Forecasts (ECMWF) is leading this effort by combining forecast products from the short-range (few days) up to the seasonal scale in a seamless framework, and by using them to drive user-oriented application to predict floods, droughts, extreme wind, forest fires and malaria.

This paper reviews the performance of these systems by providing a comprehensive assessment of their performance both on a global level and on selected regions. The final aim is to employ these prototype systems in decision support frameworks, and the developments required in order to meet this ambitious aim are carefully considered.

H01S1.02

H01S1 - Climate and land surface changes in hydrology

Oral

Accounting for climate change and uncertainty – experience from strategic adaptation projects in Sweden

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In Sweden adaptation to climate change has been addressed in connection to some strategic projects of national significance. The case of hydrological upgrading of Swedish dam safety assessments has been in the forefront. This has been followed by rather complex studies of risks in the expanding metropolitan areas of Stockholm and Gothenburg, were assumptions about hydrological changes have to be combined with considerations about future changes in sea levels.

The technique used has been rather straightforward as far as hydrology is concerned. Global climate model results have been downscaled dynamically and, after bias correction, an ensemble of regional climate simulations has been introduced into a hydrological runoff model.

The key subject in the adaptation work has, however, been to cope with the inevitable uncertainty in the absence of statistical techniques for the rather inconsistent sets of regional climate scenarios available. The way forward has been a close and long-lasting relationship with stakeholders. In the case of dam safety this was carried out during three years of work in a joint committee between the industry, responsible agencies and research. For planning in the municipalities everyday contacts have been maintained at all stages of the projects.

The presentation will highlight three high profile projects in Sweden, where climate change adaptation is an integral part; the case of dam safety, the design of a new outlet of Lake Mälaren in Stockholm and the complex system of the large Lake Vänern, its outlet River Göta älv and the downstream located City of Gothenburg. Special attention will be given to the user dialogue and how uncertainties in the scenarios are handled from the perspective of the stakeholder.

H01S1.03

H01S1 - Climate and land surface changes in hydrology

Oral

Adaptation strategies using hydrologic risks transfer models for extreme events derived from climate and land use change scenarios

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This contribution outlines conceptual experiences on coupling river basin extreme event simulations derived from climate change outputs with Hydrologic Risk Transfer Models (HRTM). We considered a conceptual linkage among Brazilian Eta-CPTEC climate model, the MGB-IPH hydrological model, and the HRTM-EESC-USP and SWAT modeling. This linkage was an adaptation strategy to assess minimum environmental flows under climate and land-use changes using distributed modelling at two Brazilian river basin conditions. On the one hand, a Nested Catchment Experiment (NCE), from 927 to 10 929 km2 of a subtropical biome, was performed at the Piracicaba-Capivari-Jundiai River. On the other hand, another NCE from 5000 and 76000 km2 was surveyed at Jaguaribe river basin of a semi-arid biome. Validation performances of either MGB-IPH and SWAT in representing the behavior of minimum flows of past time series were used to generate future scenarios for the period 2013-2099. Equally probable runs were assessed through HRTM associated to the economical values derived from water low flows at catchment scale. HRTM's indicators of water scarcity index, premium's renewal, solvency and scenario's efficiency were optimized using Water Insurance Funds (WIF) with coverage limits, vulnerability curves and return periods. Although regional impacts on WIF from global changes are evident, climate change and urbanization represent mixed signals of ca. 0.2% to 24%. Costs of 9.5 to 1433 R$ km-2 were discussed in front of trade-offs of premiums of WIF between 9.9 and 1479 R$ km-2. Next pathways for the feasibility of HRTM at different biomes were outlined in terms of value of environmental services and how these could play a special role in adapting strategies at vulnerable catchments under the scope of predicting in ungauged basins (PUB).

H01S1.04

H01S1 - Climate and land surface changes in hydrology

Oral

Hydrological flood design in Sweden – Climate change in relation to inherent uncertainties

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The standard simulation scheme for design flood determinations in Sweden was developed in the 1980s when it became obvious that current criteria were obsolete and could lead to dangerous consequences. The new guidelines were adopted in 1990 and a nation-wide re-evaluation programme of all major dams in the country started and is still ongoing. A new and revised edition of the guidelines was published in 2007, in which it is prescribed that climate change shall be considered in all design studies.

Climate change, however, is not the only factor affecting the precision of a flood design study. The traditional methods entail many inherent uncertainties that are often overlooked. Statistical analyses are susceptible to the choice of distribution function and the length and representativeness of the record used. Hydrological modelling is susceptible to the choice of the model, the time period and method used for calibration of the model and sometimes even to the individual skill of the modeller.

As a complement to the studies on climate-adaptation of design floods, attempts to put the climate change uncertainty in relation to the inherent uncertainties in the methodology has been made. The work was carried out in 5 river basins of strategic interest to the power industry. Climate change was considered by use of an ensemble of 16 regional climate scenarios as input the hydrological runoff model, which also has been calibrated and applied under different conditions in present climate.

The results imply that the uncertainty that is caused by differences in the climate change signal is larger than the inherent uncertainties of the hydrological modeling process together. The main conclusion is therefore that it really is important to consider climate change in future determinations of design floods for dams. Another conclusion is that there is a need for re-assessments of early design calculations due to advances in hydrological models and calibration schemes.

H01S1.05

H01S1 - Climate and land surface changes in hydrology

Oral

Impacts of climate and land use changes on flood frequency in an urban catchment in South East Queensland, Australia

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Over the coming decades, the projected land use change, when coupled with climate change, could potentially lead to an increased risk of flooding in urban catchments. It is therefore of interest to develop robust methods for flood risk assessment in a changing environment. This research aims to examine the impact of climate and land use changes on flood frequency in South East Queensland, Australia. A rainfall-runoff routing model, known as RORB, was firstly validated based on the observed flood hydrographs for an urbanised catchment of 128 km2 for the period of 1961-1990. RORB is widely in Australia for flood estimation, and it combines a simple infiltration model for runoff generation with kinematic wave approximation for flood routing through the catchment. The calibrated model was then used to generate flood hydrographs for a given frequency of occurrence obtained from one global climate model, GFDL, and one regional climate model, CCAM, for 2016-2045. Daily precipitation outputs for the two contrasting periods were used to derive adjustment factors for given frequency of occurrence. These adjustment factors were applied to observed 6-min rainfall intensities for flood events of the same frequency of occurrence. Two scenarios of land use change were considered to evaluate the likely impact of land use change. Based on the projected rainfall scenarios, the results showed that future flood magnitudes are unlikely to increase for large flood events in the catchment. When compared with climate change, further land use change would not significantly affect flood magnitudes for a given frequency of occurrence in this catchment. Limitations of this study include the uncertainties of climate projections and the feasibility of future land use scenarios. In addition, kinematic wave approximation used for flood routing limits the model’s capacity to represent changes in surface characteristics of the catchment.

H01S1.06

H01S1 - Climate and land surface changes in hydrology

Oral

Synchronous, linked changes in rainfall, floods and river channel changes in south eastern Australia since European settlement

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Synchronous, alternating, rainfall-driven, flood- and drought-dominated regimes have been previously identified in the flood record of many rivers in south eastern Australia over the last 200 years. During the wet phases, annual and summer rainfall, rainfall intensities, and flood magnitudes are much greater than during the dry phases. Synchronous river channel changes have also been documented on many but by no means all rivers. The theory of alternating flood- and drought-dominated regimes was proposed as an explanation of these rainfall- and flood-driven channel changes where two different channel states were recognised. The purpose of the present paper is to show that these alternating wet and dry phases are not simply related to easily measured changes in general circulation, such as ENSO or IPO, and that many river channels are so resilient due to protection by flood-tolerant vegetation that the threshold of channel stability is not exceeded by these regime changes. Sand bed-streams and rivers cleared of riparian vegetation after European settlement are the most sensitive to alternating regime changes. Furthermore, recent changes in riparian zone management have complicated the channel changes by accelerating the colonisation of flood-disturbed channel boundaries with riparian and aquatic species that are no longer grazed. Enlightened river management practices have increased the resilience of channel boundaries, even on highly sensitive sand-bed streams and deserve greater community acceptance. Synchronous, linked rainfall, flood and channel changes can only be recognised where active river management has not been practised in south eastern Australia. Current channel states on some rivers have no historical or pre-historical analogue on many rivers.

H01S1.07

H01S1 - Climate and land surface changes in hydrology

Oral

Integration of remote sensing, GIS and runoff modeling for estimating flash flood of ungauged catchments, Abu Arish area, Jizan, Saudi Arabia

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Evaluation of flash flood oscillation and flood water resource is a vital issue for establishing properly sustainable development in arid region, such as Saudi Arabia. However these flash floods are among the most catastrophic natural extreme events that present a potential threat to both lives and property. Hence, precise assessment of floods becomes a more vital demand in development planning. This study is an integrated approach including remote sensing, GIS and hydrological models, which utilized to identify, and assess flood hazards in Abu Arish area. A runoff model, adopting the simple Soil Conservation Service method, was built for ungauged catchments. Runoff modeling was carried out as a function of the descriptive parameters of the catchment area, and the maximum average rainfall occurred in 1 day. Many parameters were extracted from the available remote sensing data and field investigations. Land use/cover of the study area was extracted from the maximum likelihood classification of the Landsat-7 (ETM) and SPOT-5 imagery. Hydrologic characteristics and soil type in the sub-basins were examined during field check. Curve Number (CN) for each land use/cover type was calculated according to the US Soil Conservation System (SCS) model. Morphometric parameters of the catchment area and its channel network were carried out from the analysis of the ASTER digital elevation model (DEM). Hydrographs were drawn and routed to the main catchment outlet and the runoff and infiltration volumes were quantified, the resulting model has been used to investigate the relative potential for flooding. Results of this work can help to delineate areas where flood control measures should be directed, and effectively enhance management plans for the appropriate water resources development.

H01S2.01

H01S2 - Climate and land surface changes in hydrology

Oral

Global climate change impacts on freshwater availability –» an overview of recent assessments

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This keynote talk will chart the spread of recent quantitative assessments of global climate change impacts on freshwater availability and demand. A focus will be on «green» and «blue» water requirements for producing the vegetal and animal-based food for a growing world population. It will also be demonstrated how impacts, especially declines in water availability, might accrue as a function of global warming, and what the likelihood of such impacts is when accounting for a large ensemble of climate change projections (from ca. 20 GCMs). These impacts assessments are based primarily on simulations with a global model that couples vegetation, water and carbon dynamics in a single framework, which also allows for highlighting important vegetation-water interactions (obvious e.g. in direct CO_2 effects on plants). Findings from the recently launched Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) will be presented in addition, that is, impacts of different global warming levels (derived from the IPCC's latest RCP emissions scenarios) on water availability, computed by a suite of global hydrological models. Finally, the talk will elaborate on the potential of various crop and water management options to adapt to climate change impacts (under conditions of growing population and food demand), emphasising which countries will have to rely on «virtual water trade» even if on-farm management were fully explored.

H01S2.02

H01S2 - Climate and land surface changes in hydrology

Oral

Post-processing of Regional Climate Model results for hydrological impact studies, how well is reference state preserved?

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Evaluations of regional climate model (RCMs) outputs used to simulate impacts of climate change on hydrology show strong biases for present climate, particularly for precipitation. Various methods are often used to correct these biases prior to any hydrological impact studies where RCM data is used to force a hydrological model (HM). Bias correction (BC) is considered a preferred method for interpreting climate change results because it conserves the changes in variability of precipitation predicted by the RCMs while retaining a realistic representation of the volume. But even though the RCM outputs are adjusted to match a reference dataset, the resulting outputs from a HM will not necessarily retain this close match. The main reason for this is that most BC methods do not account for the order of events. Traditionally, BC methods are validated in HMs in their ability to reproduce discharge and little work has been done assessing internal variables. This study addresses this by comparing how well a number of variables describing runoff flow paths and nutrient leakage (nitrogen and phosphorus) can be reproduced by a HM using bias-corrected forcing. For this, the dynamic, semi-distributed HYPE HM was chosen along with the 'Distribution Based Scaling' (DBS) BC and downscaling method. HYPE runs, forced with DBS scaled data were then evaluated for their ability to reproduce the long term mean value in the reference runs for a number of variables. The preliminary results indicate varying sensitivities of the analysed variables. The most sensitive variables being surface runoff, snow and particulate phosphorus whereas discharge, specific runoff, evaporation, nitrogen and soluble phosphorous were less sensitive to the scaling. This study implies that although the DBS bias-correction tool is useful for hydrological impact studies, improvements to the method are needed to simulate climate change impacts on regions with threshold rain/snow and to correctly describe flow paths.

H01S2.03

H01S2 - Climate and land surface changes in hydrology

Oral

Water supply capacity of a meso-scale Mediterranean catchment under long-term climatic and human activities constraint

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Assessing water allocation capacity is crucial, notably in the Mediterranean region identified as a hot-spot of climate change and where water demands have been continuously increasing due to population growth and expansion of irrigated areas. The Hérault River catchment (France) is representative of this context. Since the 1960s, a negative trend in discharge has been observed. This can be attributed to a decrease in mean winter precipitation, a rise in mean temperature, and a water consumption increase. A modelling framework is thus proposed in order to assess the ability of water supply to satisfy water demands over the last 50 years. Water supply is evaluated using hydrological modelling and a dam management model. Dynamics of water demands are estimated for the environmental, domestic and agricultural sectors. A water supply capacity index is computed to assess how water demands have been satisfied at the sub-basin scale. Water resources are satisfyingly represented over the calibration (1981–2010) and validation (1961–1980) periods with (i) a Nash-Sutcliffe (NSE) criterion over 0.80 and a volume error under 15% in the hydrological model, and (ii) a NSE criterion over 0.80 for water release and over 0.70 for dam stock and a nil volume error for water release and dam stock in the dam management model. Environmental demands represent the minimum river flow. Domestic demands have largely increased since the 1980s and are characterized by a seasonal peak in summer. Agricultural demands have been increasing in the driest sub-basin and decreasing in the wettest ones where irrigated areas have decreased. Although most of water demands were highly satisfied over 1961–1980, irrigation needs have sometimes suffered a lack of satisfaction in summer since the 1980s. This work is a first step towards evaluating possible future changes in water allocation capacity in the catchment, using future scenarios of climate change, dam management and water uses.

H01S2.04

H01S2 - Climate and land surface changes in hydrology

Oral

Evaluation and comparison of two downscaling methods for daily precipitation in hydrological impact studies

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Climate change impacts the global water cycle and water resources in many regions. General Circulation Models (GCMs) are the main tools to simulate climate variables under greenhouse gas emission scenarios. They operate with a coarse spatial resolution of about 200x200 km. However, impact studies require climate simulations at higher resolution to capture the spatial variability of key variables such as precipitation. Downscaling techniques have been developed to increase the resolution of GCMs simulations in order to provide realistic inputs to impact models. This study aims to evaluate and compare two downscaling methods for daily precipitation over the Ebro catchment in Spain (85 000 km^2). The perturbation method serves as the benchmark method against which a recent probabilistic downscaling method called CDFt is compared. The local data are 10 x 10 km grids of daily precipitation over the Ebro catchment for the period 1959–1998. These gridded data are obtained by interpolating observations from 207 raingauges by the inverse distance method. The large-scale data are outputs from three GCMs used in CMIP3 (HADCM3, ECHAM5 and CNRM-CM3) under the base scenario for the 20th century. Variants of each downscaling methods were calibrated over the period 1959–1978 and then validated over the period 1979–1998. We relied on three performance criteria which relate to important features of precipitation for hydrological modeling: cumulated precipitation and seasonality aggregated over the catchment and the Nash-Sutcliffe criterion analyzed spatially for each grid cell. The perturbation method performs generally well however it is sensitive to the choice of GCM. Note that this method makes strong assumptions since the spatial and temporal dependence of the past is reproduced as is in the simulations. The CDFt method is more flexible but requires more fine-tuning. This a first step towards evaluating the performance of the two downscaling methods in terms of impacts on runoff.

H01S2.05

H01S2 - Climate and land surface changes in hydrology

Oral

Dramatic localised climate change effects on water resources

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In the south west of Western Australia, over a region of about $10^6 km^2$ the precipitation and resulting water resources have reduced dramatically. The annual precipitation is now only 90% of what it was 1900-70 and the surface runoff has declined to only about 30% of previous volumes. This has led to a huge investment in seawater desalination plants to supply fresh water to Perth (pop. 1.2M). However in the surrounding areas to the north and inland to the east these climate trends are reversed. In the same recent 40 years the annual precipitation to the north has increased by about 10% and the runoff by up to 20%. To the east the precipitation increase has been smaller. Small changes in seasonal distribution of precipitation have accentuated the reduction of surface water caused by reduced precipitation. Changes of this magnitude have not occured elsewhere in Australia. Temperatures have risen by up to 3 degrees over most of the continent but have declined by about 0.7 degrees over 10^6 km^2 in the south east. Several studies have demonstrated the marked non-stationarity of hydrometeorological data in the region and have suggested possible causes, such as changes in the average regional north-south sea level pressure gradient and increases in atmospheric aerosols. However these studies have not noted the non stationarity which has produced opposite effects on precipitation in the larger region immediately surrounding the region highlighted here. These findings demonstrate that causes of these dramatic changes in available water resources are still unclear. The findings here illustrate the need for care in discussion of global climate change. Changes are certainly occuring over parts of the globe but they are not universal. Therefore great care is needed in the selection of observation stations to define actual changes and even more care is needed in drawing conclusions on the global scale.

H01S3.01

H01S3 - Climate and land surface changes in hydrology

Oral

Study of two RCM projections and their impacts on runoff in a Mediterranean basin

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This study seeks to assess runoff response to rainfall bias corrected RCM outputs using a water balance model. A hydrological data base composed by observed rainfall and pan evaporation time series as well as mean daily discharge observations at the basin (378 km^2) outlet is available. In addition, it is taken advantage of meteorological data from three surrounding stations with air temperature, air pressure, wind speed, air relative humidity and sunshine length series for estimating monthly potential evapotranspiration (ETP). On the other hand, an ensemble of RCM simulations provided by the European Union–funded project ENSEMBLES (www. ensembles-eu.org) are used. Two RCM model runs (SMH-B, SMH-E) out of six primarily selected are analyzed for the control period 1961-2000. SMH-B and SMH-E were ranked as the most efficient in reproducing seasonal precipitation amounts and variability (Bargaoui and Tramblay, 2011). The RCM rainfall outputs of the control period were corrected for bias adjusting month by month daily rainfall cumulative distributions with Gamma distributions using the so-called quantile mapping method (Ines and Hansen, 2006). It is further assumed after Schaller et al. (2011) that RCM air temperature data are less biased than RCM precipitation data. The single store water budget model BBH (Kobayashi et al., 2001) is assumed introducing soil texture information through pedo transfer parameters (Bargaoui et Houcine, 2010). Model parameters were calibrated using both observed runoff data at basin outlet and the ratio Kv of actual evapotranspiration to potential evapotranspiration. As recommended by Eagleson (1994), the latter may be considered as basin signature and should be integrated in the calibration process. Model outputs at daily time step are then simulated using successively the daily average observed rainfall and the daily corrected RCM series for the control period. Then comparison of runoff impacts is performed at monthly resolution.

H01S3.02

H01S3 - Climate and land surface changes in hydrology

Oral

Application of ASD technique in different river basins of the eastern monsoon region, China

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The trend of global warming concluded by IPCC (Intergovernmental Panel on Climate Change) will lead to changes in rainfall and other climate variables that will be amplified in runoff. Previous studies for climate change indicated that rainfall and runoff are likely to decrease as a result of global warming, which requires active response and change in water resources management. However, GCMs (Global Climate Models) as the best tools available for simulating global and regional climate systems can only provide information at a coarse resolution which cannot be used directly in hydrological modeling. Therefore, statistical downscaling methods are used to fill the gap between large-scale climate change data and fine-scale hydrological application. Automated Statistical Downscaling (ASD) technique is investigated with the combination of a case study in three river basins of eastern monsoon region, China. Statistical relationship between predictant and predictor is developed by using observed data in three river basins and ERA-40 reanalysis data, and the high resolution daily precipitation, average air temperature, maximum and minimum air temperature are then generated. Finally, the performance and the suitability of ASD model are evaluated. Result shows that (1) ASD is able to present seasonal variation and spatial distribution of four variables during both calibration and validation periods; (2) the efficiency of simulation on air temperature variables is better than precipitation due to the high degree of uncertainty within the structure of precipitation; (3) the performance of ASD model changes in different river basins depending on geographic and meteorological factors in the study area, and the better simulation effects are obtained in areas with higher homogeneity. Overall, ASD technique performs satisfactorily in the study area, which can be used to generate future scenarios and hydrological simulation.

H01S3.03

H01S3 - Climate and land surface changes in hydrology

Oral

Assessing the impact of global changes on surface water resources in the derived savanna of Southwestern Nigeria

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Hydrological models are important not only in water resources planning, development and management, flood prediction and design but also in water quality, hydro-ecology and climate management. Understanding the relative impact of land use / land cover (LULC) and climate change patterns on basin runoff is necessary in assessing basin water stress. This study assessed the impact of changes in climate and LULC on water stress using long-term observed and future predicted rainfall data to generate monthly runoff information through hydrological simulation. Data on basin hydro-meteorological and physiographic characteristics were also used to assist in the training and calibration of the model. LULCC and change detection were conducted using orthorectified Landsat multi-temporal imageries for 1972, 1986, 2001 and 2006. The long-term (1971 - 2007) historical rainfall data and projected rainfall data (up to the year 2050) dynamically downscaled to a 60km by 60km grid, using the Conformal-Cubic Atmospheric Model (C-CAM) were used to drive the Pitman monthly rainfall-runoff model to assess changes in runoff for three selected basins – Asa, Ogun, and Owena. The model results revealed commensurate increase in the runoff coefficient with decreases in forest cover between 1981 and 2000 and, lower runoff coefficients of 5.32%, 12.0% and 6.4% for Asa, Ogun and Owena basins based on CCAM projection of low rainfall for 2010-2050. The predicted decrease is much higher for the Ogun and Owena basins for the future scenario, when compared to the Asa basin. These indicate that in the future the water stress in Asa basin would be much higher

H01S3.04

H01S3 - Climate and land surface changes in hydrology

Oral

Spatial and temporal variations of potential evapotranspiration, SPI and surface humidity in China over the last 60 years

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Using monthly meteorological observations at over 700 stations in China from 1951 to 2011, the potential evaporation (PE) is calculated using Penman-Monteith equation, and then the Standardized Precipitation Index (SPI) and humid index (HI) are calculated. SPI and HI are spatially interpolated with the method of Inverse Distance Weighted, and the temporal and spatial variations of both indices are analyzed with Mann-Kendall trend test.

The results show that in the past 60 years, PE in China exhibits a decreasing trend in general. The decrease in PE is especially significant in southern China, whereas significant increase in PE was found in midlle-upper Yellow River Basin, the south-west part, and the north-east part of China.

SPI shows that southern China exhibits a slight increase in dryness in general, whereas the development of drought in northern China has higher varibility than that in southern China; different seasons exhibit different trend of dryness, that is, in spring and autumn, drought tends to be aggravated meanwhile in summer and winter drought tends to be mitigated.

In terms of HI, there is an increase of humid area in China in general, but the east part of north-west China, the north-east China, the north China, the middle-lower parts of the Yangtze River Basin, and southeast China shows an decrease in humidity. The intensity of humidity change increases from the east to the west part of China. The humidity of south-west china is in general stable, whereas the humidity status in arid areas in northwest china is most changeable.

The change of PE is closely related to sunshine duration, wind speed and relative humidity. The major reason of the decrease in PE in most pats of China is the decrease of sunshine duration, wind speed and relative humidity. As HI is the ratio of total precipitation and PE, the spatial patern of humidity index change is a mixture of the change of precipitation and the change of PE.

H01S3.05

H01S3 - Climate and land surface changes in hydrology

Oral

Impact of climate change on runoff in the Algérois-Hodna-Soummam (AHS) Basin

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In Algeria, the problems of water resources have not been adequately addressed so far in the analysis of climate change and climate policy formulation. Similarly, in most cases, the historical evolution of climatic parameters and water resources has not been evaluated at different horizons and different scale. To observe this trend we selected the Algérois-Hodna-Soummam (AHS) Basin belong to three different regions of Algeria, We evaluated the impact of future climate change on seasonal flows of 2050 and 2100. To better understand the importance of these impacts, we have based our analysis on average flow of the reference period (1961–1990) and compared them with those that might result from changes in the main direct constraints. The methodology used is based on the GRM2 model. The analysis of the results showed a marked decrease in average monthly flows compared to the reference period in the different horizon and different scales studied.

H01S3.06

H01S3 - Climate and land surface changes in hydrology

Oral

Impacts of global changes on water resources in Sahel in West Africa

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The prospect of global change (climate change and anthropogenic impacts) remains one of the serious threats which hinder on future water resources in developing countries and particularly those of West Africa. Paradoxically, many studies pointed out that since 1970 in the Sahelian zone, runoff coefficients of the hydro-systems increase strongly whereas regional rainfall significantly decreased. In this region, all the previous works have shown that soil surfaces features influenced the distribution of rainfall to runoff, infiltration and evaporation. However, one observes at the same time a significant land use change: cultivated areas increase to the detriments of natural vegetation areas, increase of bare soils areas, and degradation of vegetation cover.

This study aims to assess the impacts of global change on future flows in the Upper Nakanbé River at the Wayen gauging station in Burkina Faso. Hydrological modeling approach takes into account environmental change (soil surfaces features) in a lumped hydrological model, GR2M.

Land use scenarios have been established over an observed period, which allowed a validation of the method, and projected up to 2050. These scenarios are based on socio-economic assumptions shored up by recent studies translating the dynamics of likely evolution of the soil surfaces features.

At the same time, climate scenarios to 2050s on the basin were built using four regional climate models (RCMs), under scenario A1B, and corrected using «delta» method. In terms of annual rainfall, the projections of four models vary in a range from -3 to 10%.

According to the climate scenarios, hydrological simulations show that flows will more or less strongly change in the future with a particular sensitivity to the land use changes

H01S4.01

H01S4 - Climate and land surface changes in hydrology

Oral

Embedding complex hydrology in the climate system - towards fully coupled climate-hydrological models

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To ensure the sustainable development of water resources and to assess the impacts of climate change on surface water and groundwater resources, it is important to understand and represent the interaction between the atmosphere and land surface and subsurface surface hydrology. Soil-Vegetation-Atmosphere-Transfer (SVAT) models simulate the interaction between the canopy and the environment, in particular the land surface water and energy fluxes. This interaction is complicated by the feedback between the two systems, the spatially variability of parameters and water processes on the land surface and more practically by our ability to accurately parameterize soil and vegetation characteristics. In this paper we present an energy-based SVAT (land surface) model based on Shuttleworth-Wallace and the application of this model to the development of a coupled climate hydrological modelling tool using OpenMI. Firstly, the sensitivity of the different SVAT model parameters under particular applications and our ability to characterise these parameters using satellite remote sensing are investigated. Secondly, field data are used to investigate the effects of model resolution and parameter scales for use in a coupled climate-hydrology model. Finally, the development of a fully coupled dynamic climate-hydrological model consisting of the MIKE SHE hydrological model and the HIRHAM regional climate model (RCM) via OpenMI is described. We will present results of a set of numerical experiments to explore the impact of hydrological processes on the sub-grid scales of a regional climate model. Important strengths of the coupled model is that more detailed hydrological processes can be represented at a finer scale, it includes lateral transport of surface water and groundwater not generally treated by RCM's and can represent catchment management processes like groundwater pumping, irrigation schemes, etc. for adaptation studies.

H01S4.02

H01S4 - Climate and land surface changes in hydrology

Oral

The impact of groundwater dynamics and soil-type for modeling coupled water exchange processes between land and atmosphere

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Shallow groundwater dynamics in combination with soil-types, characterized by high capillary rise properties, can act as a major driver for near surface soil moisture states and thus evapotranspiration. Dynamic regional atmospheric models as the Weather Research and Forecasting model (WRF) employ land-surface descriptions that usually neglect such an influence of the saturated zone. An inadequate representation of the interaction among saturated and unsaturated zone, however, could spread to unrealistic soil-moisture and -temperature conditions and thus yield to limitations in accurately describing the evapotranspiration and planetary boundary layer processes and consequently precipitation generation.

We present a process study for two different parametrization schemes for saturated-unsaturated zone interaction and their effect on water and energy exchange processes between the land surface and the atmospheric boundary layer. The two coupling schemes are applied using observation data of the TERENO Pre-Alpine observatory in Southern Germany. We analyze the impact of enabled groundwater interaction on the state of the vadose zone and on the water fluxes at the land-surface-atmosphere interface.

The process study will serve as foundation for the distributed application of the groundwater interaction approach within the fully two-way coupled hydrological-atmospheric model system WRF-Hydro.

H01S4.03

H01S4 - Climate and land surface changes in hydrology

Oral

Investigating the importance of groundwater for near surface flux and state simulation through a multi-constraint analysis of a complex surface-subsurface-atmosphere model

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A complex distributed numerical modelling framework including both groundwater- surface-water flow and heat flux exchange with the atmosphere, combined with a unique observational data set, enables a comprehensive application of multiple independent constraints to the model parameter optimization at the catchment scale (1050 km^2). Five independent observational data sets consisting of stream discharge (8 stations), groundwater head (361 stations), latent heat flux (2 stations), soil moisture (28 stations) and remotely sensed land surface temperature (full spatial coverage on 28 days) are the basis for formulating 11 objective functions focussing on bias and RMSE of time series from multiple stations. In contrast to many multiple objective studies, where objective functions essentially originate from the same observational dataset, typically discharge time series, this data set enables a truly multi-constraint evaluation of the multiple states and fluxes simulated by the model. A preliminary sensitivity analysis of 35 model parameters reveals that even surface fluxes and states such as soil moisture, heat fluxes and land surface temperatures are highly sensitive to parameters that are typically associated with the groundwater components of the model. This indicates the importance of using fully coupled modelling approaches also in detailed studies of the near surface-atmosphere exchanges. However, the high sensitivity of surface states and fluxes to groundwater parameters might also be partially attributed to the initial parameter set, hence new sensitivities are estimated after a first parameter optimization of the most sensitive parameters. This model parameter optimization shows that in spite of the independence and different nature of the five observational data sets and the large variability in temporal and spatial scales of observations, the error on all 11 objective functions can be reduced through the automated calibration.

H01S4.04

H01S4 - Climate and land surface changes in hydrology

Oral

Hydrometeorological modeling for the Poyang Lake region, China

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Climate and land use changes are important drivers for changes in the hydrological cycle. The quantification of expected changes, not only in the mean but particularly in variability, is of central importance for decision making. All components of the hydrological cycle can be affected by these changes and the feedback mechanisms among the atmosphere, the land surface, and the subsurface play a crucial role here. Dynamic feedback is primarily caused by water and energy fluxes between the land surface and the atmosphere. Investigations of the dynamic feedback require a coupled modeling system of an atmospheric and hydrological model. In our approach we combine the regional atmospheric model WRF-ARW and the distributed hydrological model HMS. Both use the same land surface model (Noah-LSM), which enables studies of the hydrometeorological fluxes to climate and land use changes at regional spatial and climate relevant temporal scales.

The model system is applied for the Poyang lake basin in China with a catchment size of approximately 160,000 km2, using a spatial resolution of 10x10km2. In this region tremendous land use changes occurred in the last decades. Firstly, we focus on uncoupled simulations of the atmospheric model WRF-ARW to identify a suited setup for the target region. For this purpose, the skill of several configurations of WRF-ARW was analyzed with respect to model physics. The simulations cover the period 2003-2005 using ECMWF's ERA-INTERIM reanalysis data as driving data. For validation, mean values and the annual cycles of temperature and precipitation are compared to publicly available observational data sets. Secondly, the integration of the hydrological model HMS into WRF-ARW is described. It required primarily changes to the pre-processing system and the introduction of a hydrology driver routine. With this coupled model system, integrated WRF-HMS simulations were performed and analyzed using the identified optimal standalone WRF setup.

H01S4.05

H01S4 - Climate and land surface changes in hydrology

Oral

Radiation or temperature based PET - Forcing a distributed Hydrological Model at a meso scale catchment

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The atmospheric water demand is the strongest forcing of hydrologic models after precipitation. Consequently realistic estimates of soil moisture and river discharge are subject to realistic estimates of potential evapotranspiration (PET). Estimating PET at meso and large scale river basins (> 100 km2) is a challenging task (1) because of scaling and parameterization of small-scale derived equations to large control areas (> 4 km2) and (2) because of estimating realistic driving variables such as radiation, relative humidity, and wind speed at the large scale.

Within this study we test the suitability of two widely-used PET models for the distributed meso scale Hydrologic Model (mHM). The first PET model is the temperature-driven Hargreaves-Samani formulation whereas the second one is the net radiation-based Priestly-Taylor model. The study is carried out in major German river basins during the period from 2005 to 2010. Cross-validation results for the Main River basin are presented. The estimation of the effective PET model parameters at the scale of 4x4 km2 was carried out with the multiscale parameter regionalization technique minimizing the volumetric error of daily observed and simulated streamflow for the two different PET formulations. Accounting for the subgrid variability of land-cover dependent PET parameters is fundamental to describe soil moisture dynamics at the selected grid size.

Different soil moisture patterns for both PET products will lead to changes in simulated river discharge which is the main target variable within hydrological modeling. We hypothesize that the two different PET forcings alter modeled soil moisture and hence we especially see differences in the low flow simulations during summer and high flows shortly after persistent dry periods. Moreover we quantify the effect on soil moisture dynamics depending on season and land cover type.

H01S5.01

H01S5 - Climate and land surface changes in hydrology

Oral

GEWEX Land - Atmosphere research: Results and outlook

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Within the World Climate Research Programme (WCRP) the Global Energy and Water Exchanges Project (GEWEX) is one of the four core projects that since 1990 has its focus on the atmospheric, terrestrial, radiative, hydrological, and coupled processes and interactions that determine the global and regional hydrological cycle, radiation and energy transitions, and their involvement in global changes. The Global Land- Atmosphere System Study (GLASS) is the panel that within GEWEX focuses on land surface modelling and processes through a variety of projects. For example the Global Soil Wetness Project 3(GWSP-3) will assess the variability of hydrological components in land surface models over a 110 year period up to current day. To better assess the performance of the various models GLASS is starting a suite of benchmarking projects using a number of in situ land surface flux observation sites from differing climates and land cover to better indicate the future needs for model development in terms of the hydrology in the land surface models. The local coupling (LOCO) projects such as the GLACE project showed that there is a large variation in land - atmosphere coupling strength between the various models. Subsequent investigations have suggested that this sensitivity could result from the interactions of atmospheric parameterisations, rather than any land - atmosphere interactions. Finally, as the human effects on our environment are more and more evident, land use and land use changes are the focus of the LUCID project which is a collaborative effort with the IGBP - iLEAPS.

H01S5.02

H01S5 - Climate and land surface changes in hydrology

Oral

A combined water- and energy flux observation and modeling study at the TERENO-prealpine observatory

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Water and energy fluxes at and between the land surface/subsurface and the atmosphere are inextricably intertwined. In the last years, detailed observations of both water- and energy fluxes in medium sized catchments become possible via new hydrometeorological observatories like TERENO. This supports and enables the further development and evaluation of fully physically based hydrological model systems that do not neglect specific parts of the energy balance and -fluxes. We show results of a high resolution distributed modeling study based on the GEOtop model. It is applied to simulate both the water- and energy balance and -fluxes in the prealpine terrain of a medium size catchment, the River Rott in Bavaria/Southern Germany. Our simulations have a spatial resolution of 90m and an hourly temporal resolution. We intercompare simulation results with observed streamflow measurements, soil moisture and soil temperature measurements at different depths, and energy flux observations obtained by a Eddy-Covariance tower. We finally address the problem of the non-closure of the energy budget measurements due to uncaptured large eddy systems.

H01S5.03

H01S5 - Climate and land surface changes in hydrology

Oral

Modeling current and projected water resources in the Colorado Headwaters region with the Fully-Coupled WRF-Hydro modeling system

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Global climate model climate change projections for the western U.S have suggested potentially dramatic changes in the seasonal evolution and magnitudes of regional hydroclimatic fluxes. However, coupled global circulation models (GCMs) such as those used in the recent Fourth and Fifth Assessment Reports of the IPCC possess numerous deficiencies in their representation of moist airflow interactions with complex terrain. Alternatives for correcting the inherent biases in GCMs include statistical modeling or dynamical modeling in order to provide scale relevant information for river basin hydroclimatic analysis and impacts studies. In this work we report on recent progress in high resolution regional climate modeling of the Colorado Headwaters region using an updated version of the Weather Research and Forecasting (WRF) model and a hydrological extension package called WRF-Hydro. An emphasis of this work is placed on evaluating simulated precipitation and streamflow projections from a series of recent (current climate) multi-year integrations with observations from the U.S. SNOTEL network and naturalized streamflow timeseries. Results from an imposed climate warming experiment and the impact of warming on total precipitation, snow-rain partitioning and surface hydrological fluxes (evapotranspiration and runoff) will also be discussed. We will summarize the results in the context of analyzing changes in the total annual volumes and seasonal cycles of snowpack, snowmelt and streamflow and the impact of projected changes on water resources management in the region.

H01S5.04

H01S5 - Climate and land surface changes in hydrology

Oral

Field- and simulation experiments for the investigation of land-atmosphere interactions within the West African climate system

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Over the last few decades the land surface has been heavily changed in West Africa due to various anthropogenic measures. The impacts of these land surface changes in conjunction with climate change on hydro-meteorological fluxes are uncertain hindering the development of valuable adaptation measures for a sustainable management of natural resources. A central problem is that land-atmosphere exchange processes and feedback mechanisms between the land surface and the overlying atmosphere are not well understood. Further challenges remain in current techniques used in land use change and climate change simulation experiments which still bear considerable limitations. To tackle these problems, we present a novel two-way coupled atmospheric-hydrological model which is applied for a semi-arid region in Northern Ghana and Southern Burkina Faso. This region is characterized by strong land surface changes and precipitation fluctuations causing severe droughts and floods in the past. The model consists of the Weather and Research Forecasting (WRF) model and the NCAR Distributed Hydrological Modeling System (NDHMS). The NDHMS is a process-based hydrological model using sophisticated process formulations for describing lateral water flow, among others. It is tested for the river basin of the Sissili, a suitably gauged and less regulated tributary of the White Volta. The land surface dynamic within the model is advanced by using spatiotemporal fine-resolved remote sensing information for key bio-physical properties of the land surface. In this study we present first simulations results with WRF and NHDMS for selected dry and wet periods using reanalysis information from ERA-Interim. Moreover, first water and energy flux measurements from three new eddy covariance stations are illustrated. These stations have been recently established along a transect of land degradation states. In future the flux measurements will be used for an evaluation of the model simulations.

H01S5.05

H01S5 - Climate and land surface changes in hydrology

Oral

Modeling and analysis of the impact of urban irrigation on land surface fluxes in Los Angeles metropolitan area

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Urban irrigation is a critical component of the water cycles in arid and semi arid regions where the volume of irrigation water applied to the planted vegetation can exceed the natural precipitation amount. Reliable representation of urban irrigation is critical for the sustainable management of water resources in these regions. Proposed work includes developing and integrating an irrigation module within Noah LSM-SLUCM (Single Urban Canopy Model) modeling framework. The proposed modeling system is used in a 49.0 sq. km study area in the water scarce Los Angeles metropolitan area at a high resolution (30 m) to understand the temporal variability and spatial heterogeneity of urban water fluxes with a focus on evapotranspiration (ET).

The developed irrigation scheme is calibrated using residential water use data and three different estimates of outdoor water consumption, including a simple proportion of outdoor to total water use and «minimum month» and «average month» methods. Our results indicate that updating soil moisture to 75% of field capacity at a 6-day interval (one irrigation pulse every 6 days) reasonably represents irrigation reality over this study region.

Simulated ET and Land Surface Temperature (LST) results, with and without incorporating the irrigation module, indicate that the irrigation-induced increase in evapotranspiration leads to LST decrease of about 2 °»C in urban landscapes. To validate the model performance, we introduce a systematic evaluation process using MODIS-Landsat ET and LST products as well as CIMIS (California Irrigation Management Information System) based landscape ET observations. In this study, we conclude that addition of an irrigation scheme is critical to adequately simulate hydrologic cycles, especially in irrigated arid and semi arid regions.

H01S6.01

H01S6 - Climate and land surface changes in hydrology

Oral

The effects of soil moisture on a summertime convective rainfall over mountainous area and its contiguous plain in central Japan

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In Japan, lightning and flooding frequently occur with summertime convective rain events. Although land surface heating is vital in development of convective rainfall, land surface processes have been treated very simply in short-term weather forecasting in Japan. Improvement of land surface process modeling should help improve short-term weather predictions. In this study, two numerical experiments using a cloud-resolving land-atmosphere coupled model were conducted to investigate the effect of initial soil moisture on a summertime convective rain event in central Japan.

Convective rainfall observed on 15 August 2001 from the Nobi Plain to an adjacent mountainous region in central Japan was selected as the target for numerical experiments. The first experiment, called WET, used the wettest soil condition observed in August 2001 as the initial soil wetness value. The other experiment, called DRY, used the driest condition in August 2001 as its initial soil wetness. Comparison of WET and DRY revealed the effects of different realistic initial soil moisture conditions on simulated convective rainfall in a very humid climate. The drier soil moisture condition created larger rainfall amounts over both the mountainous region and the Nobi Plain. Greater difference in rainfall amount was found over the plain than over the mountainous region. The difference in near-surface convergence and atmospheric stability caused by local circulation, which is affected by the steep topography of Japan, plays an important role in transmitting the difference in soil moisture to rainfall.

H01S6.02

H01S6 - Climate and land surface changes in hydrology

Oral

The heat flux from the land surface during the pre-monsoon season in the inland region of Thailand

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The heat flux during the pre-monsoon period in the inland area of Thailand are investigated using wind and moisture fields and sensible and latent heat flux by the NCEP/NCAR (the National Centers for Environmental Prediction / National Center for Atmospheric Research) reanalysis, and precipitation, OLR (Outgoing Long wave Radiation), GPS (Global Positioning System), the sensible and latent heat flux of TFM (Tak Flux Measurement) data in 1998 and 2003. From the middle or late March before the monsoon onset, the latent heat flux is continuously dominant and the land condition is wet. Moreover, the intermittent dominance of the latent heat flux is analyzed in February. The composite analysis in the intermittent dominance of the latent heat flux in February shows that the dominant area of the latent heat flux covers over the south part of China, the inland area of Thailand and Cambodia. In the upper troposphere, the trough is analyzed. Additionally, the precipitable water increases centering on the inland area of Thailand. It is suggested that the evaporation from land surface contributes to the moist condition of the atmosphere. On the other hand, the latent heat flux does not increase until the onset of summer monsoon over India and the center part of Myanmar. The property of the heat flux from land is not similar over the Asian monsoon area during the pre-monsoon period.

H01S6.03

H01S6 - Climate and land surface changes in hydrology

Oral

Evaluation of the JULES land-surface model in simulating catchment hydrology in southern Africa

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Southern Africa is a particularly water-stressed region. Competition between agriculture, industry and domestic use result in most of the region's waterways being highly exploited. Large inter-annual variability in rainfall and the potential long-term stressors resulting from anthropogenic climate change add complexity to the management of water resources in the region. A good understanding of the processes that drive variability and change in the climate-hydrology system is essential for adequate decision-making in the water sector. In order to progress this understanding, this study aims to implement a regional-scale land-surface modelling system as a tool to study interactions between climate and hydrology. The model used is the Joint UK Land Environment Simulator (JULES), which is forced by input from the WATCH Forcing Data gridded product. JULES includes a runoff routing scheme to simulate discharge in a network of river channels. The initial phase of the work is to test the model's sensitivity to various parameters and derive an appropriate configuration that captures the diversity of environments within the study region. The catchments of interest are the Orange, Okavango and Zambezi, where the model outputs will be compared against observed discharge data. Following the initial testing of JULES for southern Africa, experiments are planned to explore the mechanisms controlling both inter-annual variability and long-term change in these river systems.

H01S6.04

H01S6 - Climate and land surface changes in hydrology

Oral

Simplified methodology for floodplain inundation modelling using LiDAR DEM

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Flood inundation assessment is essential for emergency response under high flow conditions. It is also an important part in environmental planning and management. A simplified flood inundation modelling framework using LiDAR DEM is developed for rapid assessment of flood inundation area, volume and depth in the event of high flows. The LiDAR DEM is used together with climate and soil hydraulic data to simulate floodplain inundation area and volume for a given river stage height. The modelling methodology accounts for multiple flood runners as well as overbank flow on to the floodplain and constrains the total spatial extent of inundation area based of the maximum available water. It also accounts for floodplain evaporation, infiltration and return flows to the river.

The methodology has been tested across several floodplain reaches in the Lower Murrumbidgee and Macquarie region in southeast Australia for estimating floodplain inundation extent and volume for some recent flood events. The spatial inundation extents estimated using this newly developed methodology are compared to those derived from high resolution satellite imagery and on-ground measurements to assess the suitability and applicability of the method for inundation modelling. The estimated volume and depth are also compared to those from a fully distributed hydrodynamic model. The results indicate that the methodology is capable of providing reasonably good estimates of flood inundation spatial extent, volume and depth. This methodology can be easily implemented across a number of river reaches and therefore it can be used to carry out scenario modelling under various future climate conditions.

H01S6.05

H01S6 - Climate and land surface changes in hydrology

Oral

Investigation of Urban-Induced rainfall in Porto Alegre, Brazil using TRMM satellite rainfall estimation

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The traditional quantification process of rainfall is done through pluviometers that are capable to cover an area of only 10-1 m^2. This limitation implies in deficiencies in quantitative representation of spatial rainfall over larger or complex areas without an extensive and expensive network that is normally not available in developing countries such as Brazil. In the city of Porto Alegre an uncommon network of 13 sub-daily rain gauges was available, showing large differences in rainfall through the city that were coincident with urbanization patterns, thus, being linked to Urban-Induced Rainfall by some authors. Differences could imply a variation of up to 40% in flood peaks.

Due to the lack of other raingauges in the region, in order to supply these deficiencies TRMM satellite rainfall estimation has been explored to verify the observed patterns and evaluate impacts of spatial heterogeneity. The analyses of 36 cell of 3-hourly rainfall series from the TRMM product (3B42) showed that intensity tends to decrease from west to east, even if the the percentage of wet days showed opposite behavior. The results have shown statistically significant differences in the maximum precipitation through the city, confirming previous results, but have also shown 3 regional patterns that converge in the city region, showing, that at least some of the observed difference is due to regional heterogeneities, including orographic and land-sea interactions.

From the results is clear that TRMM data became a good complementary information source to traditional systems of measures in order to investigate impacts of spatial heterogeneity on land surface fluxes and hydrological predictions.

H01S7.01

H01S7 - Climate and land surface changes in hydrology

Oral

Long-term response of vegetation to environmental change – the role of observations and models

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Vegetation has different degrees of freedom for adaptation to its environment. Examples include stomatal conductance at short time scale (minutes), leaf area index and fine root distributions at longer time scales (days-months) and species composition and dominant growth forms at very long time scales (years-centuries), subject to constraints imposed by land use practices. As a result, the overall response of evapotranspiration to changes in environmental forcing may also change at different time scales.

The effect of elevated atmospheric CO_2 concentrations (eCO_2) on evapotranspiration is an example for different response patterns at different temporal and spatial scales. At the leaf scale, eCO_2 can induce stomatal closure and reduced transpiration. This effect was incorporated in global models and held responsible for an observed increase in global river runoff during the past century. However, stomatal closure is not the only means by which vegetation responds to eCO_2. If, for example, stomatal closure is offset by an increase in vegetation cover in the long term, the effect of eCO_2 on global transpiration could, in fact, be reversed.

Long-term effects of eCO_2 are difficult to capture in experiments or to deduce from past observations, because experiments are relatively short and the CO_2 levels expected in 20 years time have never been observed in the past.

Instead, predictions of such long-term effects can be derived from models that do not simply extrapolate observed responses into the future. The Vegetation Optimality Model (VOM) allows separation of different scales of adaptation, without the need for parameterisation with observed responses. This frees up observational and experimental data for model testing and allows hypothetical predictions about vegetation response at time scales beyond those of free air CO_2 enrichment experiments. In this context, observations are of paramount importance for model evaluation, rather than for model parameterisation.

H01S7.02

H01S7 - Climate and land surface changes in hydrology

Oral

A conceptual approach for transient considration of forest change in hydrological impact studies

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Several approaches have been recently presented to include transient glacier retreat scenarios in the context of modeling the impacts of climate change on water resources in mountainous areas. Only few studies attempted evaluating the impacts of forest change. We developed an approach to exploring the impacts of tree migration on the hydrology of two large Swiss catchments (Rhône and Ticino). We run the spatio-temporal forest model TreeMig for the period 1400 to 2100 with climate input from observations and from the A1B Scenario ECHAM5-REMO («ENSEMBLES»-Suite). Within the period 1950 to 2100 the resulting maps of forest biomass and leaf-area-index (LAI) were processed to modify the standard forest coverage and LAI used in the hydrological model PREVAH. PREVAH has been recently used to assess climate change impacts on water resources for entire Switzerland for the periods 1980-2009 (control period), 2021-2050 (near future) and 2070-2099 (far future). Climate scenarios were available for 10 different realizations of regional scenarios including ECHAM5-REMO.

A post-processing module has been developed in order to translate the forest maps obtained from TreeMig into rules to remove, add or modify forested areas within the domain of PREVAH. Every 5 year forest coverage and LAI were updated. Analyses show a degradation of forest for the far future in the lowest elevation ranges (< 1200 m) as a result of increased drought. This result in lower LAI, reduced interception and increased discharge as compared to a BASELINE run without implementation of forest scenarios. For elevation ranges above 1500 m TreeMig predicts higher biomasses and LAI. The simulated tree-line elevation might increase of up to 200 m. PREVAH computes in these areas higher evapotranspiration and less runoff as compared to the BASELINE run. This does not compensate the effects of degraded areas at catchment scale.

Future work will focus on establishing feedback mechanisms between PREVAH and TreeMig.

H01S7.03

H01S7 - Climate and land surface changes in hydrology

Oral

Hydrological responses to combined land use and climate change in three diverse South African catchments

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When considering the impacts of environmental change, there is no consensus as to whether land use change or climate change will be the dominant driver of hydrological response. There is, however, agreement that the effect on hydrological response will be amplified. To understand influences of environmental change on hydrological responses, the ACRU agrohydrological model was used to simulate hydrological responses of three diverse South African catchments under baseline land cover with historical climate and the current land use with downscaled GCM projections of future climate. Consideration was given to the location of key land uses in the catchments and scale issues, from catchment to subcatchment.

The impact of environmental change on hydrological responses is complex. The impacts of environmental change on the catchments hydrological response varied across both the temporal and spatial scales, with the nature of the land use and the magnitude of the projected climate change also having significant impacts on the hydrological response. Analysis of the three catchments showed that as each catchment is unique with its own complexities; each catchment will have a unique threshold of where environmental change begins to have a significant influence on the hydrological response.

H01S7.04

H01S7 - Climate and land surface changes in hydrology

Oral

Hydrological nonstationarity in southern Australian

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The Millennium Drought in south-eastern Australia from the mid-1990s until 2009 has focused attention on water-resource availability. Reductions in annual rainfall were comparable in duration and severity to those seen during the Federation Drought and the World War II Drought. However, mean annual runoff in some areas was much lower during the recent drought compared to the two previous droughts. In some regions, rainfall-runoff models calibrated under normal, wetter conditions show significant overprediction during dry periods. Here we consider the changed runoff response as an incidence of hydrological nonstationarity in two senses: (1) observed changes in the annual rainfall-runoff relationship, which render simple annually based relationships inadequate for future runoff prediction; and (2) bias (i.e. overprediction) in modelling of runoff during dry spells using rainfall-runoff models, which suggests that current rainfall-runoff models are expected to perform poorly for future, drier climate projections.

Natural responses of catchments to prolonged droughts, such as reductions in groundwater levels, and changing vegetation characteristics can affect runoff generation. Furthermore, over time there has been a substantial increase in the density and volume of farm dams in certain regions of SEA. This can potentially affect the rainfall-runoff relationship, particularly during dry spells, by intercepting surface runoff before reaching the catchment outlet. These processes are typically conceptualised poorly in rainfall-runoff models. We relate runoff bias to catchment characteristics and calibrated model parameters to explore the processes responsible for hydrological nonstationarity in southern Australia. We also explore the response of catchments in SEA to wetter conditions post-2010, and discuss the implications for the simulation of future dry sequences, which are expected to increase in both frequency and severity in the future.

H01S7.05

H01S7 - Climate and land surface changes in hydrology

Oral

Investigating discharge and rainfall variability in an Amazonian watershed: do any trends exist?

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In the past decade, the Amazon rainforest has been the focus of intense monitoring initiatives to understand the impact of degradation and deforestation in order to formulate sustainable environmental policies. In the hydrological context, time series analysis are often use as a tool to evaluate changes in watershed response to climatic and anthropogenic influences. In this study, trend analysis of stream discharge from a 17500 km^2 watershed (upper Mortes River) located in southern Amazon was performed using 40 years discharge and rainfall data (1968–2007). The study area is located in a region of increasing importance due to agricultural expansion into the Amazon rainforest and indigenous territories. The aim of this work is to investigate the temporal variability of discharge, and to relate this to associated rainfall variability in order to contribute to a better understanding of the hydrological status of the watershed. The Mann Kendall non parametric tests were done on daily, seasonal and annual discharge data. Frequency analysis using wavelet transform was also done, and annual and seasonal rainfall data was analyzed and correlated to discharge. Results from this study indicate increasing trends in discharge (intra- and inter-annual). The wavelet analysis identified a dry period between 1968 and 1976 followed a wet period until the beginning of 1982. In some cases, discharge increases could not be satisfactorily correlated to the rainfall. Further interpretation of the data for possible causes of discharge changes is needed at the local study level, and implications of these results discussed in the context of climate change, deforestation and water resource management. While results from this study largely confirm findings from other regional scale trend analyses, they also highlight that these increasing stream flow trends are significant patterns of change covering large spatial extents in the Amazonia.

H01S7.06

H01S7 - Climate and land surface changes in hydrology

Oral

Regional scale streamflow estimation using multiple data sources and regional model calibration schemes

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There have been numerous regionalisation studies on runoff prediction in ungauged catchments. Most studies calibrate the rainfall-runoff (RR) models against gauged streamflow data only and use regionalisation methods to specify parameter values to model runoff in the ungauged catchments. This study evaluates the relative benefits of using multiple data sources (observed daily streamflow at the catchment outlet, gridded monthly remotely-sensed actual evapotranspiration (ET) and gridded daily remotely-sensed soil moisture (SM)) together with different regional model calibration schemes to estimate runoff across large regions. The modelling experiments are carried out using four conceptual RR models (GR4J, Xinanjiang, AWRA-L, and Sacramento) and daily climate and streamflow data for 228 unregulated gauged catchments from southeast Australia. Half of the 228 catchments are randomly selected for regional model calibrations and other half are used for cross-validations.

The modelling results indicate that the multi-objective calibrations perform better than the traditional model calibration solely against streamflow data, in terms of overall model performance in simulating daily runoff, monthly actual ET and daily SM in the validation catchments. The runoff prediction results using the regional model calibration schemes perform similarly to (or slightly better than) the traditional regionalization approach, i.e., the nearest neighbor (or spatial proximity) approach. However, the regional model calibration approach has an advantage for runoff estimates across large regions with sparse gauge data.

H01S7.07

H01S7 - Climate and land surface changes in hydrology

Oral

Investigating the impact of conceptual model uncertainty and climate change scenarios on groundwater nitrate concentrations

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At a European scale nitrate concentration is the leading parameter that determines groundwater quality. Since in most cases nitrate input into the aquifer is a non-point source pollution problem measures to reduce nitrate leaching have to be designed on the aquifer scale. In this context we have coupled the unsaturated, vertical soil water and nitrogen transport model SIMWSER/STOTRASIM with the saturated groundwater flow and transport model FEFLOW in a sequential manner to simulate groundwater nitrate concentrations in the aquifer Westliches Leibnitzer Feld (45 km^2) in southeast Austria.

Within this aquifer diffuse groundwater recharge is the most important process of groundwater renewal. Agriculture is the dominating kind of land-use. Seepage water leaving the root zone is influenced in detail by the soil texture distribution, soil thickness, meteorological conditions and agricultural management practices. However, in Austria information about the grown crop is only available as percentages on an aggregated level of cadastral municipalities.

Thus, from a conceptual point of view delineation of the spatial distribution of groundwater recharge time distributions is highly uncertain. Within this work the impact of 3 different approaches to compute the groundwater recharge distribution are investigated: (i) one time series for the entire model area, (ii) one time series per cadastral municipality and (iii) a stochastic procedure that accounts for the unknown crop grown (and corresponding fertilizer amount) on each particular lot. Furthermore, this uncertainty is linked to 4 climate change projections, where the predicted temperature and precipitation time series have been statistically downscaled. Thus, a total of 12 different combinations of soil water and nitrate leachates are processed as input distributions to saturated groundwater flow and transport modeling for analyzing the prediction uncertainty of groundwater nitrate concentrations.

H01S8.01

H01S8 - Climate and land surface changes in hydrology

Oral

Deforestation impacts on discharge of the Ji-Paran á river - Brazilian Amazon

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Hydrological impacts of land use changes have been studied during several decades for relatively small basins using the paired catchment experimental approach. In large river basins this kind of experiment is of limited use, and the assessment of impacts can only be done by applying physically based hydrological models. However, evaluation based on hydrological models should be preceded by a sensibility analysis, and model results should be verified against available experimental results, even if those are restricted to relatively small basins. We analyzed impacts of deforestation on streamflow of the river Ji-Paran á, a tributary of the Madeira river, in the Amazon region, using the MGB-IPH hydrological model. MGB-IPH is a large-scale distributed hydrological model, based on the hydrological response units approach, and its parameters are related to soil type, land use, and vegetation. Two scenarios were simulated, considering current land-use, with 22% forest cover, and pre-occupation land use, with 100% forest cover. Results show that discharge of the river Ji-Paran á increased 184 $mm.year^{-1}$ with deforestation. These results are consistent with worldwide experimental studies, as synthesized by Bosch and Hewlett [1982] and Trimble et al. [1987].

H01S8.02

H01S8 - Climate and land surface changes in hydrology

Oral

Catchment fragmentation and hydro-ecological modification of a raised bog wetland

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The occurrence of ecological communities of conservational value on the surface of raised bog wetlands requires that specific hydrological conditions are maintained. The management of raised bogs, as active peat-forming ecosystems, requires an understanding of the relationships between regional hydrology and hydro-ecological processes operating within the wetland system. Historic hydrological studies of Clara Bog, Ireland, in the early 1990s, and recent research demonstrates this relationship and the changes induced by marginal drainage. Peripheral drainage of Clara Bog has resulted in dramatic morphological changes, with areas of the bog getting wetter, while the bog on a whole has become drier since the early 1990s. Differential peat consolidation has fragmented what was one high bog topographic catchment area into four distinct catchment areas, with runoff reducing by c.40% from the original main catchment area. Catchment alteration has resulted in hydro-ecological changes, with a c. 26% decrease of active raised bog areas supporting growth of Sphagnum moss species. Water is no longer retained in the system as it once was and water balance computations coupled with ground level subsidence surveys over a 20 year period show that water is being released from storage in the peat bog body.

In undisturbed bog systems the recharge rate of water seeping through the bog body to the regional groundwater table is in the order of 40 mm/ year. Recent calculations show the leakage rate is now between 90 and 120 mm/ year. The Clara bog system is in an unsteady state of flux, with large tracts of the bog following linear rates of ground level subsidence; in the order of 0.05 mm/ year. A reduction in pore water pressure, due to drainage of the regional groundwater table, has induced excess water loss from the peat subsrate, resulting in catchment fragmentation and hydro-ecological modification of Clara Bog.

H01S8.03

H01S8 - Climate and land surface changes in hydrology

Oral

Decision on land conservation strategies considering climate and hydrological variability and land owners behaviour

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In several tropical regions of the world, such as the semiarid north-eastern region of Brazil, climate and hydrological regimes are highly variable. The year-to-year variations in rainfall – essential for rain-fed and family-based agriculture – and runoff – that fill the surface reservoirs used for cattle water supply and small irrigation, particularly during extreme drought events, are determinant, but not the only main factor for defining land occupation. The historical and cultural background of the farmers that populate the region, as well as their social and economic vulnerability, are also strong factors that influence land use. During the past decades, a set of representative and experimental basins was established in the region, for studying its hydrological regime. This paper presents results of an experimental and modelling investigation relating hydrological and sediment yield from small catchments to land use changes, considering both climate and human factors. The study analysed a 15-year time series of rainfall, runoff and sediment yield from experimental catchments, farmers' interviews during the 2012's drought event and MODIS images of the period. The results show: (a) typical patterns of rainfall that determine runoff and sediment yield: clusters of few intense events in a year; (b) relationship between the rainfall-determined seasonal vegetation status and runoff/sediment yield; (c) farmers behaviour and willingness towards land conservation practices; (d) hydrological modelling, using SWAT, aided by remote sensing (MODIS-based Leaf Area Index) to discriminate vegetation status, and farmers behaviour to simulate scenarios that can help the decision making process for selecting land conservation practices.

H01S8.04

H01S8 - Climate and land surface changes in hydrology

Oral

Assessing hydrological impact of simulated land use measures on peak discharge and total runoff

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The consequences of extreme weather events are strongly influenced by land use in catchments. We used a cellular, dynamic, spatially distributed hydrology model to quantify overland runoff in response to four extreme rain events and five types of simulated land use changes in a catchment in Norway. The catchment consists of arable land, forest, urban area and a creek which crosses a main road at the bottom of the catchment. The main goal was to demonstrate the utility of the approach for informing the road authority that changes in hydrological conditions due to land use changes in the surrounding area have an impact on the amount of overland runoff approaching a low-lying road. Land use composition and configuration was found to affect discharge: Clear-cutting of 30 % of the catchment area produced a 60 % increase in peak discharge and a 10 % increase in total runoff resulting from a 50-year storm event occurring in summer. There were only small effects on peak discharge during smaller storms. Reforestation of 60% of basin area was the most effective measure to reduce peak flow, mainly for smaller (2-, 5- and 10-year) storms. Grassed waterways reduced water velocity in the stream and resulted in a 28 % reduction in peak flow at the catchment outlet with the same 50-year event. A smaller degree of reforestation (30 %) of the catchment area was the most efficient measure to decrease total runoff for all the storms. The specific effect of land use measures on catchment discharge depends on their spatial distribution and on the size and timing of storm events.

H01S8.05

H01S8 - Climate and land surface changes in hydrology

Oral

Impact of urbanization on hydrologic and ecological processes in Paradise Creek, PA

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The Paradise Creek Watershed is a sub-watershed with an area of 44.5 square miles in the Delaware River Basin. Historically, the high quality water, mountainous forests and low temperatures in the tributaries have provided ideal habitats for cold-water fish. However, recent and projected future urbanization, population growth and economic development represent a potential for degradation of the high quality habitats for wild trout. BASINS model is first selected to simulate the potential impacts on hydrological process under projected urbanization scenario. The results show that, on the average, daily base flow would be reduced by 30% based on the projected build out in the watershed. The annual maximum daily flow is predicted to increase by 20%. The computed low-flow is expected to decline by 15%. Then, the water quality data collected in filed survey are used to assess the possible influences of these hydrological changes on the habitat of wild trout. The analysis indicates that both the increase of high flow and the reduction of low flow will greatly impair the health habitat of wild trout. Especially, the reduction of low flow could damage 40-50% of the current ideal habitats of wild trout by elevating the temperature and depleting dissolved oxygen. The suggestions on effective watershed management are also provided to mitigate the possible negative impacts.

H01S8.06

H01S8 - Climate and land surface changes in hydrology

Oral

Subsurface water storage for the different land-use catchments evaluated by deuterium excess dispersion model of stream water
- Observation by the paired small forest and grassland catchments -

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In order to understand the change of groundwater recharge by artificial forest plantation, the catchment scale water budget observation, including stream discharge, precipitation, evapotranspiration and groundwater level monitoring, have been done in the paired forest and grassland catchments under the condition of similar geology and surface morphology of volcanic slope in the western foot of Mt. Aso, Kyushu, southwestern Japan. Two years record of the hydrograph for each catchment clearly shows much contribution of the subsurface water storage for the forest catchment than grassland. Also the EC monitoring of the stream discharge water during the specific rainfall event shows relatively larger groundwater discharge in the forest catchment than the grassland by using two component discharge water separation analysis.

While the monthly samples of precipitation and stream discharge water from each catchments has been used to analyze the stable isotopes in water and those data shows clear seasonal fluctuation of deuterium excess value caused by the change of the source vapor for the local precipitation. The dispersion model (DM) was used to evaluate the mean transit time of the stream water in both catchments as the response function which is known as a flexible transfer functions. The result shows that although the mean transit time of the stream water for both catchments are almost in the similar range, but the grassland catchment has relatively larger Dispersion parameter for the stream discharge than that of the forest catchment. This is probably caused by the much contribution of the new water component of direct runoff in the grassland catchment than that in the forest catchment.

H01S8.07

H01S8 - Climate and land surface changes in hydrology

Oral

An approach of coupling distributed topographic indices into dynamic vegetation model

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It is well known that the northern high-latitude regions may have strong impacts on the global warming, due to the high carbon storage and undergoing greater changes. In these areas the ecological function and carbon cycling are more related to the hydrological conditions. Thus an accurate hydrological description is needed to improve the prediction of vegetation distribution and carbon cycling in the ecosystem. In this paper, we have developed the distributed hydrology model (LPJ-DH), based on the dynamic vegetation model LPJ-GUESS. Our model is an enhanced version that introduces water routing and lateral water fluxes between grid cells. The fundamentals are based on spatial variability of topographic indices, calculated from Digital Elevation Models (DEM). We chose LPJ-GUESS because its ability of representing vegetation dynamics and land-atmosphere carbon and water exchanges. The runoff outputs by LPJ-DH and LPJ-GUESS were compared and the new introduced hydrology scheme showed a possible advantage in representing the drainage network and topographic effects on water redistribution. The general increase of plants transpiration was also found over the catchment by LPJ-DH and we demonstrated that the modelled evapotranspiration by LPJ-DH was in line with the observed data during the year 1988 and 1999 in the study area. Overall, the study justifies the feasibility and advantages of incorporating distributed topographic indices into the LPJ-GUESS.

H01S8.08

H01S8 - Climate and land surface changes in hydrology

Oral

Remote sensing and statistical analysis of the dynamic of vegetation in climate variability context on the Bouregreg watershed

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Bouregreg watershed belongs to the favourable ecological zone of morocco's central North-west plateau. This watershed is a rainfed fragile area for the cereal. Also, this zone belongs to the favourable pastoral areas of that kingdom. The country, as the whole of the Maghreb, knows, since the middle of the years 1970 and the beginning of the years 1980, more random rainfall condition. These rainfall changes are marked by substantial declines and greater recurrence of droughts. This study highlights the nature of the spatio temporal phytomass dynamic in this rainfall crisis, in the watershed, from 1982 to 2009. From statistics of time series consist of NDVI values of NOAA images on this period, the study finds a sharp decline in vegetation during the summers. But the regression analysis between the rainfall and vegetation finds instead an impact of the rainfall on the wet seasons. It leads so to conclude that factors other than precipitation are responsible for the sharp decline in vegetation.

H02S1.01

H02S1 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Sensitivity of the mountain snowcover to increased humidity in a warming global climate

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As the global climate continues to warm the effect of increasing temperature on the development of the seasonal snowcover is of great concern. However, the direct impact of temperature on the snowcover thermal state is relatively small when compared to the effect that can occur with an increase in humidity. Under typical conditions, water vapor flux over a mountain snowcover is from the snow, to the atmosphere, which takes energy from, and cools the snowcover. A few conditions – including rain-on-snow – can occur where condensing conditions (water vapor flux from the atmosphere, to the snow), which can add large amounts of energy to the snowcover, causing rapid melting to occur. As the climate warms, we expect condensing conditions to occur more frequently. We first present a detailed analysis of the thermodynamic sensitivity of the mountain snowcover to changes in humidity. Then, using 50+ years of detailed precipitation, snow, temperature and humidity data, show how the increase in humidity has already impacted the mountain snowcover, and why during-storm conditions are more critical than between-storm conditions. Finally, using an energy and mass balance model show the sensitivity of the mountain snowcover in a small mountain catchment to changes in humidity, using temperature and humidity scenarios to represent expected future conditions.

H02S1.02

H02S1 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Tackling complexity in modeling mountain hydrology: where do we stand, where do we go?

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The modelling of mountain hydrology is characterized by a series of challenges: Continuous accessibility of sites usually is difficult, the accuracy of measurements is limited or even unknown, and their areal representativeness is highly variable in space and time. The spatial variability of many variables that serve as model input undergoes significant scale dependence, and the validation possibilities for model output are limited. Finally, the quantification of uncertainties is usually limited to ensemble simulations across reasonable parameter spaces.

Even though sophisticated mountain hydrology modelling schemes have been developed recently, many early concepts have survived: temperature index snowmelt modelling, the negligence of snow sublimation, pragmatic gauge corrections and evapotranspiration estimations, and simple soil- and overland flow representations. Many of these models lack the ability to be transferable in space and time, and in scenario applications they produce artefacts. By means of combining physically oriented parameterizations and statistical approaches, multi-scale sensitivity studies, and integration of remote sensing data can compile improved versions of our models. This is facilitated by hydrometeorological observatories in mountain areas that are currently build up.

As an example for potential and limitations of modelling mountain hydrology, we present an attempt to combine a distributed hydrological model, physically based snow process parameterizations and an artificial neural network for an enhanced modelling of water fluxes in a high Alpine catchment in the Berchtesgaden Alps (Germany). The hydrology there is highly complex due to the very steep topographic gradients, related spatial variability of all meteorological variables, the very heterogeneous snow cover and the karst nature of the groundwater system. We demonstrate the benefit of single model enhancements, and provide a generally climate change scenario-capable application.

H02S1.03

H02S1 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Hydrological impacts of mountain pine beetle infestation: potential for river channel changes

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The mountain pine beetle epidemic in British Columbia, Canada, has killed approximately 18.1 million hectares of lodgepole pine since the late 1990s. The 1570 km^2 Baker Creek study catchment, located in the interior plateau of British Columbia has greater than 90% pine beetle infestation. Tree kill and salvage logging are profoundly changing the hydrology of pine beetle infested, snowmelt-dominated catchments. This study relates observed and modeled changes in hydrology to channel hydraulic and geomorphic controls to predict the potential for river channel change resulting from the mountain pine beetle epidemic.

Modeling using the Distributed-Hydrology-Soil-Vegetation-Model indicates that discharge is highly sensitive to tree kill and salvage logging, with increases in discharge of 65% for 40% salvage harvesting, and discharge increases of 100% for 100% salvage harvesting, across the full range of return intervals. Peak snowmelt discharges will occur 15-19 days earlier. The subdued topography of the catchment, coupled with a largely northerly aspect results in near synchronous snow-melt discharge to the river channel.

In the context of the mountain pine beetle induced hydrology changes, it was found that low-gradient reaches typical of the interior plateau are likely to be relatively insensitive to channel change, but will become significant sediment stores as sediment is mobilized elsewhere in the catchment. Higher gradient reaches, which typically occur where interior rivers incise to meet the Fraser River, are far more susceptible to change. A threshold classification based on the Shields number was found to be effective at identifying thresholds for channel change, largely because it is based on within-channel sediment and flow characteristics. Discharge increases of 60-80%, likely under salvage harvesting scenarios exceeding 50% may cause the channel to cross geomorphic stability thresholds, leading to significant changes in channel character.

H02S1.04

H02S1 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Water availability in a mountainous Andean watershed under CMIP5 climate change scenarios

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Recent updates to climate change scenarios have been developed under Coupled Model Intercomparison Project Phase 5 (CMIP5). These are based on Representative Concentration Pathways (RCP), which are defined under different scenarios of radiative forcing, which recognizes that different socioeconomic and demographic conditions and different technologic advances can achieve similar results. The study compares water resources availability in an Andean mountainous watershed located in the vicinity of Chile's capital city, Santiago. Hydrologic simulations at monthly level for base line period and future scenarios are carried out through the software WEAP, previously calibrated for the watershed defined by the Maipo en San Alfonso stream gauge, with an area of 2812 km2. Precipitation and temperature monthly time series are predicted for scenarios A2 using GCM MK3.0 and RCP 2.6 and RCP 8.5 using GCM MK3.6. The comparison is established for meteorological data available at San Gabriel precipitation gauge and Pirque temperature gauge as well as for mean monthly flow registered at the Maipo en San Alfonso gauge. The uncertainty of the future data in the RCP scenarios is given by the simulated values using the ten ensembles given by the GCM model. The future hydrological simulations are carried out from years 2011 to 2070 and results are analysed for periods 2011 to 2040 and 2041 to 2070. Comparisons between former most critical scenario A2 and RCP 2.6 and 8.5 are done considering that they represent the most extreme possible cases. Results show that A2 scenario predicts mean annual precipitation similar to the observed in base line period but the mean temperature increase of 0.8°C and 1.7°C for future periods under analysis generate mean annual flows that tend to decrease 8% essentially during snowmelt period. For RCP 2.6 precipitation and temperature tend to increase. By other hand precipitation reductions and temperature increases represent the RCP 8.5 future climate.

H02S2.01

H02S2 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Changing surface water systems in the discontinuous permafrost zone: Implications to stream flow

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The southern margin of permafrost is experiencing unprecedented rates of thaw, yet the effect of this thaw on northern water resources is poorly understood. The hydrology of the active layer on a thawing peat plateau in the wetland-dominated zone of discontinuous permafrost was studied at Scotty Creek, Northwest Territories (Canada), from 2001 to 2010. Two distinct and seasonally characteristic levels of unfrozen moisture were evident in the 0.7-m active layer. Over-winter moisture migration produced a zone of high ice content near the ground surface. The runoff response of a plateau depends on which of the three distinct zones of hydraulic conductivity the water table is displaced into. The moisture and temperature of the active layer steadily rose with each year, with the largest increases close to the ground surface. Permafrost thaw reduced subsurface runoff by i) lowering the hydraulic gradient, ii) thickening the active layer and, most importantly, iii) reducing the surface area of the plateau. By 2010, the cumulative permafrost thaw had reduced plateau runoff to 47% of what it would have been had there been no change in hydraulic gradient, active layer thickness and plateau surface area over the decade.

H02S2.02

H02S2 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Investigating the ability of a land surface model to simulate hydrological processes in cold and mountainous regions

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The aim of the present work is to investigate the ability of a physically based land surface model (LSM) SWAP, which treats energy and water exchange at the land-atmosphere interface, to simulate snow and runoff formation processes in mountainous and high latitude regions. Two regions characterised by different climatic conditions were selected for this study: the French Alps and pan-Arctic river basins located in Russia. In the first case, the results of snow depth simulations by SWAP were compared with daily snow depth measured during three years at 24 mountainous sites (with the altitudes varying from 910 to 2590 m). In the second case, snow depth and river runoff simulated by SWAP for several northern river basins on a long-term basis were validated against daily observations conducted during 20-30 years. It was concluded that, in general, SWAP can capture evolution of snowpack depth and runoff hydrographs and performs fairly well statistically.

H02S2.03

H02S2 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Modelling snowpack formation processes and meltwater runoff using the LSM SWAP under permafrost and highland conditions

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The aims of the present work are to investigate the ability of a physically-based land surface model SWAP (Soil Water - Atmosphere - Plants), developed previously by the authors, to simulate (1) snowpack formation processes (including accumulation of snow with its partitioning between solid and liquid fractions, snow evaporation/sublimation, snowmelt, freezing of water in snowpack, densification of snow, formation of water yield of snow cover) and (2) snowmelt and rain driven streamflow under permafrost and highland conditions. This goal stems from the fact that the SWAP model is to be used as an instrument for scenario forecasting of the dynamics of hydrological processes in the presence of climate change. Data for the study were obtained at the Kolyma of water-balance stations (KWS, East Siberia, Russia), located within the Kontaktovyi Creek basin (the upper course of the Kolyma River) in the permafrost and highland zone. The climate of the region is subarctic continental. Vegetation consists of sparse larch forest (up to 1000 m a.s.l.), low creeping cedar, moss and grass. The upper parts of slopes are presented by rock debries. Model simulations were performed for a ten-year period (1969-1978) using daily meteorological data from the KWS. Vegetation and soil parameters were derived on the basis of qualitative description of vegetation and soil classes located within the basin. The validation data represented snow water equivalent, snow depth and snow density; soil thawing depth; daily soil surface and snow surface temperature; snow evaporation; monthly values of evaporation from the soil covered by moss and grass; daily values of soil temperature at different depths, as well as daily values of runoff from different catchments and river basins located within the KWS. Analysis of the results of model validation has shown that the LSM SWAP is able to reproduce heat and water exchange processes under permafrost and highland conditions quite reasonable.

H02S2.04

H02S2 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Calculation and analysis of Yukon River heat flux

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Water temperature is the most important climatic and hydrologic variable, as it directly reflects river physical and thermal features. In the northern regions, discharge and stream temperature significantly impact the freeze-up/break-up processes, thickness of river ice, and thermal erosions along the riverbanks. Due to climate change and human impact, both discharge and stream temperatures have changed significantly over the high latitudes. This presentation reports preliminary results of systematic analyses of long-term water temperature records for the large Siberian rivers (such as Lena, Yenisei, Ob, and Kolyma). It defines the water temperature regimes and its changes near the basin outlets. The focus of this work is to detect and quantify the sudden changes in river temperatures due the effect of reservoir regulation. These methods and results of this research are useful for cold region climate and hydrology change investigations.

H02S3.01

H02S3 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Numerical modeling of snowpack seasonal evolution in various climatic conditions

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A numerical model of snow cover, including evaluation of seasonal evolution of snow characteristics and its layered metamorphism, is tested against various natural conditions, including interannual variability. The model is based on physical laws of the snow cover evolution and snow crystals' transformation, the latter being described with phenomenological relationships depending on weather conditions and the snowpack characteristics. Such an approach allows one to take into account main physical processes in the snow layers and their transformation, including crystallic metamorphism, avoiding precise modeling at molecular-crystallic level. The snow model is interactively coupled with the land surface heat/water exchange model SPONSOR. The model complex has demonstrated its ability to successfully reproduce seasonal evolution of snow water equivalent and snow depth in a wide range of natural conditions, thus providing an opportunity to model future climate conditions for many locations. The model was tested against data obtained at polygons Churlyanis Dome (Franz-Josef Land) with significant snow accumulation and very strong winds, Valdai with long snow season and significant daily and interannual variability of meteorological conditions, Dukant (Western Tien Shan mountains) with mild winter and heavy snowfalls. The model successfully evaluates the snow cover characteristics under significant interannual weather variability. One should pay special attention to the situations with very strong winds and melting events to evaluate the snow evolution properly.

H02S3.02

H02S3 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Assessing runoff sensitivity to climate change in the Arctic basin: Empirical and modelling approaches

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A physically-based distributed model ECOMAG was applied to assess the possible impact of climate change on runoff generation in large river basins of the Arctic region. The application was carried out on the example of the Lena River (the catchment area is 2488000 km2) and the Northern Dvina River (357000 km2). The parameters of the model were adjusted through calibration against runoff hydrographs observed for the ten-year period of 2000-2009. Validation of the model was performed for the periods 1970-1990 for the Northern Dvina River and 1986-1999 for the Lena River. At that, the climatic conditions of the validation periods are rather different from ones observed during the calibration periods: the latter are warmer and more humid than the periods of validation. The observed runoff turned out slightly sensitive to these changes: both the observed annual runoff and annual peak discharge increased slightly in the calibration period in comparison with the corresponding values observed in the validation period. The numerical experiments were carried out to analyse sensitivity of the runoff regime of the both rivers to possible future changes in annual precipitation and air temperature in their basins. It was shown that one-degree increase of the annual temperature leads to decreasing annual runoff of about 5-7%, mainly due to increasing evaporation. Winter runoff is changed insignificantly. Increase of precipitation causes the changes in annual runoff and peak discharge of the same order.

H02S3.03

H02S3 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Adaption of a high resolution semi-distributed hydrological model for simulation of the Arctic Ocean drainage basin using remote sensing snow and ice data

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The timing and amount of freshwater inflow from land areas to the Arctic Ocean is of high importance for it's salinity and circulation, and is thus an important factor in improving our understanding of the coupled land-atmosphere-ocean climate system in the polar region. Discharge observations are important to improve and evaluate our ability to model these flows in a changing climate. However, the proportion of un-gauged basins in the Arctic region has increased over recent decades, which calls for alternative data and methods to evaluate models in these areas. In this study, a semi-distributed hydrological model HYPE (Hydrological Predictions for the Environment) was applied to the entire Arctic Ocean drainage basin (excluding Greenland), simulating daily discharge rates for the period 1961-2010. The objective of the study was first of all to analyse and improve the models process representation with regard to snow and ice, challenging the model with the various temporal and spatial climatic variations in the available data. Secondly, the objective was to evaluate the model and estimate prediction uncertainty in un-gauged basins using remote sensing data on snow and ice processes. The model was setup using globally available datasets on soil type, land cover, elevation, and river discharge. Driving data of air temperature and precipitation was adopted from ERA-interim. The results show that the use of remote sensing data was an important step in both the model adaption to the Arctic region and in the model evaluation and uncertainty estimation process. The use of GlobSnow snow water equivalent and snow cover area data was used to improve the modeling of both temperature and precipitation inputs, as well as snow process representation. Additionally, the use of MODIS derived water surface temperature and in-situ lake and river ice data was used in the calibration and validation of a thermodynamic lake and river ice model.

H02S3.04

H02S3 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

More than 100 years of climatic and hydrologic variability of a mediterranean & montainous watershed : the Durance river

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Improving the understanding of mountain watersheds hydrological variability is a great scientific issue, for both researchers and water resources managers, such as Electricite de France (Hydropower Company). The Durance river watershed (14000 km2), situated in the French Alps, is a good example of the complexity of this issue. It is characterized by a variety of hydrological processes (from snowy to Mediterranean regimes) and a wide range of anthropogenic influences, which mixes numerous potential causes of changes in its hydrological regimes.

As a first source of information, about ten long historical series of daily streamflows have just been unearthed, beginning on the early 20th century. This type of series is unfortunately not always available, and the more we go back to the past, the weaker spatial density of such data becomes. The first part of this paper starts by the assessment of the quality and the spatio-temporal homogeneity of the historical time-series. Then, these time-series allow a better knowledge of the spatio-temporal hydrological variability of the Durance River over the last century.

The second part of this paper presents a methodology to build long climatic series (air temperature and precipitation), mixing large scale climatic data (geopotential fields, some of them available from 1850) and local observations. Streamflow series are then easily obtained using a hydrological model. Long historical streamflow data of the Durance river watershed allow us to validate the whole reconstruction chain. Surprisingly, results reveal a rather good reconstruction of the interannual variability, streamflow distributions and hydrological regimes.

This reconstruction methodology has the advantage to be based on large scale climatic data, which reduces the influences of local observations, potentially biased by local effects. Hence, this method has been used to test the homogeneity of long records by comparison with the reconstructed series.

H02S3.05

H02S3 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Rainfall-runoff modelling as a tool for constraining the reanalysis of daily precipitation and temperature fields in mountainous regions

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Hydrological modeling of mountain catchments is a challenging task. The intrinsic complexity of local processes (e.g., snow and ice dynamics) is added to the difficulty of estimating spatially-distributed inputs such as rainfall and temperature, which exhibit a high spatial heterogeneity that cannot be captured by the measurement network. Hence, an interpolation step is often required prior to the hydrological modeling step.

In most cases, the reconstruction of meteorological forcings and the calibration of the hydrological model are done sequentially. The outputs of the hydrological model (discharge estimates) may give some insight on the quality of the reconstructed forcings used to feed it, but in this two-step approach it is not possible to feed the interpolation procedure back with the discrepancies between observed and simulated discharges. Yet, discharge at the outlet of a (sub)catchment is still an interesting integrator (spatial low-pass filter) of the forcing fields and is an ancillary areal information complementing the direct, point-scale data collected at raingages. In this perspective, chosing the best interpolation scheme partly becomes an inverse hydrological problem.

In this study, we present a one-step calibration strategy where the parameters of both the interpolation model and the hydrological model (i.e., snow cover evolution, soil moisture accounting, and flow routing schemes) are jointly infered in a multi-site and multi-variable approach. Interpolated fields are rainfall and temperature, whereas hydrological prognostic variables consist in discharge and snow water equivalent (SWE) time series at several locations in the 3,600-square kilometer Upper Durance River catchment (French Alps).

Using cross-validation and jack-knife procedures, we show that the parameters infered in such a way lead to more mutually-consistent estimates of the different variables (SWE, discharge, or estimed rainfall / temperature at an ungaged location)

H02S3.06

H02S3 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Modeling current and future trends in water availability for agriculture on a semi-arid and mountainous Chilean catchment

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This study aims to develop an integrated and basin-scale modeling approach to assess current and future trends in water availability for agricultural purposes on a semi-arid and mountainous catchment in the Chilean Andes: the upper Elqui basin (5 660 km^2). A hydrological model including a snow reservoir was combined with an agricultural water demand model to provide an index of the capacity to meet water needs. Particular account has been taken of flow regulation by a storage-dam through modeling of the reservoir water balance and its operating rules, and by dividing the basin into two sub-basins located respectively upstream and downstream of the dam. The modeling chain was applied and tested over a long reference period (1979–2008) and then run over the 2041–2060 period under the constraint of 4 climate scenarios statistically downscaled from various GCMs. Simulations of the discharge at the basin outlet reached a fair degree of realism over the reference period, despite a reproduction of peak flows which tends to deteriorate over the validation period. Although the dam model and the agricultural water demand model could be improved in the future, they already provide reliable simulations with regard to observed dam releases on the one hand, and to withdrawal authorizations for irrigation on the other hand. In spite of significant discrepancies, the 4 climate scenarios all lead to a decrease in the capacity to meet water needs at the height of the irrigation period (from December to March). This can be explained in particular by less abundant precipitation (-22–48%) according to 3 of the 4 climate scenarios and by earlier peak flows for 2 scenarios due to the impact of higher temperatures (+1.7–2.1°C) on the snowmelt regime. This is a first step towards improving the efficiency of the different models and assessing the propagation of uncertainties through the modeling chain. Water use scenarios should also be diversified to identify possible adaptation strategies.

H02S4.01

H02S4 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Assessment of climate change impact on river discharge in cold and mountainious region in Japan

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To evaluate the impacts of climate change on river discharge, we applied a hydrological simulation to several major river basins in Japan located in the cold and mountanious region, using a super-high-resolution atmospheric general circulation model (AGCM) with a horizontal resolution of about 20 km that was developed by the Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA). For our analysis, we used two AGCM datasets corresponding to the current climate (1980-1999) and future climate (2080-2099) based on the sea surface temperature (SST) ensemble projected by the Coupled Model Intercomparison Project phase 3 (CMIP3), assuming the A1B scenario of the IPCC Special Report on Emission Scenarios (SRES). River discharge was estimated using a distributed hydrological model that was calibrated in advance with observed river discharge. We investigated the impact of climate change on river discharge by comparing hydrological simulations of current and future climate conditions. The results showed that even if the amount of precipitation does not change greatly in the future, river discharges will change significantly as air temperature rises, owing to increased rainfall, decreased snowmelt, and increased evapotranspiration. The impact of climate change on river discharge will become more significant in northern Japan, especially in the Tohoku and Hokuriku regions. Our results imply that the increase in air temperature will have important consequences on the hydrological cycle, particularly in regions where the water supply is currently dominated by snowmelt.

H02S4.02

H02S4 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Changes in eco-hydrological systems under recent climate change in eastern Siberia

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Global warming will likely transform Siberian environments. Recent eco-hydrological evidence indicates that water-carbon cycles have been changing rapidly, with potentially grave effects on the Siberian flora and fauna. We comprehensively analysed dendrochronological, hydrological, and meteorological data and satellite remote sensing data to track changes in vegetation and water-carbon cycles in the Lena River Basin. In eastern Siberia, the basin is covered mainly in larch forest, and receives little precipitation. From 2005 to 2008, however, the central part of the basin suffered from extraordinary precipitation in late-summer and winter. This resulted in the degradation of permafrost, forest, and hydrological elements in the region. Dendrochronological data implied that this event was the first such case in the past 150 years. Based on data collected before and after the event, we developed a permafrost-ecosystem model including surface soil freezing–thawing processes in order to better represent the heat, water, and carbon fluxes in the region. We focused on the surface soil layer, in which we now see increased thawing depth, surface soil moisture, and net primary production. The analyses of observed and modelled data indicated that the annual maximum thawing depth (AMTD) had increased gradually on a decadal scale and deepened abruptly after 2005. Climatological analyses of atmospheric water circulation over the region indicated that the recent increases in precipitation over the central Lena River Basin were related to cyclone activities. Consequently, the increased precipitation from late-summer to winter resulted in increases in soil moisture, soil temperature, and AMTD in the region.

H02S4.03

H02S4 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Effects of distribution level of hydrological models in mountainous catchments

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Hydrologiska Byråns Vattenbalansavdelning (HBV) model is one of the widely used hydrological models for flood forecasting, water resources assessments and impact study of environment change. However, in the era of distributed models, Norwegian Water Resources and Energy Directorate (NVE) is still using a lumped model in daily discharge forecasting for catchments. The main purpose of this study is to develop and test a fully distributed HBV model with the emphasis of obtaining a most suitable flow routing algorithm for seasonally snow-covered and forested mountain catchments in Norway. Two most widely used flow routing algorithms were built into the distributed HBV model and they were tested on two catchments, Losna (11, 213 sq. km) and Norsfoss (18, 932 sq. km) in Central Norway. In the first algorithm flow is routed from cell-to-cell and hydrographs are calculated at each cell, and then routed by the Muskingum-Cunge method in river channel. The second algorithm is a source-to-sink method in the literature, which routes runoff of all cells flowing to the catchment outlet at a calibrated constant velocity adjusted by local cell slope. The results of model validation for 1991-2010 (calibrated during 1981-1990) show that the Nash-Sutcliff efficiencies of daily model without routing algorithms were 0.79 in Losna and 0.81 in Norsfoss. The newly developed fully distributed HBV model was able to reach 0.85 in the first algorithm case and 0.80 in the second algorithm case in Losna catchment; and 0.91 in the first algorithm case and 0.87 in the second algorithm in Norfoss. The lower model performance in Losna catchment was believed mainly due to higher hydraulic regulation and larger glacier covered area.

H02S4.04

H02S4 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Coupled modelling of soil thaw/freeze dynamics and runoff generation in permafrost landscapes, Upper Kolyma, Russia

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Active layer formation and flow generation mechanisms in mountainous permafrost landscapes of the Kolyma Water Balance Station, including rocky talus, mountainous tundra and moist larch forest, were studied. Each landscape is characterized by dominant hydrological processes which strongly relate to the ground freezing/thawing dynamics. Subsurface flow prevails in rocky talus due to fast and deep ground thawing. Surface flow forms in larch forest during the snowmelt period because of ice saturated peaty soil. The mountainous tundra performs transitional flow regime.Modelling of ground thaw/freeze processes and runoff formation was conducted at daily time steps for 1969–1990 at four small-scale watersheds and three active layer observation sites. Soil-vegetation profile schematization and corresponding sets of the model parameters were developed for each landscape. The process-based model Hydrograph which describes all components of land hydrological cycle and integrates coupled algorithms of water and heat dynamics in soil was applied. Main model parameters are observable land cover properties. Simulated results of soil thaw/freeze depth and runoff yield reasonable agreement with observed values.Analysis of data has shown that despite of significant differences of runoff formation mechanisms in neighboring permafrost landscapes due to variation of active layer depths, the hydrographs do not perform much diversity. It means that it is possible to calibrate the model and “adequately mimic” the runoff without accounting for proper active layer depth representation. We question the applicability of such calibration approaches and propose modelling with proper level of process conceptualization and usage of observable parameters in climate change studies and runoff simulations in ungauged basins.

H02S4.05

H02S4 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Hydrological and geocryological controls on fluvial activity of rivers in cold environments

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Cold climate rivers with sand and silt alluvium are subject to deep seasonal freeze of the channel material. Freeze depth is highly affected by deep winter low flow and great ice thickness, which are common for rivers in cold environments. Thus, geocryological conditions play a significant role in channel adjustment to projected climate change.

The extent of channel bed area, which is subject to seasonal freeze, is tightly linked with the variability of hydrological conditions. Winter lowest water stage defines the extent of channel area, exposed to contact with cold air. Bed material freeze is also possible under the ice cover, due to extremely low air temperatures, thus thicker ice contributes to higher frozen alluvium extent. Probabilistic estimates for the middle reach of the Lena river (Central Yakutia) show, that under extreme hydrological conditions (lowest water stage, thickest ice), about 50% of the meandering channel and up to 85% of the braided channel alluvium are affected by seasonal freeze.

Alluvial bars of different sizes dominate the bed topography of the sand and silt channels, forming an ordered hierarchical structure. Characteristic bed form heights were determined for the middle reach of the Lena river using the calculation technique offered by N.I. Alekseevskiy (2004). Calculation results show that alluvium freeze limits the mobility of the whole hierarchy of the bed forms, including the most mobile bedforms.

Reduced bed material mobility plays a significant role in restricting vertical bed deformations during high-flow events, and limits bedload volumes. This promotes rapid bank erosion and increases the complexity of braided channel patterns. Changes in thermal state of permafrost and hydrological objects under observed climate change will lead to the intensification of fluvial activity and channel adjustment of the cold climate rivers.

H02S4.06

H02S4 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Feature analysis and prediction of ice regime in Source Region of Yellow River

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The source region of Yellow River refers to the catchment area above Tangnaihai hydrological station. The typical climate in the region is cold and dry with the annual mean precipitation of 560 mm, and annual mean temperature of -4¡ãC. The stations for feature analysis are Yellow River Region, Jimai, Maqu and Tangnaihai, while for prediction there is no Tangnaihai station.

The Source Region of Yellow River has a frozen period ranging from 108 days to 69 days. The freeze-up usually starts in mid to late November in Yellow River Region station and the break-up usually appears in mid to late March in Jimai. In recent years, affected by the increasing temperature, the stable frozen period in the research area has been decreasing and the frequency of twice freezing and breaking in one year has increased.

Analyzing the main influence factors of the freeze-up and break-up date including air temperature, quantity of flow, and the channel conditions, a selection of prediction factors can be made. By using multiple linear regression and artificial neural network method, this paper set up two models for prediction of freeze-up and break-up date. In MLR model, stepwise regression analysis is used to put the highly-related factors into the prediction equation. Three research stations has different factors and their own equations. In ANN model, multilayer perceptron in SPSS is used to set up topology between input factors and output date. And a comparison between the results of the two different methods has been made.

The freeze-up goes from upstream to downstream, but delays in the canyon, meanwhile the break-up process goes on the contrary. And the main influence factors of the freeze-up and break-up date are air temperature, quantity of flow, and the channel conditions. Both MLR model and ANN model can make a qualified prediction result, but under complicated conditions, ANN is better.

H02S4.07

H02S4 - Cold and mountain region hydrological systems under climate change: towards improved projections

Oral

Exploring the relationship between polar motion and a primitive river's runoff based on Granger causality

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Assessing the sensitivity of cold-and mountain hydrological systems to climate change poses challenges. The driving force data to the hydrological models in cold-and mountain regions are sparse due to high elevation and cold environment which make the observation more difficult than plain area. New methods are proposed in this paper to combine the distributed physical hydrological modeling with the statistical analysis. The flows of the rivers in Qinghai-Tibet Plateau are simulated by the VIP distributed eco-hydrological model. As there are no observed data for validating the model, the data borrowed from other models are used for comparison. Grangers were used to do the statistical test to the relationship between the runoff and possible influencing factors with special consideration to earth rotation factors such as polar motion. The sensitivity of hydrological systems to climate change is then analyzed.

H04S1.01

H04S1 - Understanding fresh-water quality problems in a changing world

Oral

The monitoring of European priority substances in the context of the water framework directive

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The article 16 of the water framework directive (WFD) is the legal basis for the identification and review of the European priority substances that are substances that should be reduced or eliminated (priority hazardous substances) from all emissions, releases and losses in surface water bodies within a specific deadline. The Directive 2008/105/EC has defined environmental quality standards (EQS) in the water column for 33 priority substances and 8 other pollutants: for hexachlorobenzene, mercury and hexachlorobutadiene the EQS have been derived for biota and member states have also the possibility to derive EQS in the sediment compartment. In 2012 the European Commission has published a proposal directive, COM (2011) 876, with the revision of the list of priority substances and the derivation of EQS in water column and biota: 15 new substances have been selected through a procedure of prioritization based, as required by article 16 of WFD, on a risk assessment procedure with the use of monitoring and modelling data collected during a period of 4 years. In the list of the new substances there are several pesticides widely used in Europe, biocides, pharmaceuticals, flame retardants, industrial chemicals and also POP such as dioxins and heptachlor. The control of priority substances requires a great effort from all the member states for the monitoring strategies and in particular for the selection of analytical methods that must comply with the legal obligation required by the directive 2009/90/EC. For this reason in the context of the Working Group E on chemical aspects of the WFD an expert group, CMEP (chemical monitoring and emerging pollutant), chaired by Italy, JRC and European Commission has been established with the aim to support all the member states for the implementation of chemical monitoring in the European surface water bodies.

H04S1.02

H04S1 - Understanding fresh-water quality problems in a changing world

Oral

Pan-European information needs on quality of freshwater

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In Europe, the Water Framework Directive (WFD) requires EU Member States to achieve good ecological and chemical status of their water bodies by the year 2015. In 2009, Member States reported the status of their water bodies including pressures, impacts and measures taken to the European Commission. This huge amount of data has been analysed since then and the results have been published by the end of 2012 in a series of reports by the European Environment Agency and its European Topic Centre on inland, coastal and marine waters. The political analysis will be published by the end of 2012 as 'a Blueprint to safeguard Europe's water resources' by the European Commission including accompanying documents.
The analysis of the reported data shows that more than half of the surface water bodies in Europe are reported to be in less than good ecological status or potential, and will need mitigation and/or restoration measures to meet the WFD objective. The information on chemical status is incomplete, but shows poor chemical status for groundwaterbodies by area of about 25% across Europe, cause mostly by excessive levels of nitrate. Pressures on waterbodies are coming mostly from diffuse sources of pollution and hydromorphological alterations. For the latter, no regular data reporting exists at European level within the annual State of Environment reporting. Further research is needed with regard to hydromorphology, water quantity accounting, ecological status and typology, as well as chemical status.

H04S1.03

H04S1 - Understanding fresh-water quality problems in a changing world

Oral

Regional overview of nutrient load in Europe – challenges when using a large-scale model approach, E-HYPE

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Nutrients cause eutrophication problems in surface water, and a deeper understanding of sources and pathways may help water managers to improve water status more efficiently. This study gives a pan-European overview of riverine nutrient transport from land to sea, and surface water concentrations across the continent. The overview is based on a dynamic process-based model, E-HYPE. Results indicate that loads and concentrations of total nitrogen are highest in the western part of Europe, e.g. Denmark, Germany, the Netherlands, Belgium, Northwest France and the Southern UK, all draining to the North Atlantic Ocean. High phosphorous concentrations were more dispersed and coincided principally with major urban centres, e.g south of England and the Netherlands. Spatially consistent moderate total phosphorus loads were also seen across the agricultural regions of Western Europe and north of the Black Sea. By analysing the disagreements between modelled data and observations it may be possible to identify major knowledge gaps in the model processes. Spatial variation in results can help contribute to understanding of hydrological and nutrient processes in the wide variety of climates, physiological and anthropogenic conditions represented across the European continent. The predictability in a large-scale model is limited by the quality of the continental scale input, forcing data and new methods to constrain model parameters. Nevertheless, given the level of predictability, such models can provide regional overviews, source apportionment and can highlight hotspots for which more detailed modelling may be required. The homogenous setup of the E-HYPE model for the European continent can be further used for simulating impact of changes in climate, environment or society, e.g. as a result of European directives and their implementation. The model also provides input to coastal and oceanographic models around the European coast.

H04S1.04

H04S1 - Understanding fresh-water quality problems in a changing world

Oral

The complex task of maintaining water quality in Mediterranean basins

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Many river basins in southern European countries suffer common fresh-water quality and management problems. Although in the last decades there has been an improvement in waste water treatment and number of people connected to treatment facilities, eutrophication problem has not decreased and emerging contaminants are becoming a new social concern. Irregular Mediterranean hydrology, highly populated areas and an extensive use of water resources for agriculture are the main environmental pressures of Mediterranean basins where maintaining adequate water quality, good status of the environment and reliable water supply is a difficult task. In many of these basins water scarcity and long droughts periods affect river flows and, consequently, dilution and self-depuration capacity of water bodies. Furthermore, diffuse and groundwater agriculture pollution and the massive use of water resources by irrigated agriculture are other main factors in river and aquifers water quality. On the other hand, new water policies, including the European Framework Directive, are demanding more environmental protection for our water bodies. In this paper we explain the common stressors for environment and water quality in these southern countries' basins.

As an example of such basins we present the Llobregat river case (Spain). The importance of this river is that it is a main water supply resource of several cities, including Barcelona, and the main receptor of effects of different human activities. A water quality model of the whole basin was developed to analyse the links between the water resource system management and the water quality of the system. The model was developed with GESCAL module, a water quality simulation program part of the Decision Support System AQUATOOL. Conductivity, organic matter, dissolved oxygen, nitrogen cycle, and phosphorous were modelled. The analysis is focused in the last drought period, when the water system was quantitative and qualitatively stressed

H04S1.05

H04S1 - Understanding fresh-water quality problems in a changing world

Oral

Overview of water quality problems in Estonia with the focus on drained peat areas as source of nutrients

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The eutrophication, caused by enlarged loads of nutrients (nitrogen and phosphorus) from watersheds, remains one of the most important problems for surface waters in Estonia. In many rivers, the concentrations of nutrients exceed the upper hydrochemical limit values of good status 5-fold. Sometimes it is impossible to explain such high nitrogen concentrations by known pollution sources. This fact impedes elaboration of the effective water protection measures. According to current opinion, the drastic increase of surface water pollution by nutrients during the late 1970s was caused, above all, by effluent discharge (point sources) and by intensive use of commercial fertilizer in agriculture (diffuse pollution). Reconstruction of old treatment plants and opening the new ones significantly decreased nutrient pollution load from point sources. The changes in the agricultural sector of Estonian economy at the beginning of 1990s led to a drastic decrease in application of mineral fertilizers and also in livestock population. Nevertheless, very little evidence was found that these changes in agricultural practices noticeably affected the concentrations of nutrients in rivers. The nutrients runoff from some watersheds remained at undesirably and unexpectedly high levels. This fact confirms the opinion of some researches that impact of agriculture on the pollution of surface water by nutrients was overestimated. Intensive pollution of surface water may be caused by wide-scale melioration. Peat soils can act as a source as well as a sink of nutrients, depending on the peat type and drainage conditions. However, intensively managed peat soils are generally considered as a source of nutrients because the indigenous peat can contain considerable amounts of nutrients, available for leaching. Aim of the presentation is to show the importance of this source in Estonia. Currently, about one third of the Estonian territory is drained and most part of this area covered by peat soils.

H04S2.01

H04S2 - Understanding fresh-water quality problems in a changing world

Oral

Water quality problems in Russia: current status and some approaches to their solution

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An overview of water resources in Russia is presented in terms of the problem of water scarcity. It is shown that physical water scarcity, defined as insufficient resources to satisfy demand, is a feature of water security in a very few regions of Russia, while most regions have enough water to meet industrial, agricultural, household and environmental needs. Inadequate water quality creates, in larger extent than physical availability of water, the most serious problems of water scarcity in the country. The current status of the water quality problems in Russia is presented. It is shown that the status is, in a significant degree, the policy-induced outcome of the extensive use of water resources, which are considered often as an infinitely available resource to be diverted, drained or polluted for generating a short-term profit. As the predictable consequence of inexhaustible demand in underpriced resource, many river systems in industrial and urbanized regions of Russia are badly polluted. The main sources of surface water pollution and changes of their relative contributions for the last two decades are analyzed. As a specific concern, the problem of drinking water quality is presented in more details. Opportunities of both structural, technological solutions of the water quality problems and some non-structural, water management approaches to water protection in Russia are discussed. Among the technological solutions, modernization of water treatment facilities, renovation of water and sanitation networks, as well as new development of new technologies for water quality monitoring are considered. Opportunity of the non-structural approach is illustrated by the development of new modeling tools for water quality prediction. Applicability of the developed models for water quality prediction in a changing environment is discussed.

H04S2.02

H04S2 - Understanding fresh-water quality problems in a changing world

Oral

Water quality issues in West, Central and Northeast Africa – Present status and future challenges

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Water pollution is a major problem in Africa and is responsible for many premature deaths or diseases due to pathogens and toxic pollutants. In a context of climate change, with increasing pressure on water resources, there is a need to identify news challenges for a regional solution to achieve MDO. This communication proposes an overview on water quality in West, Central and Northeast Africa by reviewing recent selected literatures. Water quality in the region is mainly attributable to: 1) anthropogenic activities (agriculture, different types of industries, domestic waste); 2) communities socio economic conditions and behaviors; 3) and natural sources linked to the geology. Water resources are directly or indirectly polluted. Several report show surface and groundwater pollutants as OM, TOC, pathogens, nitrates, pesticides, pharmaceutical products, hydrocarbons, heavy metals… Persistent pesticides residues in water are observed from Senegal to Ethiopia via Burkina Faso in all countries with cash crops production. From domestic activities, unsafe solid wastes are important source of water pollution in many capitals as Yaoundé due overcrowding, poverty, low sanitation in precarious neighborhoods' habitats. Eutrophication of famous lacks/lagoons in Africa is the conjunction of many anthropogenic activities (domestic, agricultural). Challenges to overcome are a promotion of pollution prevention measures which include communities behavior, a disposal of financial support for water analysis and treatment, suitable sanitation for health preservation. The governance in water management through the application of laws and respect of norms is key point to prevent water pollution. The enhancement of population educational level constitutes also an important aspect. In scientific research domain, there is need to focus on studies based on local natural materials for water cleaning to develop cheap and easy technologies.
Keywords: water quality, Africa, Pollution, Challenges

H04S2.03

H04S2 - Understanding fresh-water quality problems in a changing world

Oral

Field to watershed scale water quality adaptations to address a changing world

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The United States faces environmental challenges given its inherent physical and chemical variabilities and geography as well as anthropogenic contributions. Climate forecasting for commodities is pertinent for food security and overall environmental health. Contaminants of emerging concern [(CECs) i.e. metals, pests] have impacted our coastal areas and our interior river systems. These CECs affect soil, water, and air quality with concomitant impacts on human health and wildlife. The U.S. Department of Agriculture's Conservation Effects Assessment Project (USDA CEAP) utilizes watersheds throughout the U.S. to compare measured data to model results for the both non-point and point sources of pollution to determine the benefits of conservation practices. The Agricultural Policy eXtender Model (APEX) provides the physical and chemical process-level accounting that enables regional scale modeling. APEX is being enhanced in its routing and chemical capacities to address regional concerns and allow for proper accounting of CEC's . This model offers a spatial weather generator to assist these data scarce regions. APEX can simulate landscape to large scale watersheds with steep rainfall gradients. APEX weather generator creates daily weather values that are correlated in time and space, based on monthly weather statistics using a probabilistic method that are then linked to flow, water quality, and soil properties. The CECs are being linked to soil physical and chemical properties (i.e. metals linked to soil saturation and clay content). Nutrient pools have also been altered. From working on algorithms that address the Southern Oscillation Index to heavy metals that are especially problematic in the Midwest region, APEX is continually in development to increase its reliability as a tool used for environmental policy decision making. The improvements employed in APEX will be utilized nationally in rangeland, cropland, pastureland, and wetland projects.

H04S2.04

H04S2 - Understanding fresh-water quality problems in a changing world

Oral

Water-quality in South America: pollutants, sources and trends

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South America is the continent with the largest availability of water resources both per capita and per area. However, the continent also hosts some of the world's regions with the highest water scarcity. Although a lot of attention has been paid to the issue of water quantity, water quality is a much more silent threat. However, it is increasing rapidly under the pressure of increasing urbanization and vigorous economic growth, especially in highly water demanding industries such as mining and agriculture. We present a review of the major drivers of water quality deterioration in South America. Although water quality is a complex and intertwined issue, some geographical patterns can be identified, relating to the agricultural dominated south east of the continent, the Andes mountains in the west, and the Amazonian basin. Large regions of Brazil and countries such as Paraguay, Uruguay and Argentina are representatives of the intensive agricultural utilization, namely by cultivation of bioenergy crops, livestock feeds, and livestock raising. These production systems lead to diffuse pollution problems. Agriculture in the Andes is less intensive but point sources are gaining importance in impacting water quality, such as aquaculture in Ecuador. Additionally, water quality issues in the Andes are often related to mining, either from chemicals used in the extraction process, or from waste products. The increasing number of large reservoirs has a further impact on water resources and is a typical element of Amazonian development. Reservoirs, mainly built for irrigation purposes and hydropower generation, dramatically change upstream and downstream sedimentation loads, thereby altering longitudinal distribution of nutrients. Large reservoirs also impact stream ecology, directly through changing species composition and distribution but also stream temperatures. Lastly, the dramatic growth of megacities entails specific issues of both clean water supply and pollution.

H04S2.05

H04S2 - Understanding fresh-water quality problems in a changing world

Oral

The water quality problems and control strategies required in China

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China's development is severely limited by the water shortage, where the per capita water resource is only one quarter of world average. The water limitation has been further aggravated by the decrease of water quality during last three decades. Till now, almost all water bodies in China, i.e. rivers, lakes and offshore sea waters, are polluted in some extents. According to the Environment Bulletin of China, 24.3% of the monitored sections of the seven river systems were in water quality grade IV and V and 18.4% as worse than the quality grade V in 2009. The water quality in the river systems of north China was particularly lower. For example, 42.2% of monitor sections in Haihe river were worse than the quality grade V, which cannot be used in any scope. Seven of the nine key lakes in China are severely polluted and eutrophicated with higher concentration of nitrogen and phosphor. All offshore sea waters are also polluted, as 21.1% of them were worse than the quality grade IV in 2009. The groundwater for 97% of 195 cities investigated was found to be polluted. Key pollutants are organic or inorganic nitrogen and active phosphate, which sourced from not only industrial pollution, but increasingly from agricultural areal pollution, living waste water, and aquiculture. Although big efforts were made to reduce water pollution, it was mostly offset by the increasing overuse of pesticide and fertilizer, and low percentage of sewage disposal. Some strategic suggestions for more rigorous rules of environment protection and the application of synthetic techniques were given here for restoring the water quality in China.

H04S2.06

H04S2 - Understanding fresh-water quality problems in a changing world

Oral

Recent developments in river water quality in a typical Mongolian river basin, the Kharaa River case study

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Mongolia is facing a tremendous change in climate and of land-use intensification due to expansions in the agricultural sector, an increase of cattle and livestock and a growth of urban settlements by migration of the rural population to the cities. It is expected that this may lead to unfavorable changes in surface water quality. The objective of this study is to evaluate current water quality conditions in the typical 15,000 km2 Kharaa River basin in Northern Mongolia. Based on surveillance data from Mongolian environmental authorities and a complementary own monitoring scheme, we evaluated nutrient and sediment bound heavy metal contamination on a sub-basin scale. Although the headwaters of the Kharaa represent natural background conditions (total nitrogen (TN) 0.46 to 0.58 mg N L–1, total phosphorus (TP) 0.011 to 0.018 mg P L–1) and population densities within the catchment are very low (< 10 inhabitants km–2), the river basin is facing relatively high anthropogenic pressures on water quality in the middle and especially in the lower reaches (total nitrogen 1.50 to 1.52 mg N L–1, total phosphorus 0.18 to 0.26 mg P L–1). Main contributors to these nutrient emissions are urban settlements with a high proportion of households without connection to wastewater treatment plants and, to a lesser extent, agricultural land-use. Heavy metal concentrations in river sediments show a significant variability within the river system. Especially elevated concentrations of As, Pb and U can be related to the impact of mining activities in parts of the river catchments. The nutrient levels have a significant eutrophication potential in the Kharaa River and we observed functional shifts of the macroinvertebrates and fish fauna, while the drinking water abstraction through bank filtration showed no significant alteration of raw water quality. The results of the Kharaa River basin case study will also be related to water quality conditions in other Mongolian river basins.

H04S2.07

H04S2 - Understanding fresh-water quality problems in a changing world

Oral

Water-quality problems in Japanese lakes: regulations, the past, and the future

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Japan encountered serious water pollutions along with the explosive economic growth in 1960s–80s. As a result, the Japanese government enacted the Basic Law for Environmental Pollution in 1967, which was updated to the Basic Environment Law in 1993. Based on the law, various measures have been carried out such as regulation on concentration in industrial and domestic effluent, total pollutant load control, etc. These measures successfully decreased serious water pollutions, like heavy metal contamination and serious eutrophication. However, about the half of lakes has not satisfied water quality standards yet because of the accumulation of organic contaminants in the bottom sediment for many years.

Nowadays, we have encountered an inexplicable water quality phenomenon in lakes: an increase in chemical oxygen demand (COD) with a decrease in biochemical oxygen demand (BOD). As BOD is an index of biodegradable organic matter, it suggests an accumulation of biochemically persistent organic matter. This phenomenon gives a serious challenge to us, because organic pollution in a lake is regulated by water quality standard of COD in Japan. Our research group has made efforts on elucidating the mechanism of the diremption phenomenon of COD and BOD in Lake Biwa, which is the largest lake in Japan. As a result of mass balance analysis, it was inferred that changes in bacterial biodegradation activity and primary production in the lake potentially influence the diremption phenomenon. Furthermore, these changes correlate with oligotrophication, lake warming, and wind-induced water mixing of the lake. Accordingly, a control of biodegradation activity and primary production in the lake will be our challenge for the future.

H04S2.08

H04S2 - Understanding fresh-water quality problems in a changing world

Oral

Issues of water quality, health, and poverty- The Indian scenario

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India faces a grim challenge from environmental pollution as almost 85% of the prevalent diseases are still water borne due to microbiological or chemical contamination. Rajasthan, the country's largest state has about 56% of water sources contaminated with Total Dissolved Solids, Fluorides & Nitrate in excessive amount of the prescribed national standards. This paper summarizes some recent developments in the field of fluorosis and nitrate toxicity along with the technologies devised to remove these chemicals from drinking water through research carried out by our team.

Fluorides in drinking water may cause skeletal fluorosis, clinical fluorosis, dental fluorosis, or non-skeletal manifestations, while in the final stages it may cause premature aging. Our recent research has resulted in the formulation of detailed pathophysiology of fluorosis and has also indicated successful medical treatment of fluorosis. The outcome indicated reversal of various grades of dental fluorosis in children. The two commonly used field defluoridation techniques in India are Nalgonda process and Activated Alumina process that leave an unacceptable concentration of residual aluminum in treated water. A new, low cost defluoridation technology has been developed by our team that could avoid the major shortcomings of the above technologies.

Excessive nitrate concentration in drinking water is reported to cause methemoglobinemia in infants upto 6 months. As against the WHO permissible limit of 50 mg/l, in India consumption of water containing high nitrate up to 500 mg/L is not uncommon. An epidemiological investigation was undertaken by us to evaluate the toxicity of inorganic nitrate ingestion. It yielded results to explain the mechanism of nitrate toxicity, the defense system in human body to counteract this toxicity and some other manifestations of nitrates apart from causing methemoglobinemia (Stomatitis, diarrhea) that could be of interest to environmental scientists.

H04S3.01

H04S3 - Understanding fresh-water quality problems in a changing world

Oral

Challenges for water-quality research in the new IAHS decade on hydrology under societal and environmental change

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Much of hydrological science is about reducing complexity to elucidate fundamental relationships that describe catchment function. However, many of the science challenges of the next decade are related to understanding how the function of complex catchment sub-systems interact and co-evolve in response to an unprecedented level of environmental change, and this is particularly the case for emerging water quality challenges. Dealing with complexity, nonstationarity and an uncertain future is essential for sustainable management of our water resources. A potential way forward lies in the community-driven integration of the diversity of models of hydrology, biogeochemistry and society, with environmental sensing approaches and cyber-infrastructure in a way that balances process-driven and data-driven approaches for exploring water quality dynamics. These approaches must be integrated in a way that accommodates spatial heterogeneity, sub-system connectivity, and the ongoing synthesis of their multi-scale dynamics. The implementation of such a system requires formalization and adoption of flexible (but standardized) approaches and frameworks for model use by the science community, such as the routine use of rich multi-scale diagnostic metrics for assessing model performance including novel water quality signatures and emergent relationships that help us build confidence in our models. The careful adaptation of model function can then be guided by learning from data-driven informatics techniques in a way that hybridizes our process models with observations. Such an iterative refinement in our thinking will improve our models and our understanding of response pathways of catchment systems to change. By embedding our collective efforts in development of such “adaptive” observatories within global science networks, we can ultimately support knowledge discovery as a community through facilitating cross-domain synthesis.

H04S3.02

H04S3 - Understanding fresh-water quality problems in a changing world

Oral

Water quality hot spots in rivers of India

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Deteriorating water quality has become a serious problem in developing countries like India due to increasing population, urbanization and industrialization. Almost 70% of India's surface water resources and growing number of its ground water reserves have become contaminated. India is rich in water resources, being endowed with a network of rivers and blessed with snow cover in the Himalayan range that can meet a variety of water requirements of the country.However, with the rapid increase in the population of the country and the need to meet the increasing demands of irrigation, human and industrial consumption, the available water resources in many parts of the country are getting depleted and the water quality has deteriorated.Indian rivers are polluted due to the discharge of untreated sewage and industrial effluents. The Central water Commission and Central Pollution Control Board has established a network of monitoring stations on rivers across the country. The river monitoring is done on monthly, bi monthly or quarterly in all rivers of 22basins of India. Water samples are being analyzed for physico-chemical, bacteriological and trace toxic metals. The water quality monitoring of major rivers indicates that organic pollution is predominant and almost all the surface water sources are contaminated to some extent by Coliform Group of Bacteria that make them unfit for human consumption unless disinfected. The grossly polluted rivers on specific stretches are Sabarmati, Godavari, Satluj, Yamuna, Cauvery, Ganga, Krishna, Tapi, Mahanadi and Brahmani whereas relatively clean rivers are Chambal, Mahi, Narmada, Brahmaputra and Beas with respect to organic and bacterial pollution.Data reveal water quality stations at Chenab, Jhelum, Ganga, Mahi, Sabarmati, Tapi, Narmada, Bharigathi, Brahmani, Subarnarekha, Mahanadi, Brahmaputra, Cauvery, and KrishnaRivers and tributaries have high level of trace and toxic metals

H04S3.03

H04S3 - Understanding fresh-water quality problems in a changing world

Oral

Community perception in adaptation of technical and traditional fluoride mitigation practices

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India has 14.1% of total fluoride deposits on the earth's crust. It is not surprising, therefore, that the fluorosis is endemic in 17 states of India. Indian continent, the higher concentration of fluoride in groundwater is associated with igneous and metamorphic rocks and about 62 million people are at risk of developing fluorosis from drinking high fluoride water. The problems are most pronounced in Andhra Pradesh, Bihar, Gujarat, Madhya Pradesh, Punjab, Rajasthan, Tamil Nadu, and Uttar Pradesh. There are a lot of studies on the distribution of fluoride in groundwater however, the impact assessment studies still lacking. There is also evidence that the adverse health effects of fluoride are enhanced by a lack of Ca, vitamins, and protein in the diet.

In Rajasthan, 24 out of 32 districts are fluorotic and 15 million of the populations are at risk. An exploratory qualitative study was carried out to describe perception of the community regarding fluoride and related health problems in central. 746 habitations among 1160 habitation studied were found to have >1.5 mg/l fluoride. Fluoride concentration varies from 0.2 to 21.2 mg/l. in the area A detailed fluorosis study was done in 50 habitations with >5.0 mg/l fluoride. 7424 individuals were examined. The overall prevalence of dental and skeletal fluorosis was found to be 5,053/7,424 (68.06%) and 529/3,885 (13.62%), respectively. The Dean’s Community Fluorosis Index for the studied area varies from 1.14 to 3.04. Government has introduced some domestic and community based defluoridation techniques but they are not accepted by community. People are still preventing themselves by fluorosis using traditional tactics. Therefore a questionnaire was designed to find out the traditional tactics to mitigate fluorosis.

H04S3.04

H04S3 - Understanding fresh-water quality problems in a changing world

Oral

Loire River eutrophication mitigation (1981-2011) measured by seasonal nutrients and algal biomass cycles

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The Loire River basin is very sensitive to eutrophication (Moatar&Meybeck, 2005) due to: multiple channels morphology, summer low flows (1,8 L.s-1.km2 in summer 2003), high water temperatures (30°C in summer 2003) and significant agriculture and urban pressures. During the 1980's in the Middle Loire, chlorophyll-a concentration maximum reached 250 µg.L-1 with a summer average of 140 µg.L-1. This last decade, average summer concentration did not exceed 50 µg.L-1. Total phosphorus concentration has been divided by four since 1981. In contrast, winter nitrate concentration is stable during the whole period. (Moatar et al, submitted). The seasonal variation of nutrients and chlorophyll is studied on the basis of monthly or weekly data from the headwater to the estuary (1012km, 15 monitoring stations from the Loire River basin authority). Harmonic analysis is performed to assess seasonal features for three periods. Seasonal amplitudes and phases differences are analyzed. Spatial interpolations and trend analysis take into account uncertainties calculated for concentration indicators according to sampling frequency. A seasonal typology is set by Principal Component Analysis and hierarchical classification to highlight the role of hydro-climatic forcing and biogeochemical cycles.

The summer chlorophyll-a maximum is generally observed during late summer and the seasonal biomass is nearly synchronous on a 450 km river stretch, with a maximum 220 km upstream of the estuarine limit. In the Middle Loire section, nitrate and phosphate concentrations also show marked synchronous seasonal variations. A summer phosphate minimum is attributed to algal uptake, and a summer nitrate minimum is attributed partly to algal uptake and denitrification. However, limited seasonal variation is observed for total P. The following control factors of algal biomass are tested: nutrient reduction, clam filtration by Corbicula biomass, summer temperature increase and summer low flow decrease.

H04S3.05

H04S3 - Understanding fresh-water quality problems in a changing world

Oral

Nutrient loadings and water quality in the Po River basin: relationships with land uses and river hydrology

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The Po river watershed accounts for up to 40% of the Italian gross domestic product and is heavily impacted by agriculture, industrial settlements and urban area development. From 30 to 50% of the annual river discharge is exploited for irrigation, which contribute to water pollution. Tributaries and some ten thousand kilometres of canals are regulated, man-managed and often deeply altered. In such context, frequent persistent summer drought and extreme floods occurred in the last two decades, which induced significant changes in both timing and amount of water discharge and water quality, and their impacts on the adjacent coastal zone. In this contribution, four main topics are reviewed.

1) A brief synthesis of the main river modifications since mid 1900s, which have deeply altered hydrogeomorphology with effects on both river discharge and solid transport.

2) The assessment of relationships between land uses and water quality in the basins of two tributaries of the Po River (Parma and Oglio rivers) with different livestock pressure, crop production and population densities. Overall, nitrate pollution in the two rivers correlates with the nitrogen surplus in the farmland.

3) The impact of river damming on water quality and nutrient stoichiometry.

4) A short term study (2003-2007) of effects of persistent drought conditions on river discharge, nutrient loadings and stoichiometry, and saline wedge ingression in the deltaic branches.

After periods of low discharge, up to 30-40% of P loading is delivered in less than two months by flash-flood events, of which up to 90% is in the suspended particulate fraction and refractory. Whereas, N load is not related to floods, and composes mainly of dissolved nitrates. Such patterns are responsible for unbalanced nutrient ratios with possible effects on natural and man managed processes in the lowland river reaches and coastal lagoons, e.g. eutrophication and macroalgal blooms.

H04S3.06

H04S3 - Understanding fresh-water quality problems in a changing world

Oral

Effects of residence time and nutrient load on the eutrophic condition and phytoplankton variation in agricultural reservoirs

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Reservoirs and ponds have been used as important water resources in the agriculture area with little rain, and its importance will increase with the worldwide climate change. However, the lack of maintenance causes eutrophication and phytoplankton bloom, which often induces the problem such as clogging of irrigation line. For the sustainable use of agricultural reservoirs, it is important to clarify the trigger of eutrophication and control it based on the characteristics of reservoirs. We aimed to examine the effects of residence time and nutrient load on the eutrophic condition and phytoplankton variation in the ponds highly influenced by the agricultural activity. We conducted measurements on the morphometry, volume of inflow and outflow, water temperature, salinity, chlorophyll-a and turbidity at 6 ponds (P1~P6) with the different catchment area from 5 to 220 ha and the citrus farm ratio from 14 to 82 % of total catchment area in August 2012. Water samples were analyzed for nutrients (DIN, DIP and DSi). Estimated residence times in respective ponds tend to be longer with the increase of volume, which is the longest in P1 with 93 days and is the shortest in P4 with 17 days. The nutrient concentration and its balance shows that most ponds are in the N-rich condition compared with the Redfiled ratio (N: P: Si = 16: 1: 16). However, more than 40 % of DIN and DIP inflows to the ponds are estimated to be removed before it outflows to the downstream. Chlorophyll-a concentrations were higher in P1 and P2 with 440 and 210 µg/L, respectively characterized by longer residence time than that in the other ponds from 20 to 60 µg/L with shorter residence time. However, in P4 with shortest residence time, floating plants covered all around water surface, which is obviously different condition from the other ponds. These results suggest that residence time is one of the most critical factors for controlling the eutrophic condition and phytoplankton variation in the ponds.

H04S4.01

H04S4 - Understanding fresh-water quality problems in a changing world

Oral

Assessment of groundwater quality contamination by nitrate leaching using multivariate statistics and Geographic Information Systems

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The present study draws on the groundwater quality of Megara basin (Attica Prefecture-Greece), giving special attention to nitrate contamination. Hydrochemical data were analyzed by performing a multivariate statistical analysis in order to classify the samples into a small number of mutually exclusive groups based on the hydrochemical similarities among them, as well as to investigate the factors, both geochemical and human related, responsible for the groundwater quality. In addition, thematic information and chemical data of groundwater were processed in a Geographic Information System (GIS) environment with the aim to study the extent and variation of nitrate contamination and to establish spatial relationships with responsible land use types. The outcome of the two approaches reflected the polluted nature of nitrates in the groundwaters. Seventy three percent of the groundwater samples located around the national highway showed nitrate concentrations above the acceptable level (50 mg/l NO_3) according to the European legislation (Directive 98/83/EC, Directive 2000/60/EC). The spatial analysis together with the statistical hydrochemical evaluation indicated that groundwater contamination by nitrate is closely associated with specific land use classes and activities (e.g. agriculture, pastures, industries, urban effluents). In particular, the groundwater contamination due to nitrate leaching around the city of Megara was significantly higher than that in the margins of the basin, as a result of the local continuous and intense human activities.

H04S4.02

H04S4 - Understanding fresh-water quality problems in a changing world

Oral

Groundwater pollution and safe water supply challenge in Cotonou town, Benin (West Africa)

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Urbanization and population growth in the Cotonou induce increasing of water demand. But natural factors (geological, topographic, hydroclimatic variability) combined with human factors (demographic pressure, uncontrolled land use land cover, etc.) influence water systems.

So, for the major part of population in Cotonou access to safe water is compromised because of groundwater physicochemical and bacteriological pollution.

So it is important to strengthen drinking water supply problem at Cotonou, focusing on water pollution and alternative approaches of safe water providing. This study based on existing literature, physicochemical and bacteriological analysis of groundwater sample, assessment of drinking water quantity and participative investigations in the urban area of Cotonou. Water quality is appreciated from the drinking water quality standards of WHO. This method helped to emphasise environmental change impacts on groundwater quality and how to take up the challenge of safe water supply for Cotonou town.

The study shows that the shallow aquifer which depth varying between 1 and 2 m in Cotonou is polluted by wastes and often by septic tanks situated less than 5 m of water source (well). Groundwater mineralization is dominated by nitrogen, sodium and chloride depending on human activities, induced recharge and saltwater intrusion. Bacterial polluting agents like total coliforms, Escherichia coli and fecal streptococcus present in the well water largely exceeded (too numerous to count) drinking water guidelines and standards 0 CFU/100 ml of WHO. Consequently water from this aquifer is excluded for drinking water supply in aid of the Continental Terminal aquifers on the Plateau of Allada far from Cotonou. Sustainable safe water supply, for Cotonou people, implies groundwater quality protection by ecohealth approach. On the other hand, rational water use and deep aquifer water extraction could be strategies to face increasing of water demand.

H04S4.03

H04S4 - Understanding fresh-water quality problems in a changing world

Oral

Nutrient transport with the surface water-groundwater interaction in the tidal river of a coastal megacity in Japan

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In coastal megacities, sever groundwater depression and water pollution occurred. These impacts affected to river environment change. Especially, the river mouth area has been deposited the polluted matters. These areas have characteristics of water level fluctuation which causes river water-groundwater interaction and the associated change in dynamics of nutrients. However, these effects on the nutrient transport in tidal reaches and nutrient load to the sea have not been fully evaluated in previous studies. Therefore, we aimed to clarify the characteristics of the nutrient transport with the river water-groundwater interaction in the tidal river of Osaka metropolitan city. We conducted the field survey from the river mouth to the 7km upstream area of Yamato River, which has a length of 68km and a watershed area of 1070 km2. Spatial variations in radon (222Rn) concentrations and the difference of hydraulic potential between river waters and the pore waters suggest that the groundwater discharges to the river channel in the upstream area. In contrast, the river water recharged into the groundwater near the river mouth area. It may be caused by the lowering of groundwater level associated with the excess abstraction of groundwater in the urban area. The result also implies the seawater intrusion would accelerate the salinization of groundwater. The spatial and temporal variations in nutrient concentrations indicate that nitrate-nitrogen (NO3-N) concentrations changed temporally and it negative correlated with dissolved organic nitrogen (DON) concentrations. Inorganic phosphorous (PO4-P) concentrations showed the increasing trend with the increase of the river water level. Based on the mass balance, nutrient reproduction from the river bed was suggested in tidal reach. That was estimated to be 10 % of total nitrogen and 3% of phosphorus loads from the upstream.

H04S4.04

H04S4 - Understanding fresh-water quality problems in a changing world

Oral

Dynamics of dissolved oxygen and metabolic rates in a shallow subtropical urban lake

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Ecosystem metabolism is an important indicator of biological activities and nutrient fluxes in freshwater quality. In this study we assessed the gross primary production, net primary production, and respiration of a shallow subtropical lake, influenced by a highly developed urban environment. A water quality monitoring platform with multi-parameter probes was deployed in the center of the lake to record changes in dissolved oxygen (DO) concentration and other water quality parameters at 15 minute time intervals from July 2008 to July 2009. The measurements were used to quantify lake productivity with a single station diel oxygen change method. We found a mean annual gross primary productivity of 4.41 g O2 m-2 d-1, a mean annual net primary production of 2.13 g O2 m-2 d-1, and a mean annual respiration of 5.90 g O2 m-2 d-1. Annually, a total of 1610 g O2 m-2 were produced while a sum of 2150 g O2 m-2 were respired. Respiration rates were equal to or greater than productivity rates during the year, indicating that this shallow subtropical urban lake was net heterotrophic throughout most of the year.

H04S4.05

H04S4 - Understanding fresh-water quality problems in a changing world

Oral

ECOMAG: distributed model of runoff formation and pollution transformation in river basins

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ECOMAG is the acronym for ECOlogical Model for Applied Geophysics, a distributed physically based model developed for description of runoff formation and pollution transformation in river basins located in the cold regions of the Earth. The ECOMAG consists of hydrological and water quality sub-models that are operated on a daily time step. The hydrological sub-model describes the main processes of hydrological cycle of land: snow accumulation and melt, soil freezing and thawing, water infiltration into unfrozen and frozen soil, evapotranspiration, thermal and water regime of soil column, overland, lateral subsurface, groundwater and channel flow. The water quality sub-model describes the processes of accumulation of pollutants on the surface, dissolution of pollutants by rain or snowmelt waters, penetration of soluble pollutants into soil, interaction with soil solution and soil matrix, biochemical degradation of pollutants. The transfer and transformation of pollutants in river system are described taking into account the lateral diffusive inflow of pollutants by surface, subsurface and groundwater flow, the load from point-sources of pollutants on the rivers, the exchange of pollutants between river water and river bed. Hydrological submodel of ECOMAG is applied since 2004 in operative mode for simulation hydrological characteristics and inflow of water into reservoirs of Volga-Kama and Angara-Yenisey cascades. An application of the hydrological and water quality sub-models is presented for simulating water quality dynamics in the river basins of Kola Peninsula, exposed by intensive pollution as a result of activity “Pechenganickel” industrial complex. The simulations of nickel and copper concentrations are shown in comparison with the corresponding observed data for several years. Results of the modelling experiments are presented for illustrating the impact of activity Pechenganickel on water quality in river channels.

H04S4.06

H04S4 - Understanding fresh-water quality problems in a changing world

Oral

Parameterising dynamic water quality models in ungauged basins: issues and solutions

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To dynamically model contaminant transport, attenuation and environmental impacts, a hydrological model is needed that can correctly model the flow dynamics and contaminant transport and transformation though each of its conceptual pathways. The redundancy and ill-conditioned nature of model identification and parameter estimation make this very difficult to achieve from time-series of rainfall and river discharge alone. The Pathways project, funded by the Irish EPA, combines insights from detailed fieldwork with catchment modelling to form a greater understanding of water quality processes and interactions. Conceptual catchment modelling and detailed fieldwork investigations including tracer studies and end member mixing analysis have been combined with previous research findings and expert opinion to inform an integrated water management tool.

The Pathways Catchment Management Toolbox (CMT) is a user-friendly GIS application being developed for environmental managers interested in water quality modelling and its environmental consequences. Its variable structure water quality model can be used to investigate the hydrological and contaminant processes at sub-catchment scale and to incorporate expert knowledge relating to flow pathways and contaminant transport along these pathways. Although parameters are initially linked to geological, soils and vegetation information the water manager can use a variety of data sources and expert opinion, to constrain parameters to physically realistic values essential for predictions in ungauged basins, while allowing calibration when data is available.

Catchment managers and other domain experts can use the CMT to enhance their understanding of a catchment’s response by changing the degree of complexity used to model individual processes, including source mobilisation and fate of water-borne contaminants and, through its flexible structure, incorporate field experience by altering the catchment hydraulic connectivity.

H04S5.01

H04S5 - Understanding fresh-water quality problems in a changing world

Oral

Water quality as a limitation factor of irrigated agriculture

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In the northern part of Serbia (Vojvodina Province), with 1.67 millions ha of quality arable land, the river Danube and the hydro system Danube-Tisa-Danube represent the source of irrigation water. Irrigated agriculture needs to be sustained and rejuvenated. Reform of irrigation water quality policies is thus the first and most important step towards creating conditions which make sustainable use of water possible. Often the use of comparative classification gave contradictory assessments. A possible solution for this problem is to introduce “additional” assessment of usability of irrigation water. Evaluation of water quality for the irrigation is given for specific watercourses in the area of Vojvodina. During the years of research, water samples were taken 6-24 times per year, depending on the analyzed profile. Surveys include the period from 1980 to 2009 for 30 measurement profiles of all mayor waterways in Vojvodina, on the large and small rivers, small streams and canal network which is the part of Hydro System Danube-Tisa-Danube (CN HS DTD). Classifications used to assess the usability of irrigation water quality are FAO classification, USSL classification, classification according to Nejgebauer and chloride classification of irrigation water. An additional assessment of usability of irrigation water was also used and it included determining the value of sodium Sodium Adsorption Ratio (SAR), Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Residual Sodium Bi-Carbonate (RSBC), Magnesium Content (MAR), Permeability index (PI), Kelly’s Ratio (KR). Global estimation is that water on analyzed irrigation systems can not be used because of its inappropriate effects to soil salinity. An analysis of suitability of the phreatic aquifer for irrigation showed their inappropriate characteristics. Only a small number of water samples could be recommended for irrigation.

H04S5.02

H04S5 - Understanding fresh-water quality problems in a changing world

Oral

Impacts of Yellow River irrigation practice on trace metals in surfacewater

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A case study of the environment behavior and health risk to humans posed by trace metals in an agriculture area of China, which has a long history of irrigation using the water transfered from the Yellow River, is presented. Relatively large-scale irrigation project have the chronically potential impact to local hydrological cycle and water/nitrogen migration, however, the influence to the regional trace metal in the surfacewater remains unknown. Multivariate statistical analyses and a risk assessment model were employed to interpret the environmental data. Our results indicate that Zn, Se, B, Ba, Fe, Mn, Mo, Ni, V, Al, Li, Sr, Be, Cd, Cr, Cu, and Pb were all detected in the surface water in the study area. Compared to drinking water guidelines, the primary trace metal pollution components (Al, Fe, Se, B, Mn, and Zn) exceeded drinking water standard levels by 40.7%, 14.8%, 29.6%, 25.9%, 11.1%, and 14.8%, respectively. Landscape features of trace metals conducted by Kriging simulation dentified a uniform source of trace metals for all sampling sites, excluding some part of the site that exhibited anomalous concentrations. The calculated mean value of the sum Hazard Quotients (HQs) associated with corresponding metals by Monte Carlo analyse exceeded the generally acceptable risk level recommended by the USEPA, the maximum was 2.88 times than the threshold value. Contamination at the chemical industrial parks caused significant spatial diffusion of trace metals. Based on the patterns of relative loadings of individual metals calculated by principal component analysis (PCA), the primary trace metal sources were associated with natural source agrochemical processes a mixed source of both geogenic and anthropogenic origin in north part of Henan-Liaocheng Irrigation Area.

H04S5.03

H04S5 - Understanding fresh-water quality problems in a changing world

Oral

Multiple use of stable isotope ratios ($\Delta^{13}C$, $\Delta^{15}N$, $\Delta^{18}O$, and $\Delta^{34}S$) to understand groundwater quality changes and attenuation processes of pollutions in Kumamoto area, southern Japan

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Combination use of several stable isotope ratios are increasingly recognized as important approach for comprehensive understanding of the water deterioration and pollution attenuation mechanisms. However, such trial has not been seen so often and importance of the application of these tracers has not been fully understood. This paper presents a case study of Kumamoto groundwater in southern Japan applying multiple isotope ratios ($\Delta^{13}C_{DIC}$, $\Delta^{15}N_{NO3}$, $\Delta^{34}S_{SO4}$, $\Delta^{18}O_{NO3}$, and $\Delta^{18}O_{SO4}$) for better understanding the sources of groundwater pollutions and natural attenuation processes. Our results showed that sulfate in groundwater is originated from multiple sources (pyrite oxidation, volcanic components, and anthropogenic materials), although nitrate was most largely derived from anthropogenic sources (chemical fertilizers). Furthermore, occurrence of some bacterial activities such as sulfate reduction and methanogens were suggested in addition to denitrification. This study implies that the approach using multiple tracers is advantageous for comprehensive understanding of the cause of water quality change. However, utility of this approach should be improved as focusing to individual research target such as pollution source determination and pollution attenuation mechanism.

H04S5.04

H04S5 - Understanding fresh-water quality problems in a changing world

Oral

Assessing the improvement in the quality of groundwater contaminated with chromium around tanneries

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A study was carried out with an aim of assessing the groundwater quality with respect to chromium around tanneries in a part of Chennai, southern India. The wastes from these tanneries are treated in the common effluent treatment plant (CETP) and let into the river flowing nearby. Groundwater samples were collected from 22 locations in March 2010 and analysed for chromium content. The chromium concentration in groundwater was compared with the study carried out in 2008. EC was from 985 to 5344µS/cm and was permissible only in 5.3% of groundwater samples. The chromium concentrations ranged from 5 to 35µg/l which was within the permissible limit of 50µg/l. A general pattern of high concentration in the northeastern part of the study area was found where the tanning industries and CETP are located. The highest EC was recorded closer to the CETP which indicates the impact of effluent on groundwater. The CETP started functioning in 1995 in this area after stringent rules were imposed to treat the effluent before its disposal. However before this period the wastewater with high concentration of many ions was let off into open drains without proper treatment. In 2008, the chromium concentration in the study area ranged from 4 to 990µg/l while EC ranged from 584 to 6690µS/cm. Due to the functioning of CETP, the chromium in groundwater has decreased which is evident from the study in 2008 and 2010. However, the quality of groundwater based on EC is still poor which may be because the CETP removes chromium effectively as it is a potentially toxic heavy metal rather than on decreasing the concentration of all the ions in groundwater. Hence it is very essential to remove the TDS and to frequently monitor the groundwater quality at regular intervals.

H04S5.05

H04S5 - Understanding fresh-water quality problems in a changing world

Oral

Fresh-water quality monitoring systems: ways towards improvements

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Investigation and management of the quality of fresh-water resources require data on the status of aquatic environments. These data are traditionally collected by routine monitoring systems which are supported by federal and/or local governments operating under limited budgets. This makes issues of optimization of water quality monitoring systems, in general, and monitoring designs, in particular, urgent. The paper presents a model driven approach to the development of efficient multi-parameter temporal designs for stream monitoring systems. The approach is based on an operation research model developed using cost-effectiveness analysis and regression models describing multi-parameter interactions. The developed operation research model does not require site specific parameterization other than series of concentrations of water constituents measured at a given observation site. This model can be applied to tiered monitoring systems when water quality parameters of interest are split into the core set and supplemental set according to their importance for a given site and with different uncertainty requirements. Different articulations of the monitoring effectiveness are compared in the study. The approach is tested on small rivers with highly urbanized watersheds.

H04S5.06

H04S5 - Understanding fresh-water quality problems in a changing world

Oral

Spatial and temporal distribution of PAHs in the North Saskatchewan River, Alberta Canada

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Northern Canadian Rivers provide a broad range of ecosystem services but increasing pressures from development and resource extraction have negatively impacted the ecology and water quality of many of these relatively pristine river ecosystems. The North Saskatchewan River (NSR) drains an area of 57,000 km2 in northern Alberta and provides water for domestic and municipal use, agriculture, forestry, petroleum and other industries including recreation and tourism. However, recent studies indicate that increasing natural and anthropogenic landscape disturbances have increased the flux of a variety of sediment and associated contaminants to the NSR. To evaluate the spatial (gradient from headwater sites to downstream) and temporal (inter-annual) variation of PAHs in the NSR, grab samples of fine grained river bed/bank sediment deposits were collected at 20 monitoring sites over a distance of 1000 km from Rocky Mountain House to Lloydminister in 2010 and 2011. An additional 10 samples were collected in 2011 at the river confluence with tributaries of varying land use. Individual congeners of 16 PAHs were extracted in sediment samples and analyzed for PAHs. The PAH data are presented and discussed in the context of their spatial and temporal variation and related to PAH data reported for other northern Canadian rivers. An assessment for sediment quality conditions is provided by comparing the PAH data to sediment quality guidelines (SQGs) that include the consensus based Threshold Effect Concentration (TEC) and Probable Effect concentration (PEC) reported by MacDonald et al., (2000). The presentation will address contributing sources/processes governing the distribution and environmental impacts of PAHs in northern river basins.

H04S6.01

H04S6 - Understanding fresh-water quality problems in a changing world

Oral

Spatial and temporal variations of heavy metal contamination at the global scale: an indicator of complex relations between societies and river basins

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Metal contamination was initiated by the first mining and industrial activities and follows closely the Human history, including the recent phase of environmental concern in some parts of the world. Such history is archived in river flood-plain sediments, as demonstrated in some US and western Europe rivers, all characterized by limited suspended particulate sediment transport, which dilute the contaminants inputs. In comparison to these rivers, large industrialized basins with high sediment loads present limited contamination. Floodplain cores in USA and Western EU provide long term record, often over 100 yr, characterized by: (i) a similar order of sensitivity to Human impacts and evidence of impacts, (ii) a maximum contamination from 1950 to 1970, (iii) an effective decontamination for all sensitive elements since 1980, attributed to technological changes, metal recycling, decrease of coal use, i.e. before major environmental measures. The current situation is often much better than before 1940.

A case study on the Seine River shows that the rate of river metal flux compared to metal flow within the basin has dropped by one order of magnitude since 1970, while the use continued to grow: an indication of environmental efficiency for this basin. In contrast, the leakage rate for Hg remains stable while Hg use, much regulated since the 1970s, dropped by a factor 100. Previous global estimates mixed pristine and contaminated rivers and were also biased by sample contamination. This paper provides estimates for global pristine river sediments, but these figures should only be considered if local background references cannot be determined. Current global estimates are twice as much for Cd and Hg and 15-20% more for the others; they depend on scenarios for the un-surveyed rivers in fast developing countries. In many regions a 10-fold increase of some metals is suspected: global rivers have entered the Anthropocene era.

H04S6.02

H04S6 - Understanding fresh-water quality problems in a changing world

Oral

Summer dredging campaigns and their effect on water quality

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The Canal & River Trust was established in July 2012 within England and Wales, to manage inland waterways, docks, reservoirs and estates which had previously been the responsibility of British Waterways. The key purpose of the new Trust is to '*act as guardian for the canals and rivers of England and Wales – ensuring that history, nature and communities are central to everything we do*'.

As part of this remit, the Trust is responsible for maintaining navigation for approx. 2000 miles of waterways. In order to achieve this, the Trust needs to dredge sediment out of its waterways to maintain a minimum depth of ~1.5m. In the past, dredging was only conducted over the winter months from October through to March, but due to contractual changes and a backlog of identified problems, a 'year round' dredging program has been operating since 2011.

In September 2011, dredging on the Aylesbury Arm contributed to a fish kill in the area. On investigation mean ammoniacal nitrogen in the sediment was 181 mg kg^{-1}, coupled with water pH 8.0 and temperature of 15.1 °C, led to ammoniacal nitrogen concentrations >4 mg l^{-1} in the water column. A second fish kill the Tame Valley canal during a dredging project in July 2012, appeared to be attributed to high water temperatures, BOD and COD in the sediment leachate samples taken after the event. Parallels were drawn between the two cases and questions were raised about the sediment sampling regime, which historically has been based on determining a safe and cost effective reuse or disposal routes. This paper discusses the events over the last two years and the proposed new approaches to future sediment testing.

H04S6.03

H04S6 - Understanding fresh-water quality problems in a changing world

Oral

Land use and water quality trends of the Fitzroy Basin in Australia

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Analysing the long-term trend in water quality indicators is critical to an in-depth understanding of the cause and effect of environmental change for better resources management. The Fitzroy Basin in Queensland, (142,000km2) is the second largest coastal catchment in Australia, and one of the largest sources of freshwater and fine sediment to the Great Barrier Reef Lagoon (GBRL). The climate is tropical and runoff occurs sporadically, both in time and space. The basin was largely undisturbed prior to the 1960s. The land was progressively cleared for cropping and sown pasture with the Brigalow Land Development Scheme from the 1960s. The mean annual runoff is 32.6 mm with a mean sediment concentration of 737mg/L over the period of 1965-2008. Elevated sediment concentration as a result of land use intensification and sub-optimal management practice is of great concern because of the detrimental effect on the Reef. The paper examines the land use change and the observed trends in water quality in the basin over the past 44 years. There is clear evidence to suggest an increase in sediment concentrations for a given flow rate over time, and the increase apparently occurred concurrently as land use intensified within the basin. Detailed analysis, however, shows that there are no statistically significant trends in the flow-weighted mean sediment concentration nor in the sediment discharge into the GBRL as the total sediment delivery very much depends on where surface runoff was generated and how intensive the runoff event was. At the small scale, the effect of land use change is direct, observable, and explicable on physical grounds. As the basin size increases, the effect of land use change becomes less predictable as a result of a nearly random combination of where land use intensification occurs and where runoff-generating events occur. This scenario is particularly true of the Fitzroy Basin with a highly variable climate and flow pattern.

H04S6.04

H04S6 - Understanding fresh-water quality problems in a changing world

Oral

Water temperaturesensitivity under climatic change: comparison between mountain and lowland rivers in the Loire Basin (France)

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In a context of Climate Changes, the capacity to forecast the thermal regime of rivers constitutes a great challenge for water resource management and for aquatic ecosystem preservation.

Physically-based approaches including conservation of energy principle, advection and diffusion processes are generally recommended, despite the requirement for many forcing variables but are limited to reach and stream scales (Sinokrot and Stefan, 1993), because of the difficulties to simulate the complex effects of long-distance advection and mixing at the confluences.

To address the geographic distribution of daily water temperature within the entire hydrographic network of the Loire Basin (110 000 km^2), we rely on the equilibrium temperature concept (Edinger, 1968), as developed in the ICC-Hydroqual project (Bustillo et al., 2012). 68 subbasins (300 to 3000 km^2) are delineated, in which Strahler orders are considered to behave similarly. The model uses a heat balance with 5 terms on the basis of the meteorological variables provided by Safran interpolation analysis (8km x 8 km) of Météo-France (Vidal et al, 2012). The simulation of the river discharge was performed by means of the semi-distributed hydrological model EROS.

The performance of the model for simulating the water temperature over the last 33 years (1974-2007) for 71 sampling stations led to median RMSE = 1.97°C. Thermal regime at the middle of the 21st century (2046-2065) was simulated using 14 changing climate (A1B) and hydrological scenarios derived by the EROS model. The combination of these scenarios results in an increase of mean annual temperature of 2.2°C (±0.6°C). However, the mean July temperature increase is 2.5°C (±0.7°C) for mountain rivers (mean basin elevation 600m) and 1.7°C (±0.5°C) for lowland rivers (mean basin elevation 130m). This difference can be explained by the influence of Climate Change on the heat budget, especially for the evaporation term, reduced in July for mountain rivers.

H09S1.01

H09S1 - Considering hydrological change in reservoir planning and management

Oral

Challenges of reservoir planning and management in a changing world

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Possible shifts of the rainfall regime in the next decades may have important implications for reservoir management. Also, land use change may alter the inflow regime to reservoirs, including the water and sediment dynamics. This paper reviews methods of reservoir management, and emerging approaches of how to prioritise the implementation of these methods in a changing world. Prioritisation can follow two paths: The top-down approach is based on climate projections and has an economic motivation; recent focus has been on quantifying the uncertainty of alternative management strategies. The bottom-up approach is vulnerability or resilience centred and has a social motivation; recent focus has been on exploring the full range of possibilities from a local risk management perspective. The bottom-up approach is less dependent on climate projections and may be more suitable for dealing with surprising, high impact (Black Swan) events. It is suggested that the primary approach to reservoir management in a changing world should be a bottom-up approach which may be complemented by top-down (scenario) approaches.

H09S1.02

H09S1 - Considering hydrological change in reservoir planning and management

Oral

Research on the jointly optimal water-supply operation of multi-reservoir system in Jinchang City of Shiyang River basin, China

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There are three reservoirs providing the water of Jinchang City in the Shiyang River basin, China. In this paper, in order to resolve the water scarcity problem, the mathematical model of jointly optimal operation of multi-reservoir is established, which is based on the minimum amount of water shortage as the aim function of model. The processes of optimal operation of three reservoirs are calculated according to in-out discharge data from year 1990 to 2007 by using Genetic Algorithm method. The result indicates that the total amount of water supply reaches to 0.63 billion cubic meters in Jinchang City through the jointly optimal operation of multi-reservoir, the ratio of water shortage decreases from 28.1% to 16.1%. On the meantime, an artificial neural network (ANN) model of the optimal operation function of multi-reservoir is proposed. Comparing with the Genetic Algorithm method, ANN model is better to reflect the little simulation error. It is less than 5%. The pattern of jointly optimal operation of multi-reservoir can provide the basis for the optimization allocation of water resources in Jinchang City.

H09S1.03

H09S1 - Considering hydrological change in reservoir planning and management

Oral

Improving the performance and reliability of multi-purpose multi-reservoir systems with adopted reservoir management strategies derived by multi-objective optimization

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Current climate circulation models simulate a climate change induced increase of temperatures and a decreasing amount of precipitation in the region of Saxony (Germany) in summer. Consequently, the operation of reservoirs has to consider decreasing inflows, more severe drought periods as well as increasing demands for water. In order to adapt to these new pressuring conditions and to meet the future demands of all water sectors and simultaneously to provide flood protection new management strategies for the reservoirs are required. This study combines multi-objective optimization and Monte Carlo simlation for finding effective management strategies for multi-purpose reservoirs and multi-reservoir systems. To achieve robust operating strategies (rule curves and diversions) a new framework is developed which comprises (i) the physically based rainfall-runoff model WaSim-ETH (ii) a time series model for the generation of a large number of synthetic inflow time series, (iii) a comprehensive reservoir model, (iv) an adapted multi-objective optimization algorithm and advanced visualization methods for a compact presentation of the results for the decision maker. In a real case application the new framework is used to find operating strategies to potential impacts of the projected climate change for the multi-purpose multi-reservoir system Klingenberg – Lehnmühle – Rauschenbach in the Ore Mountains (Saxony, Germany). The automatically calibrated model WaSim-ETH is applied to different climatic conditions of the time periods of the WETTREG 2010 climate model and the IPCC CO2 emission scenarios A1B, B1 and A2 for generating reservoir inflows. In addition to the climate change scenarios different scenarios describing increased demands or enlarged flood protection zones are considered. The overall robustness of the multi-reservoir system operation is quantified and possible intensifications of trade-offs between management goals or reservoir utilizations are shown.

H09S1.04

H09S1 - Considering hydrological change in reservoir planning and management

Oral

A simulation model for assessing impacts of modifying reservoir operation on flood mitigation and water supply

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A simulation model was used to evaluate two proposed reservoir operation rules in Bhumibol and Sirikit Reservoirs in the Chao Phraya River Basin. H08, an integrated hydrology and water resources model, was combined with CaMa-Flood, a river routing model considering inundation dynamics, to simulate the impacts of reservoir operation on the river basin. Simulated reservoir inflows were used as input to the reservoir operation module coupled with H08. The inclusion of CaMa-Flood in the system allows the assessment of impacts of reservoir operation on inundation situation in the entire river basin. It was found that hedging significantly reduces the occurrence of reservoir dry ups during dry seasons. A low linear storage constraint set three months before the onset of rainy season significantly reduces the reservoir overflows. The developed simulation modeling approach would be useful to design optimal reservoir operation rules that are effective for mitigating both flood and drought damages.

H09S1.05

H09S1 - Considering hydrological change in reservoir planning and management

Oral

Flood risk mitigation by reservoirs – application of multivariate statistical methods for risk-based design

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A risk oriented approach in flood design demands a new quality of hydrologic information. Instead of a single design flood which is mainly specified by the return period of its peak, the hydrological loads have to be defined by the combination of characteristics which are relevant for the flood retention: peak, volume and shape. The flood protection downstream depends often on the interaction of tributaries and the coincidences of floods originating in different sub-basins. Here a methodology is presented which is based on a combination of a weather generator with a hydrological model where planned and existing reservoirs are embedded. After long-term simulations with different planning scenarios the performance of reservoirs is assessed in several ways: for the single reservoirs the performance of flood retention can be estimated considering the most critical events which can be specified in their return periods by copulas of flood peaks and volumes. The flood mitigation downstream is assessed by application of copula statistics as well. Here the coincidence of floods is described by copulas where the marginal distributions are changed according to the flood retention of the reservoirs. This methodology offers new options to get a more holistic view on options and limitations for flood risk mitigation by reservoirs. It was successful applied in a river basin in Germany.

H09S2.01

H09S2 - Considering hydrological change in reservoir planning and management

Oral

How Flexibility in Urban Water Resource Decisions Helps to Manage Uncertainty?

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Abstract Uncertainty in future climate change and demand presents a significant challenge to the planning and management of urban water supply systems. One of the approaches to deal with uncertainty is to break large investments into a series of smaller decisions. In fact, spreading investments over time lets decision makers respond to unfolding contingences. This study considers the issue of identifying Pareto-optimal solutions for urban water supply that are robust in the face of uncertain future demand. The approach is based on the simulation of three plausible future demand scenarios to allow expected economic performance to be traded off against the variability in performance. A case study demonstrates the feasibility of this approach for a complex urban water supply system. The primary objective is to minimize the expected present worth of costs associated with infrastructure decisions, operating rules and drought contingency plans. By introducing a second objective which minimizes the difference in present worth costs across future demand scenarios, the trade-off between efficiency and robustness is identified. The results show that a significant change in investment and operating strategy occurs when the decision maker expresses a stronger preference for robustness.

H09S2.02

H09S2 - Considering hydrological change in reservoir planning and management

Oral

Real-time dynamic control of the Three Gorges Reservoir by coupling numerical weather prediction rainfall and flood forecasting

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In reservoir operation improvement of the accuracy of forecast flood inflow and extension of forecast lead-time can effectively be achieved by using rainfall forecasts from numerical weather predictions with a hydrological catchment model. In this study, the Regional Spectrum Model (RSM), which is developed by the Japan Meteorological Agency, was used to forecast rainfall with 5 days lead-time in the upper region of the Three Gorges Reservoir (TGR). A conceptual hydrological model, the Xinanjiang Model, has been set up to forecast the inflow flood of TGR by the Ministry of Water Resources Information Center. Here, the flood forecast model coupled with the rainfall forecast from RSM has been employed to carry out real-time dynamic control of the Flood Limiting Water Level (FLWL) of TGR in order to improve the hydropower generation without increasing the flood risk. Taking the flood events of the flood season 2012 as example, real-time dynamic control of the FLWL was implemented by using the forecasted reservoir flood inflow as input. The forecasted inflow with 5 days lead-time rainfall forecast was evaluated by several performance indices, including the mean relative error of the volumetric reservoir content, the relative error of peak flow and the time difference between the forecasted and the observed peak flow, all showing good performance of the forecast. Using the forecasted inflow as input to the FLWL model of TGR, the results showed that the dynamic control scheme did not increase the flood risk, and significantly increased hydropower generation in comparison with the current static operation rule.

H09S2.03

H09S2 - Considering hydrological change in reservoir planning and management

Oral

Impact analysis of long-term stochastic inflow prediction and its uncertainty on reservoir operation during drought situation

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Impacts of long-term stochastic inflow predictions and their uncertainties on reservoir operation for water supply under drought situations are analyzed and discussed in this study. Multiple sets of stochastic inflow predictions are pseudorandomly generated with five-day resolution for three months arbitrarily changing the prediction�fs uncertainty for a comprehensive analysis of the impact of the stochastic inflow prediction. Two types of stochastic prediction's attributes, namely reliability and discrimination, are introduced here, and the stochastic predictions are generated changing the two attributes so as to make it possible to analyze impacts of the stochastic inflow prediction's uncertainties comprehensively. Monte Carlo simulations of long-term reservoir operation for water supply under drought situations are then conducted considering generated multiple stochastic inflow predictions. The simulations are repeatedly conducted with different conditions in initial storage volume and inflow regime as well as two parameters of stochastic inflow prediction in order to thoroughly analyze the impacts of long-term stochastic inflow prediction on reservoir operation during drought situations. Proposed analyzing method is applied to an assumed reservoir which physical and hydrological conditions are derived from Sameura Reservoir in the Yoshino River in Japan, clarifying expected impacts of stochastic inflow predictions and their uncertainties on the long-term reservoir operation and giving a suggestion what type of uncertainty in stochastic inflow prediction is more important to be considered in the real-time reservoir operation for more adaptive drought management.

H09S2.04

H09S2 - Considering hydrological change in reservoir planning and management

Oral

Reservoir operation and the frequency of decision making

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Restricting water use during times of drought is an accepted practice in many arid countries to ensure the sustainable use of reservoirs and large systems of interlinked reservoirs. The timing and magnitude of restrictions, referred to in this paper as an operating rule, has been investigated in term of how often the decision is made as to whether or not to apply restrictions at any point in time. The current practice in South Africa is to make a decision once a year based on the state of storage in the reservoir or system of reservoirs together with stochastic projections of likely inflows over the next 5 to 10 years. The question that is explored in this paper is whether there is an advantage of making this decision more frequently? This analysis has been carried out by adapting an existing water resources model to be able to toggle between annual and monthly decisions. Several hypothetical systems were modelled using both annual and monthly decisions based on the state of storage of the system. The systems modelled varied from those with large carry-over periods, or long critical periods, to those with short critical periods. Multiple users with high and low risk profiles were included in the simulations. The outcome of these simulations in terms of the volume of water supplied to high and low risk users was recorded for each simulation. The conclusion reached is that there is a significant benefit to users from systems with short critical periods to make more frequent decisions on water restrictions rather than an annual decision. Based on this conclusion a recommendation is made about the appropriate frequency of decision making based on the type of system and the risk profile of the user.

H09S2.05

H09S2 - Considering hydrological change in reservoir planning and management

Oral

Ostrom's institutional design principles and reservoir management: a study on adaptation to climate variability and change

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Elinor Ostrom's institutional design principles for common pool resources management were refined and extended recently by water resources researchers for studying the governance of adaptation to climate change. Regarding hydrological variability and change and their influence on the management of water reservoirs, this paper shows how Ostrom's theory can be helpful to better analyse the institutional framework that supports the governance of these systems. Reservoir management is affected by natural factors, such as climate and hydrological variability, social and economic factors and changes in land use, which catalyze conflicts and uncertainty on these water resources. Management strategies should be well designed to cope with the process of adaptation to those factors' variability and, furthermore, with the process of adaptation to climate change. This paper analyses the political process of generating adaptation strategies for the management of water resources of one particular reservoir located in the drought prone semiarid region of Brazil, in order to identify institutional gaps and devices that may influence proper strategies. The work was based on documental analysis of water resources policy frameworks and plans, as well past experiences in coping with extreme drought events. The application of Ostrom's extended principles allowed treating peculiarities of such change factors considering the hydrological particularities of the region and generating the composition of various institutional proposals for a more robust management of the analysed reservoir. Among them, it was suggested the revision of the State water resources policy and water resources management plans, which have not yet established clear programs for the treatment of drought events and do not consider uncertainties and conflicts associated with such events under a future climate. This approach represents a sound option to support a flexible and adaptive reservoir management.

H09S2.06

H09S2 - Considering hydrological change in reservoir planning and management

Oral

Reservoir operating rules across a range of system complexity and degree of operator competencies

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South Africa, as with most developing countries, have historically focused their efforts on developing operating rules for reservoirs and systems of interlinked reservoirs on large schemes which support major economic zones. In order to achieve a more equitable approach to water resources management, South Africa embarked on a process to develop operating rules for the smaller reservoirs and systems supplying water to towns and rural areas. This process entailed developing operating rules for over 100 dams across the country. This paper presents some of the lessons learnt from this process. One of the main conclusions is that the operating rules needs to be adapted to the level of sophistication that can be accommodated by the reservoir operators. In it simplest form the operating rule is a simple graph which indicates the water level at which restrictions must be applied to users. At the other extreme are complex decision support systems which include stochastic simulation models which carry out simulations every month and advise users of the risk of entering a restriction zone in future so that informed decisions can be made. This could include advice on transfer of water from other sources, the use of groundwater, or using desalination plants during serious droughts. A range of example operating rules will be presented which covers the scope of this project.

H09S3.01

H09S3 - Considering hydrological change in reservoir planning and management

Oral

Etude de l'évolution de l'occupation du sol sur deux grands bassins d'Algérie et du Maroc, et relation avec les barrages

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En Afrique du nord, le comblement des retenues d'eau par les matériaux sédimentaires transportés est un problème majeur pour certains barrages situés dans les zones les plus sensibles. La relation avec l'évolution de l'occupation des sols et le changement climatique est mal connue. L'hypothèse est que les changements d'usage des sols et l'augmentation de la pression agricole, associés à une diminution durable des pluies, fragilisent les sols et les rendent plus sensibles à l'érosion.

Deux grands basins versants sont étudiés dans le cadre du programme SIGMED (approche spatialisée de l'impact des activités agricoles sur les transports solides, et les ressources en eau de grands bassins versants) : l'oued Bouregreg au Maroc et l'oued Mina en Algérie. Un des objectifs est de suivre l'évolution de l'occupation du sol, principalement par analyse diachronique d'images LANDSAT, pour identifier les zones sensibles à l'érosion, puis d'effectuer des corrélations avec les taux de sédimentation dans les grands barrages qui recueillent les écoulements de ces deux cours d'eau : Sidi Mohamed Ben Abdellah sur le Bouregreg, et Sidi Mohamed Ben Aouda sur la Mina. On observe un comblement des retenues étudiées au Maroc et en Algérie, mais la qualité des données est discutable, et il y a peu de données d'observations continues des apports solides par les rivières.

Il ressort cependant de ces premières études que l'érosion en provenance des versants immédiats des barrages, par érosion en ravines et en nappes, pourrait constituer une source d'alimentation majeure en sédiments dans les retenues, et par conséquent pourrait ê;tre le lieu privilégié d'opérations de protection et de restauration de la végétation, en prévention des risques de comblement.

H09S3.02

H09S3 - Considering hydrological change in reservoir planning and management

Oral

Using caesium-137 measurements to establish a sediment budget for the catchment of a small reservoir in southern Italy

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Predicting the expected life of a reservoir and assessing the potential for increasing this life is a great challenge for the hydraulic engineer, as it involves predicting sedimentation rates upstream of the dam. The rate of sedimentation in a reservoir will primarily reflect the amount of sediment eroded from the upstream catchment and the efficiency of sediment delivery to the reservoir. When fine particles dominate the soil texture of a catchment and the land use is conducive to erosion, a large proportion of the soil loss can commonly be ascribed to sheet erosion from the slopes. The fallout radionuclide caesium-137 (137Cs) has been increasingly used to document rates of soil loss from sheet erosion in recent years, both as an alternative to conventional measurements and for calibrating physically based soil erosion models. This paper reports an example of the application of the 137Cs technique in a medium-scale (14.8 km2) catchment upstream of a reservoir in southern Italy, aimed at assembling information on soil erosion and redistribution on the catchment slopes and floodplain sedimentation rates, in order to establish a catchment sediment budget. Data available from sediment (turbidity) monitoring undertaken at the catchment outlet prior to reservoir construction, have been used to estimate the catchment sediment yield. This estimate has been combined with the information provided by the 137Cs measurements, to establish a sediment budget for the catchment. The sediment budget provides a valuable tool for understanding sediment inputs to a reservoir and their sensitivity to climate change and for planning and implementing sediment control measures within the catchment, in order to reduce reservoir sedimentation rates.

H09S3.03

H09S3 - Considering hydrological change in reservoir planning and management

Oral

Effects of land use and climate changes on small reservoir siltation rates across the agricultural belt of the European Russia

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Small reservoirs in dry valleys, small streams and rivers of agriculture-dominated areas have experienced a severe increase in sediment input caused by accelerated soil erosion on cultivated slopes, as well as by gully erosion at some locations. This caused a rapid decrease of the reservoir water storage capacity and shortened periods of the reservoir functioning. Additional problems may arise when earthen dams are breached by overflows caused by spring snowmelt or rainstorm-induced floods exceeding the reduced reservoir capacity. In this paper we discuss several examples demonstrating the usefulness of the 137Cs fallout radionuclide to reconstruct the short-term chronology of small reservoir siltation in different landscape zones (from forest-steppe on the north to dry steppe on the south) within the agricultural belt of the European Russia. Two to four time marks could be detected along the 137Cs depth distribution curves constructed from depth-incremental sampling of reservoir infill sediment. This work allowed reconstruction of sediment microstratigraphy and deposition rates for the last 26 to 58 years (depending on presence of the Chernobyl-derived radioisotope input). Examined together with available documentary information on reservoir construction dates, initial storage capacity, land use changes and meteorological data, such microstratigraphic evidences allow us making some conclusions on the relative importance of recent land use changes and climatic variability in controlling sediment delivery within small agriculture-dominated fluvial systems. By combining this detailed investigation with soil and sediment redistribution studies conducted on cultivated slopes and in small valleys, it has become possible to construct closed sediment budgets for catchments of several reservoirs and make a quantitative assessment of sediment delivery variability. Such information is important for appropriate design and management of small agricultural reservoirs in Russia.

H09S3.04

H09S3 - Considering hydrological change in reservoir planning and management

Oral

Impact of the Ertan HEP reservoir on the sediment loads in the downstream Lower Jinshajiang River,China

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The Ertan HEP reservoir is located on the lower reaches of Yalong River, the biggest tributary of Jinsha River, and has a water storage capacity of 58 10^8 m^3 with a dam height of 240m. It has a drainage area of 11.64 10^4 km^2, which accounts for 24.0% of Jinsha River and average annual inflow water discharge and sediment load of 527 10^8 m^3 yr^{-1} and 2720 10^4 t yr^{-1} , which account for 36.9% and 11.1% of the values of Jinsha River at Pinsha, respectively.

Since impoundment of the reservoir in 1998, sediment loads in the lower Jinsha River below the conjunction of Yalong River has dramatically decreased. The mean annual sediment loads at the Huatan and Pinsha Stations during the period from 1999 to 2007 decreased by 27.9%(-0.60 10^8t yr^{-1}) and 31.9%(-0.91 10^8tyr^{-1}) to the loads during the period from 1988 to 1998 , respectively. The decreases of the annual sediment loads at the Huatan and Pinsha Stations have been greater than the annual inflow sediment load of 0.272 10^8 t yr^{-1} to the Ertan reservoir since 1999.

A mechanics of reduction of sediment transportation capacity by a reservoir is proposed in this paper to explain the sudden decreases of sediment yields at Huatan and Pinshan since 1999, which should be essentially caused by the Ertan Reservoir . Therefore, reduction of sediment yields by large reservoirs in the downstream river is attributed not only to capture of sediments, but also to reduction of sediment transportation capacity.

H09S3.05

H09S3 - Considering hydrological change in reservoir planning and management

Oral

Water use in Hydropower Reservoirs – State-of-the art

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Climate change and the needed reductions in the use of fossil fuels call for the development of renewable energy sources. Energy production is, however, recognised as potentially having an impact on the water resources and vice versa. This has lead to a growing interest of assessing the 'water footprint' of energy production. The recently published Special Report on Renewable Energy Sources and Climate Change Mitigation (IPCC 2012) compared renewable energy sources with respect to water consumption, revealing that the variation in water consumption per unit of electricity produced from hydropower projects was extremely large, ranging from close to 0 m3/MWh up to 209 m3/MWh, where the maximum value was far beyond the other renewable energy sources. The high value of hydropower is explained by the high evaporation rates from reservoirs located in subtropical and tropical regions.

The methodological approach of calculating the water footprint of hydropower projects has, however, been questioned as it calculates the gross evaporation from the reservoir, not taking into account the evaporation from the reservoir areas prior to the hydropower project, which could be a natural lake or vegetated areas. Secondly, in the case of multi-purpose reservoirs, the water consumption is not shared between the various water uses, but all assigned to the hydropower project. Thirdly, the fact that reservoirs could improve the availability of water both in the reservoir area and the downstream areas due to its regulating effect is not accounted for.

This paper will review the state of art regarding published studies and methodology for computation of water consumption in hydropower projects. In particular, we will discuss the methodology used for computing 'Water footprint' and suggest ways to improve the methodology by introducing concepts like 'Net water consumption', 'Water availability' and include the multipurpose aspects of reservoirs.

H09S3.06

H09S3 - Considering hydrological change in reservoir planning and management

Oral

Cumulative influence of small reservoirs on downstream flows in a semi-arid catchment

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Despite small reservoirs becoming increasingly widespread across many semi-arid regions, their cumulative influence in large catchments remains poorly understood. Part of the difficulty lies in distinguishing their effect over concurrent human and climatic processes which affect runoff. In the Merguellil catchment, in Central Tunisia, reservoirs and contour benches drain over 30% of the basin surface area, but no systematic reduction in downstream flows was identified over the period 1989-2010. Detailed analysis revealed that the annual variations in downstream flows are closely linked to the runoff generated by a very limited number of rainfall events over 15 mm (5 to 6 per year). Changes in the number of these events but also large variations in their runoff coefficient (K_R) have a determining influence on annual inflow into the El Haouareb dam. Analysis of 114 rainfall events over 15 mm identified the significant and concurrent influence of rainfall intensity and volume, land cover and antecedent soil humidity on an event's runoff coefficient. The temporary decrease in annual flows witnessed after the development of reservoirs is therefore mostly due to the reduced number of rainfall events and the unfavourable characteristics of each event. The analysis of runoff coefficients however reveals an additional 45% decrease in the K_R of rainfall events under 40 mm occurring on similar conditions of land cover and soil humidity after the increase in reservoirs in the 1990s.

H09S4.01

H09S4 - Considering hydrological change in reservoir planning and management

Oral

The effect of small impoundments on nutrient transport in a suburban watershed

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There are small impoundments with depth of less than 3m on river streams such like weir in the worldwide. In spite of large number of them, the effect of those on nutrients retention is little understood. The objective of this study is to confirm the effect of small impoundments on nutrient transportation. The study area is the upper portion of Yamato River watershed in western Japan which has a catchment area of 1070 km2. A lot of weirs are built on the main stream for irrigation to the rice paddy fields. The concentrations of NO3-, NO2-, NH4 , Cl- and current velocity were measured at each inlet and outlet of six impoundments. We also analyzed the monitoring records of those concentrations and river runoff by government. The trend of seasonal variation of NO3- concentration which was dominant species of nitrogen at the lower portion of the watershed indicated high concentration consists of domestic waste water in winter season. However, low concentration in summer season was obviously influenced by impoundments which located on the upper stream from the monitoring station.

We confirmed that there is significant difference of NO3- concentration between inflow and outflow water in summer season; NO3- concentration was decreased through the impoundments due to assimilation by phytoplankton as the majority. From this result, it is confirmed that the relationship between the magnitude of decrease of NO3- and residence time. Although the threshold of turning into nitrogen decrease in large reservoirs which have a depth of more than 10 m needs 8-14 days, small impoundments was estimated almost 2 days. This result suggests that small impoundment is close to the better condition for nitrogen removal due to its shallow depth and short residence time. Consequently, it is confirmed that the small impoundments affect to riverine nutrient transport. The results also indicate small impoundments may have higher efficiency of NO3- removal than large reservoirs.

H09S4.02

H09S4 - Considering hydrological change in reservoir planning and management

Oral

Evaluation of reservoir operation flexibility under variable hydrological conditions with user defined rules

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Hydrological conditions are the main drivers of reservoir management and directly affect the decisions due to its variable and uncertain structure. On the other hand, an effective reservoir management and its strategies should be based on the hydrological response and the current situation of the system. Yuvacık reservoir has a major task to meet the water demand of about 1.5 million populated city. The reservoir is fed by Yuvacık Basin, located between 40° 30′ – 40° 41′ northern latitudes and 29° 48′ – 30° 08′ eastern longitudes with its 258 km^2 drainage basin. Reservoir volume is 3 – 4 times less than the approximate annual inflow volume of 180 hm^3. Snowmelt runoff plays an important role during February – March due to basin altitude changes between 80 – 1548 m. Also, flood pool must be eventually operated as empty as possible to decrease flood risk during March – May period. Since it is desired to operate such a relatively small reservoir without any flood and drought risk, the main purpose is to achieve the reservoir elevation as high as possible before inflow recession period takes start that is generally observed on early May for long term water supply. To that end, HEC-ResSim is selected as the reservoir simulation model and integrated with daily runoff forecasts. The simulation model with user defined rules is developed through 2007 – 2011 in which a drought and a wet year included. Several methods are analyzed taking hydrological conditions (snow potential, inflow, season and current level) into consideration to construct operation rules with simulation model. In this study, aforementioned robust simulation model is enriched and analyzed for 1999 – 2012; therefore the reservoir operation flexibility is investigated. As a conclusion, the extended period results show that the simulation model is sensitive to the hydrological changes and applicable for real time operation.

H09S4.03

H09S4 - Considering hydrological change in reservoir planning and management

Oral

Assessment of possible changes in deficit volumes in an ensemble of RCM simulations for reservoir planning in the Czech Republic

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Climate change scenarios for the Czech Republic indicate an increase in frequency of deficit events and volume of deficit discharges (defined as the volume under given threshold). The Czech water management legislation considers a number of protected areas potentially suitable for construction of reservoirs for flood protection and/or improving the water balance in the drought periods. In present study we use hydrological modelling to quantify the volume of the deficit discharges as projected by an ensemble of transient regional climate model (RCM) simulations. The changes in the deficit volumes are assessed using a simple statistical model assuming exponential distribution of deficit volumes. Changes in characteristics of deficit volumes can than be described by changes in the probability of deficit and rate of the exponential distribution. Derived deficits are subsequently compared to the potential volume of the considered reservoirs. It is concluded that for many RCM simulations the deficits are significantly larger than the available volume of water in the reservoirs, therefore different adaptation measures should be considered also. The uncertainty is, however, large.

H09S4.04

H09S4 - Considering hydrological change in reservoir planning and management

Oral

Assessing the sensitivity of an Alpine reservoir to hydrological change and improving its operation by adaptive optimization

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There is a great concern about climate change as a threat to future water availability. In the last years, a huge research effort has been devoted to improve our understanding of climate dynamics and translate it into projections of future climate evolution. More recently, research has been extended to the impacts of climate scenarios on the hydrological cycle and water resources at the basin scale. Much of this research has converged on the conclusion that the «scenario-based» approach traditionally used in planning and management of water systems cannot cope with the non-stationary nature of hydro-climatic conditions and the deep uncertainty in their prediction.

In order to support water resources management in a global change context, new approaches are needed where flexibility and adaptation are the key. In this paper, we contribute to this purpose by developing systems analysis tools to:

(i) assess the sensitivity of water resource systems to hydrological changes;

(ii) increase the adaptation capacity of reservoir systems by adaptive optimization.

We use the multipurpose regulated lake Maggiore, at the border between Switzerland in Italy, as a case study. Application of trend detection techniques over the recorded lake inflows in the last 37 years shows that significant hydrological changes are already undergoing. On the one hand this confirms that the «stationary principle» underpinning most of our modelling and planning activities is far from being satisfied. On the other hand it means that historical time series can be exploited as a testing ground for the design of future adaptation strategies, for instance adaptive optimization of the lake operating policy. By simulation and optimization over this historical horizon, our study shows that hydrological changes may not automatically reflect into negative impacts on water uses/concerns because of non-linearity and threshold effects, and because of the adaptation capacity of the management system.

H09S4.05

H09S4 - Considering hydrological change in reservoir planning and management

Oral

Assessing the capacity of water resources to meet current and future water demands over the Ebro catchment (Spain)

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Worldwide studies have shown that the Mediterranean region is one of the most vulnerable areas to water crisis. It is characterised by limited and unequally distributed water resources and highly increasing water demands. The Ebro catchment (85 000 km^2, Spain) is very representative of this context. Since the late 1970s, a negative trend in river discharge has been observed. This can be attributed to a decrease in mean precipitation, a rise in mean temperature , and a water consumption increase. This catchment is indeed a key region for Spain's agricultural production and its population has increased by 20% over the last 30 years. Finally, over 230 storage dams, built for hydropower production and irrigation water supply, regulate river discharge in the basin. In order to assess whether future water demands could be satisfied under climatic and anthropogenic changes, an integrated water resources modelling framework was developed. This approach is driven by water supplies generated by a conceptual rainfall-runoff model and by a storage dam module accounting for water demands and environmental flow requirements. Water demands are evaluated for the most water-demanding sector, i.e. irrigated agriculture, and the domestic sector that is of prior importance for water supply. The capacity of water resources to meet demands is assessed through a water allocation index, which depends on site priorities and supply preferences. This modelling framework was applied to 9 sub-catchments to which 11 demand sites were associated, thus considering heterogeneous climatic and human pressures and the influence of the main dams on the hydrological regime of the basin. The results show growing competition among users, especially during the summer season. They also highlight the interest of integrated modelling with regard to providing complete analysis of water resources' capacity to meet water demands under complex evolution scenarios by 2050 in order to support decision-making.

H09S4.06

H09S4 - Considering hydrological change in reservoir planning and management

Oral

Assessing climate change impacts on operation and planning characteristics of Pong reservoir, Beas (India)

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In India, there is a considerable change in both spatial and temporal patterns of the monsoon rainfall, resulting in reduced crop yields and increasing uncertainty in the agriculture-based livelihoods of the rural population. Changes in rainfall, temperature and evapotranspiration are affecting water resources availability and demands and hence the performance of irrigation water supply facilities such as reservoirs and canal diversions. In order to accommodate these changes in the water resources situation, there must be substantial improvement in water use and management efficiency but this can only be meaningfully done if the impact of climate change and variability is quantified. Consequently, this work has investigated the effects of climate change and variability on irrigation water security in Beas river basin in India by characterising the yield and performance (reliability, resilience, vulnerability and sustainability) of the associated Pong reservoir for current (baseline) and climate-change perturbed future horizons. Climate change perturbations based on ensemble of GCMs for different IPCC SRES socio-economic scenarios and appropriately downscaled to regional/basin scale were used. The whole analysis was conducted within a Monte Carlo simulation framework, thus enabling the variability and uncertainty associated with each of these variables to also be quantified. Information derived from the climate change impacts and variability assessment was then used to develop more effective operational rules for water allocation from the Pong reservoir that incorporate precise hedging targets for more effective use of available water resources and that serve as trigger for the introduction of alternative sources of water in high irrigation water demand season.

HP1PS.01

HP1PS - Deltas: landforms, ecosystems and human activities

Poster

Environmental risk and water-resource management near the Port Harcourt Refinery, Niger Delta

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Water-resource management requires 3D-evaluation if it is to be robust and environmentally sustainable. The 3D perspective may be limited by the accessible information, its qualitative character and 2D-capacity of GIS software. Using an area with extensive pollution threats near the Port Harcourt Refinery, we illustrate several problems and possibilities for addressing complex environmental and resource problems despite these methodological issues. In addition to the pollution stress of urban wastes refinery area has been exposed to effluent oil and hydrocarbon products. In particular, the drainage channel leading south through the mangrove swamps where there are scattered settlements that have been impacted.

The main methodological steps are: 1) Classification of "Functional Facies" to integrate geological, geochemical and biological conditions and processes at the surface with the 3D structure of sub-surface architecture. 2) Mapping FF units. Different ground and sub-surface conditions and pollution histories are documented using several scales of detail (identifying land features of 1000, 100 and 10 m size). The focus of characterization shifts from regional mapping of environmental subdivisions to local processes and parameter trends that govern resource vulnerability. Resource identification is initially a regional questions, but local detail is necessary for practical management, especially protection and remediation actions. 3) Calculation of water, sediment and selected contaminant budgets within each FF type area, using parameter relationships from both quantitative data and qualitative information. 4) Risk and resource Ranking, where identified sources for stressors (pollutants or environmental change) and the receptors and habitats are ranked and evaluated with the multi-criteria approach of Analytical Hierarchy Process to give relative measures of the vulnerability or value of the end-point sensors.

HP1PS.02

HP1PS - Deltas: landforms, ecosystems and human activities

Poster

Explaining the physical relation of estuaries shape and bankfull flood discharge - ONLY FOR POSTER PRESENTATION

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Estimating flood discharge in the tidal region of estuaries is always difficult as most of the available gauging stations are installed much further upstream outside the tidal region. Inside the tidal region, it is hard to observe the river discharge accurately. In the morphology and hydrodynamic studies of estuaries, it is known that river discharge is one of the important parameters. Unfortunately, research on morphology and hydrodynamics in estuaries is done separately. Until today, little research has been done to identify the relationship between these two processes in alluvial estuaries, and to understand why certain relations in nature exist. This study aims to discover the physical explanation for the relation between the geometrical characteristics of estuaries and flood discharge. The relationship between the ideal estuary depth and fresh water discharge was analyzed in 13 estuaries around the world using a stepwise regression and the outcome was compared to Lacey's theory of hydraulic geometry. From the analysis, it shows that the ideal depth of the estuaries is a function to the bankfull flood discharge to the power of 1/3 to 1/2 which indicates an agreement with Lacey's formula. In order to verify the accuracy of the relation, more data on the morphology and hydrodynamics are required. Thus, existing and new measurement data from estuaries worldwide will be collected and compiled to strengthen the reliability of the finding.

HP1PS.03

HP1PS - Deltas: landforms, ecosystems and human activities

Poster

The Mekong River Delta – variation of sedimentation and morphology in a mega-delta - ONLY FOR POSTER PRESENTATION

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The Mekong River Delta belongs to the global mega-deltas. Its tidal regime that changes from semi-diurnal tides over mixed tides to diurnal tides along a more than 500 km long coastline is unique. Investigations on the delta plain show the transition from tide-dominated to tide and wave dominated regime around 3500 years BP. The monsoon seasons dominate flow regime and sediment transport along the river, in the delta plain and also in the subaqueous delta. Both coastal erosion and accretional progradation occur along the deltaic coast. However, only sparse data exist on delta dynamics and its footprints in the subaqueous delta.

Two cruises in 2007 and 2008 using local fishing boats were carried out in the subaqueous delta region between the Bassac River, the main distributary of the Mekong River Delta, and the Gulf of Thailand. Seismic surveys, grab and sediment core sampling allow the reconstruction of the subaqueous delta shape and sediment distribution. Additionally, point and transect ADCP-measurements provide data of current directions and velocities during the inter-monsoon season. Together with data on suspended matter (LISST-measurements) sediment transport could be specified.

With our results the delta can be subdivided in erosional and still prograding delta slope regions with submarine landslides triggered by high sediment accumulation rates. Sediment cores show time variations in sediment deposition and sediment distribution pattern. In particular a shore parallel mega-furrow system consisting of two main channels with erosional character in its central regions was found. It is cut until 13 m deep into the subaqueous delta platform and connects the prograding southeastern and western part. The two 4 km wide furrows extend over more than 120 km from east to west. Results show the complexity of sedimentation, erosion and sediment transport in this specific Mega-Delta. Although the Mekong River Delta grows fast southwestwards it erodes in other regions.

HP1PS.04

HP1PS - Deltas: landforms, ecosystems and human activities

Poster

Estuarial-deltaic system of the Amur River

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The Amur River mouth refers to estuary-delta type. One of the main features of this estuary is the absence of the above-water delta. In current conditions the Amur River forms intensively underwater delta - sleeves and fairways of the Amur liman. About 50% of the total volume of freshwater runoff of Far East rivers is carried Across the mouth of the Amur River into the sea. The proceed discusses the following issues: A quantitative and qualitative assessment of changes in the water runoff in natural conditions and changes caused by human impact. To determine the role of economic activity on the other characteristics of the hydrological regime there were calculated dependences of these characteristics according to the water flow. The critical velocity of the stream, in which all sediments a certain grain size stop moving, is calculated. Curves of the interface of surface level of the river and the sea in the quasi-steady flow of water and in periods of tides are calculated. A graphical relationship between the flow of water in the top of the estuarial area, and a fixed drop of water between the posts at the mouth of the river (Nikolaevsk-on-Amur) and in the near-shore zone (Cape Pronge), allows to calculate the water flow in the tidal estuary of the Amur River without measurement of tidal flow rates.

HP1PS.05

HP1PS - Deltas: landforms, ecosystems and human activities

Poster

Hydrological changes in the Inner Niger Delta in Mali: How people perceive their environment changes?

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The hydrological functioning of the Inner Niger Delta, a large wetland located in Mali, depends upon the capricious West African moonson but also the increasing human demand on the Niger and Bani rivers upstream. Amplitude and the rhythm of the annual of floods have a direct impact of the delta's traditional activities such as fishing, farming, herding and tourism. As delta people are particularly concerned regarding their future, scientists explore some prediction tools regarding climate and flood. In this paper the authors analyze a flood forecasting tools of the delta and investigate the water users' expectations. A questionnaire was administered to a sample of 198 users of the water located in 3 districts of the delta. The results show a wide range of expectations. A significant number of users feel some discomfort with predicting natural phenomena. Breeders have a particular interest in this prediction, but it must be coupled with other forecasts. Fishermen need to know in advance the time of the flood recession, while rice farmers need to know the date of the start of the recession but also the start of the rainy season. Most users are willing to pay to get this information and believe that a reliable flood and climate forecasting will increase investment and income but are concerned about forecasting errors.

HP1PS.06

HP1PS - Deltas: landforms, ecosystems and human activities

Poster

Analysis of surface water quality upstream Niger Delta system

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Delta region result from the varied interaction of fluvial (river) and marine systems and are usually characterized by complex and fragile natural endowed environment. This environment is very attractive to man existence and his socio-economic sustenance.

The Niger delta is an end-product of Lower Niger River catchment processes and is rich in luxuriant diverse mosaic of ecological system with wide-ranging culture and heritage system with a population growth rate of about 2.7% per annum. It is necessary therefore to assess the quality of upstream surface water quality input to the Niger delta, upon which the growing population highly depends on. This is imperative considering the marked decrease in flow with an ever-increasing demand for water, set against a background of degradation of the water resources both in terms of quantity and quality as well as unsustainable water resource use and development, in the face of increasing water demand per capita and water abstraction activities with varied water challenges among riparian states.

This study focuses on analysis of available renewable water resources quality of selected sampled locations for major ions and trace elements concentration in the Lower River Niger basin and part of Lagos region. For standardization and comparison, WHO maximum allowable concentrations in drinking water and mean annual European Quality standards (EQS) for priority metals and dissolved trace element concentrations in the Seine, Rhone, Thames and Lena Rivers are also provided for comparison. Trace element analysis reveals a moderate contamination upstream Niger and Benue Basins confluence while arsenic concentrations are lower than the drinking water quality standards. Hence, a sustainable water usage and development plan within the Niger Delta region beyond 21st century was suggested.

HP1PS.07

HP1PS - Deltas: landforms, ecosystems and human activities

Poster

Analysis of Krishna and Godavari river outflows to evaluate effects on river mouth changes

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Water resources projects are meant to store water or divert water mainly for irrigating crops and supplying water for drinking and industrial needs. The role of human activity has become a significant modifier of hydrologic budget in a river basin. Interferences made in one part of the basin are felt at distant places, unexpectedly. It is a fact that river water is not only essential for mankind but also for all living organisms that depend on it. Also, the proper maintenance of sediment budget along the river reach checks the erosion of riverbanks and delta formation at river mouth. The timing, quantity and quality of river water have direct impact on the fragile ecosystem of the river basin, especially along wetlands of the river corridor. Changes in flow regime impact the survival of the habitat and may damage the connectivity of riverine ecosystem. In this paper, variation in surplus river flows passing the most down stream gauge sites on the river Krishna (258, 948 km^2), a water starved basin and the river Godavari (312, 813 km^2), with not much upstream developments, are analyzed. Both the rivers drain most of the south Indian peninsula and form typical river delta formations with mangroves and rich biodiversity at their river mouths. With a normal precipitation of about 1000 mm only 6 mm is surplus to sea in the Krishna whereas in the Godavari about 265 mm is the surplus to Bay of Bengal during latest water year. Thus, River Krishna is almost dried up, as little river water flows out to sea, even when compared to the adjoining Vamsadhara River, with medium size catchment area of 10, 000 km^2, which drained about 140 mm in the same water year. The present paper analyses the surplus river flows in the two largest rivers to evaluate the scale of reduction in river discharges to sea, over the years, due to upstream developments, in order to understand the resultant consequences on the rate of delta progression and other consequential changes at the river mouths.

HP1PS.08

HP1PS - Deltas: landforms, ecosystems and human activities

Poster

Indian Sunderbans Delta and Sea level rise: Its consequences on the marginalized people - ONLY FOR POSTER PRESENTATION

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Sunderbans mangrove delta, the world's largest delta situated at the mouth of Bay of Bengal between India and Bangladesh, is a geographically challenged region of the world, where loss of lands and habitats are the two major issues due to sea level rise. This has displaced more than 50,000 thousand people in recent years. Formation of new islands is constantly going on, what land waters shallow from one end, they spit out as sandbanks and new islands at another. This has created a wide range of ecological and socio-economic problems leading to crisis in the livelihoods of the marginalized people.

Objectives: This paper analyses the contemporary risks of sea level rise in Sunderbans, and its future consequences. It talks about the problem of mangrove depletion and the plight of the people where there is absolute failure of decentralized planning. It critically studies the plans and policies of government, how effective they are for implementing climate adaptive strategies for this particular region. How this densely populated region of 4.1 million in Sunderban alone, can battle this increasing loss of land due to sea level rise? What are the alternatives that fishermen and farmers can look for to offset their declining economy?

It is expected that after 2015, the rate of sea level rise will accelerate resulting into higher rate of land erosion. Vanishing of two big islands has displaced thousand of climate refugees and their inward migration is responsible for mangrove deforestation. Intrusion of saline water into the agricultural land results in loss of yield and creates risk to the farmers- loss of agricultural land and making them migrate in search of new lands. Sunderban reveals the extreme consequences of climate change and is one of the most productive bio-diverse wetlands on earth and may disappear quickly than other tropical forests.

HP1S1.01

HP1S1 - Deltas: landforms, ecosystems and human activities

Oral

Changing fluvial sediment inputs to the world's deltas

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The world's deltas currently face many important threats to their longer term stability and existence. Subsidence and sea level rise are key problems for many deltas and their potential impact is strongly influenced by changes in sediment supply. Fluvial sediment inputs exert a key control on delta evolution and stability, as well as providing an important source of nutrients to delta ecosystems. The sediment loads of the world's rivers are highly sensitive to both human impact and climate change, and the sediment loads of many rivers have changed markedly in recent decades. Some rivers have demonstrated increasing sediment loads, as a result of land clearance and intensification of land use, but in most cases sediment loads are declining. Dam building and associated sediment trapping are the primary causes of reduced sediment loads, but the implementation of large scale soil conservation and sediment control programmes and the expansion of sand mining are also important. Rivers vary in the sensitivity of their sediment loads to changes in sediment mobilisation and storage in their upstream catchments, and some appear to possess considerable capacity to buffer changes in sediment delivery to their downstream reaches. Changes in the magnitude of sediment loads can also be coupled with changes in grain size composition and chemistry, which may have important implications for the receiving delta. Although attention frequently focuses on contemporary changes in sediment flux, it is important to recognise that the sediment loads of many rivers are likely to have varied significantly over the longer-term, in response to the history of human impact on their upstream catchments. Current changes in sediment load and sediment inputs to deltas must therefore be viewed in the context of longer-term trends. Climate change is increasingly seen as likely to cause further changes in fluvial sediment loads and thus sediment inputs to delta systems in the future.

HP1S1.02

HP1S1 - Deltas: landforms, ecosystems and human activities

Oral

Salinity and tides in alluvial deltas. Can we predict tidal processes and salinity intrusion in poorly gauged deltas?

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Alluvial deltas and estuaries are complex systems. They form the interface between the terrestrial drainage system and the sea. Deltas have multiple functions: morphologic, hydraulic, hydrologic, ecologic and socio-economic. They are also the areas where different sources of energy converge: tidal energy, wind energy, potential energy from fresh water and sediments, and solar energy to feed the biotic system. The dissipation of all this energy has created a unique environment, with very special tidal and morphological characteristics.

One would expect that such a complex system is difficult to describe in simple mathematical terms, but the opposite is true. If considered at the right scale, deltas and estuaries appear to obey surprisingly simple 'laws'. For instance, the shape of an alluvial estuary obeys a very simple exponential law. The amplitude of the tidal velocity is 1 m/s at spring tide throughout the tidal region. And more surprisingly, this amplitude is the same throughout the world. If left undisturbed, estuaries tend to become 'ideal' estuaries, where the tidal wave is undamped propagating as a simple shallow water wave. And as a result, there is also simplicity in the process of salt intrusion and the mixing of substances in estuaries.

There are two important research questions related to this surprising simplicity. The first one is of course the understanding of the more fundamental physical laws behind this surprising simplicity and uniformity; the second one is how to predict the behavior of estuaries in poorly gauged regions, because this simplicity may help us to predict how estuaries behave when we have very limited knowledge on the ground. In this presentation, examples are given of a wide variety of real estuaries where predictive equations appear to work remarkably well.

HP1S1.03

HP1S1 - Deltas: landforms, ecosystems and human activities

Oral

Backwater hydrodynamics and sediment transport in the lowermost Mississippi River Delta: Implications for the development of fluvial-deltaic landform in a large lowland river

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Where rivers enter the coastal zone, gradually varying non-uniform flow conditions develop in the channel. The section of the river is referred to as the backwater segment, and for large rivers, backwater flow extends many hundreds of kilometers upstream of the river outlet. Studies from the Mississippi River document a persistent backwater zone that influences sediment mobility throughout the lowermost five-hundred kilometers of the river. Reach-average shear stress varies temporally in accordance with the annual hydrograph, affecting the timing, magnitude, and grain size of transported sediment. A net reduction in shear stress restricts the downstream movement of coarse sediment, and this portion of the river's sediment load does not reach the coastline. Instead, coarse sediment is caught at the backwater transition and is sequestered in the river channel. Information about the timing and magnitude of sediment flux in the backwater segments of large rivers is critical to addressing the landscape dynamics of deltas. Research from the Mississippi River delta, where roughly 5000 km2 of land has converted to open water in the past century, is presented as a case study. The collapse of the Mississippi River delta is driven by rapid land subsidence associated with the extraction of subsurface fluids, eustatic sea-level rise, and the construction of levees, which prevent the movement of sediment to the neighboring floodplain. Recent studies have demonstrated that current sediment loads in the Mississippi River are sufficient to offset much of the future land loss, if measures are undertaken to extract sediment for delta building. Local conditions favor the development of channel bars and such locations are optimal for river diversions that deliver sediment from to the surrounding delta. Studies from the Mississippi River delta can be extended to other large river-delta systems around the world to assess appropriate measures for sustaining delta landscapes.

HP1S1.04

HP1S1 - Deltas: landforms, ecosystems and human activities

Oral

The effect of river discharge on tidal dynamics in alluvial estuaries

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The natural variability of river flow into estuaries is greatly modified by human activities, such as dam construction, flow diversion and drainage. These activities impact on tidal damping and tidal wave propagation. In addition, they influence salt intrusion and even storm surge propagation into the estuary. In the engineering community, many impact studies have been done throughout the world that make use of numerical models. However, for an enhanced understanding of human impacts on estuarine processes, numerical models are not much more than black boxes. Hence, the aim of this study is to derive analytical solutions to provide an analytical instrument for assessing the effect of river discharge on tidal dynamics.

A new analytical framework for tidal hydrodynamics has been developed, which takes into account the effect of river discharge. For given topography, friction, tidal amplitude at the seaward boundary, river discharge at the landward boundary, we are able to reproduce the main tidal dynamics (e.g., velocity amplitude, wave celerity, tidal amplitude, and phase lag) along the estuary axis by solving a set of four implicit equations (i.e., phase lag, scaling, damping and celerity equations). In this approach the damping equation is obtained by subtracting the envelope curves of high water and low water, where the velocity of flow is a combination of tidal velocity and river velocity. The analytical solutions both with and without the effect of the river discharge are compared with observations of a wide range of estuaries worldwide, such as the Scheldt estuary in the Netherlands, Thames in the UK, Delaware in the US, Elbe in Germany, the Modaomen and Yangtze in China, the Hau and Tien in the Vietnam etc., showing that the proposed hybrid model fits the observations with realistic roughness values in the upstream part where the influence of river discharge is measurable.

HP1S2.01

HP1S2 - Deltas: landforms, ecosystems and human activities

Oral

Late pleistocene - holocene deltas in the southern Buenos Aires province, Argentina

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On the Argentina coast there are only 2 deltas, Paran á and Colorado deltas. However, the Colorado Delta is only a minor expression of a much larger delta system that was active from approximately 11,000 calibrated years BP, when mean sea level (msl) was about -30 m. Based on bathymetric and topographic maps, regional geology and bibliography, the evolution of the delta system is proposed. During the Last Glacial Maximum (LGM), 24,000 calibrated years BP, msl was -130 m, at the present shelf break. During this period fluvial drainage was minimum as there are little evidences of river valleys across the continental shelf. Four well defined terraces present in today's shelf suggest that the msl increased in pulses as climate conditions changed and msl rose The uppermost terrace, located at -25/-30 m is estimated to correspond to deltaic front of the Colorado and Negro rivers. At this time, the fluvial discharge was large and a series of rivers, most of them no longer exist today, were providing sediments to the deltas. The Colorado River and a set of unnamed rivers were active to the northern and central portion of this 430 km delta front, whereas the Negro River provided materials to the lower central and southern portions. We estimate that the major sediment and water inputs occurred at about 9,000 calibrated years BP, when msl was -18 m. Delta evolution was significantly modified when msl was up to 7 m above present 6,000 calibrated years BP. At this time, both the Colorado and Negro rivers migrated southward. Msl decreased at about 4 mm/yr until it reached the lowest level, about -2 m during the Little Ice Age. Today, the only active delta is the one maintained by a diminished Colorado River in the central part of the area. The northern and southern portions are now extensive intertidal areas with remnant islands and large tidal channels corresponding, respectively, to Bahía Blanca and Anegada Bay. The Negro River has an estuary at its mouth but no active delta

HP1S2.02

HP1S2 - Deltas: landforms, ecosystems and human activities

Oral

Water Balance and nutrient delivery in a densely populated delta for a future sustainable environment

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Water budget, nitrogen, phosphorous and silica are the four variables most likely to control the productive function of aquatic ecosystems, mainly in delta ecosystems. Besides the nutrient flux transported by river systems depends on a number of factors, including the hydrology, the inputs of material from land-based sources and the in-stream processes leading to transformation, retention and elimination of nutrients during their downstream travel through the river continuum. For a region in densely populated areas such as the Red River Delta where river water quality has been dramatically deteriorated due to rapid population growth, industrialization and economic development in the recent 10 years, we applied a model for assessing the significance of the complex and inter-related processes and understanding how river water quality and ecological functioning reflect the land-use and human activities in the watershed. A large fraction of the total population of the Red River basin is settled in the delta area, especially on the right bank where the Hanoi city and conurbation is located. Therefore, we have chosen to implement the model on the right bank of the hydrological system of the delta, the Day-Nhue river system, and to connect it to the upper Red River model, in order to further understand the biogeochemical functioning of the delta system. Additionally, the aim was also to develop some scenarios based on expected demographic and land use changes in order to evaluate the resulting changes in water quality and nutrient loading delivered to the coastal zone at the horizon 2050. We also explored how the water flux of the upstream Red River could be better managed for possibly reducing the pollution of the Day River system by dilution.

HP1S2.03

HP1S2 - Deltas: landforms, ecosystems and human activities

Oral

Influence of ecosystem on hydrochemistry and stable isotope of surface and ground waters in the Yellow River Delta

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To determine the influence of ecosystem on surface and ground waters in the Yellow River Delta, 22 surface and ground waters were sampled from cotton land, forest, wetland and marine in the coastal zone adjacent to the Bohai Sea. Major ion (Na, K, Mg, Ca, NO_3, SO_4, Br, Cl and HCO_3) and stable isotope analysis ($^{2}H/^{18}O$) were analyzed. The hydrochemical compositions are most complicated in the cotton land and wetland groundwater, indicating the mixing process with water transferred from the Yellow River whereas the ones in the coast are dominated by Na-Cl. The ratios of $^{2}H/^{18}O$ in the cotton land and wetland groundwater are plotted on or close to the local meteoric water line (LMWL), and ones from coast are enriched in both ^{2}H and ^{18}O (~ the seawater). The NO_3 positively corresponds with Cl in the cotton land and wetland, with 40% of groundwater samples exceeding the allowable nitrate drinking water level (10mg/L as nitrogen). It is inferred that irrigation water from the Yellow River and anthropogenic pollution are two nitrogen sources of nitrate.

HP1S2.04

HP1S2 - Deltas: landforms, ecosystems and human activities

Oral

Mississippi-Atchafalaya River Delta and Yellow River Delta: What can we learn from recent development of the two deltas?

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Globally, many river deltas have been altered through anthropogenic disturbances both to the deltas as well as their drainage basins in the past century. Alterations such as dam construction, channel modification, and land cover changes in the drainage basins have led to changes in riverine sediment transport, deposition, distribution, and deltaic subsidence. Two of the most highly engineered rivers in the world are the Mississippi/Atchafalaya River system in the United States and the Yellow River (Huanghe) in China. Both have experienced tremendous hydrologic and land use alterations in the past. The anthropogenic changes have caused the Mississippi River Delta Plain to undergo land loss endangering coastal communities and impacting major economies. Even with land loss the main distributary of the Mississippi, the Atchafalaya River, has developed a prograding delta feature at the man-made Wax Lake Outlet and main stem south of Morgan City, LA. The Yellow River also has had many alterations with dams completed over the past 50 years, and agriculture expansion within the drainage basin. This has led to interrupted river discharge causing intermittent land loss, but extensive poor land practices have created a large sediment load supporting a prograding delta. An understanding of how the two deltas respond to land and river alterations is integral to continued sustainability of environmental, commercial, and industrial capabilities. This study compares over 20 years (1989-2010) of delta development (growth/erosion) at approximately 5 year intervals in these two largely modified river systems using remotely sensed images, river discharge, and suspended sediment yield data to better understand the long-term effect of river alterations on deltaic development.

HP1S2.05

HP1S2 - Deltas: landforms, ecosystems and human activities

Oral

Geomorphology and sedimentology of the Mogo Creek fluvial delta, NSW, Australia

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Mogo Creek is an active, ephemeral sand-bed stream that drains a 210 km2 basin and flows into a blocked valley lake that functions as a terminal sediment sink. The blocked valley lake, in turn, discharges in the main stream, Macdonald River. A Gilbert-type fluvial delta has formed where Mogo Creek flows into the lake and a reverse delta has formed where the Macdonald River back floods into the blocked valley lake. This indicates that the density of the inflowing waters closely matches the lake water (homopycnal inflows). We have documented the development of the fluvial delta since 1848 from a combination of maps, vertical air photographs and field surveys. The Mogo Creek fluvial delta prograded into the lake as a series of lobate sand bodies that episodically changed direction over time. Over a 13.5 years period 71700 m3 of sand (94600 t) was deposited on the delta plain and in the river channel and 1042 m3 (1150 t) was deposited on the delta front. Sediment bulk densities were determined so that the total delta depositional mass was computed as 95790 t or 7095 t/yr. Progradation of the delta front has segmented the lake by blocking a former side bay. Topset beds include sand splays, marsh deposits chutes and chute bars, levees and channel deposits of tabular bars, dunes, ripples and plane beds. Foreset beds are delta front sets of planar tabular medium sands. Bottomset beds are horizontally laminated prodelta muddy sands and sandy muds grading into massive, low density, benthic muds. The emergent macrophyte, Eleocharis sphacelata, dominates the shoreline of the lake. From our survey of the lake volume, present rates of delta progradation will totally infill the blocked valley lake in 48 years. Overbank sediments progressively raise the floodplain upstream of the delta plain over time resulting in a localised but pronounced downstream decrease in channel capacity.

HP1S2.06

HP1S2 - Deltas: landforms, ecosystems and human activities

Oral

Hydrological process and its ecological effects of a re-established freshwater wetland in the Yellow River Delta, China

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A national program for the restoration of freshwater wetlands in the Yellow River Delta National Natural Reserve was initiated in 2000. A new re-established freshwater wetland was constructed in the reserve and was first rewetted in 2009 during water regulation in the upper reaches of the Yellow River. This paper is to assess the effects of the re-established wetland on local hydrological process and the corresponding ecological response.

Basic observation has shown that after water was diverted into the artificial wetland, the water body covers 1200 ha with an average water depth of 1.5m. Regional groundwater level fluctuates with both net precipitation and the rewet process. The rewet process has a noticeable impact on reducing salinity of groundwater. Aqua and herbaceous plants quickly response during growing season, switching from seepweed dominated to ditch reed dominated.

A groundwater flow model was then built by Visual Modflow and a corresponding groundwater salinity prediction model was constructed by multi-variable regression method (from 23-06-2010 to 31-08-2010). Numerical simulation results show that local groundwater balance is mainly consisted of precipitation (77% of total recharge), wetland (19%) and evapotranspiration (92% of total discharge). Total infiltration to groundwater from the wetland during the simulation period is $16.67 \times 10^6 m^3$. Salinity of groundwater also decreases by 11% due to infiltration of freshwater from the wetland. The model simulation is in good agreement with the sample plots. Due to the fine sediment of this region, hydraulic conductivity of the aquifer is as low as 0.03m/d, therefore groundwater infiltration is restricted to local scale and radius of the capture zone of groundwater adjacent to the wetland is from 1000m to 1500m. Some management measures to increase infiltration and to enlarge capture zone of the wetland are proposed in the last section.

HP1S3.02

HP1S3 - Deltas: landforms, ecosystems and human activities

Oral

Flood-tidal and fluvial deltas of Tuggerah Lakes, Australia: Human impacts on geomorphology, sedimentology, hydrodynamics and seagrasses

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Tuggerah Lakes are a series of three interconnected shallow estuarine lagoons impounded by a coastal sand barrier on the seaward or eastern side. They are a barrier estuary or a wave-dominated estuary. Sea level reached its present level or slightly higher about 7000 yBP in eastern Australia and throughout most of the early, mid- and late Holocene Tuggerah lakes had two entrances to the Pacific Ocean, one in Tuggerah Lake at The Entrance and another in Budgewoi Lake near Budgewoi. During the late Holocene, the entrance near Budgewoi became completely blocked (fossil flood-tidal delta) and the remaining channel at The Entrance became ensconced on bedrock to such an extent that dredging is now required to maintain it open. The Entrance flood-tidal delta is currenty inactive, except for dredging. The current tidal range is about 0.03 m during non-flood conditions and mixing is dependent on wind and floods. Two flood-tide deltas of marine quartzose sand and muddy sand formed at the former and current entrances. They exhibit sand flats, islands, channels, seagrass meadows and a well-defined, landward-facing delta front and prodelta. Where rivers debouche into the estuary, fluvial deltas have formed. Two large fluvial deltas (Ourimbah Creek and Wyong River), one medium-sized delta (Wallarah Creek) and two very small deltas (Tumbi Umbi and Satwater creeks) are present. The small deltas experienced rapid sedimentation during catchment urbanisation since the 1960s. Well-developed river-mouth bars, seaward-facing delta fronts and prodetas have been dissected by deep dredge channels which have altered the natural sedimentation pattern and distribution of seagrasses. Seagrass distributions are spatio-temporally very dynamic making it difficult to identify clear human impacts. However, high nutrient inflows during urbanisation caused eutrophication before nutrient abatement programs were successfully introduced over the last two decades.

HP1S3.03

HP1S3 - Deltas: landforms, ecosystems and human activities

Oral

Interdisciplinary research on new approaches for future managing the River Elbe Estuary

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The tidal River Elbe in Northern Germany is a varied landscape of nature and culture as well as an international waterway for economic use. In the last centuries, ongoing river training measures like proceeding embankment, adaption of navigation channel, or technical bank protection, lead to a heavily modified water body, as classified by the European Water Framework Directive (WFD). For example more than 60 percent of the river banks are technically trained, resulting in e.g. poor hydro-morphological conditions and poor distinctive estuarine vegetation.

Climate change and its expected hydro-morphological impact pose a challenge for water management, safeguarding navigation as well as protecting natural concerns, additionally considering demands of implementing targets of the WFD. This is why actors in the river sphere like the German Waterways- and Shipping Administration (WSV) are exposed to new challenges in river maintenance.

Scientific advice in this context is delivered by the German Federal Institute of Hydrology (BfG) which, amongst others, focuses the tidal part of the river Elbe in its research. The expected change on hydrodynamics, sediment transport and budgets, habitat quality, or foreland management are topics of this research. A special example of interdisciplinary analyses focuses on natural processes and stability of river banks and wants to figure out the dynamic interaction between soils, sediment transport and budgets as well as estuarine vegetation.

This article compiles ongoing Elbe research, that means i) the reaction of tidal reeds and invasive plant species on climate change induced shift in tidal ranges by means of field work and habitat modelling. ii) The resilience of bank soils and sediments against hydro-mechanical stress like wave attack, and moreover iii) the analyses of socio-economic aspects in the context of bank restoration by applying the approach of ecosystems services. Consequences for river management will be highlighted.

HP1S3.04

HP1S3 - Deltas: landforms, ecosystems and human activities

Oral

A story of water, salt and sediments: constraints and limits for adaptive management in the Rhone river delta

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The «Ile de Camargue», central part of the Rhône delta delimited by the two embanked branches of the Rhône river, is a complex hydrosystem. It includes agricultural drainage basin with low elevation gradient, marshes, and the brackish shallow Vaccarès lagoon system, core of a Man and Biosphere reserve, whose connection with the sea is managed. This hydrosystem is particularly affected by water management, whose major historical impact was the endykement from the river and the sea by the end of 19th century. Decrease of sediment river input to the coast and sea level rise contribute to a global erosion of the shoreline. Within the endyked hydrosystem, during rice cultivation period, large amounts of water are pumped from the river for irrigation, generating important water and sediment fluxes. Hydrosystem modelling and multi source data are used to derive suspended sediment balance and salt stock dynamics. Current water management and climate forcing will make impossible to manage efficiently both water levels and salinity in the delta. A more natural deltaic hydraulic functioning, which implies increased hydraulic connectivity with river and sea appears to be the only sustainable way in the long term. To promote adaptation in a such physically and socially complex system, on going trans-disciplinary research is an important issue

HP1S3.05

HP1S3 - Deltas: landforms, ecosystems and human activities

Oral

Geomorphic mapping and human activities along the Nigeria south - western coastline

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This paper identified various coastal landforms and anthropogenic activities in relation to ecosystem degradation and stability in south-western Nigeria coastline. The total length of the coast is about 325km stretch. It uses topographical base maps, Landsat TM imagery, field survey, and ancillary data's to assess and map the various geomorphic units and ecosystem degradation along the study area. Identification of various coastal landforms was done using image interpretation elements especially the tonal and shape differentiation. The results show that recent morphological dynamics catalyst by sea level rise had led to the decrease of coastal landforms units. Sand mining, urbanization, wetland reclamation, and industrialization were identified to causing perturbation of ecosystem with an estimated average of 0.3675 X 106 ha loss of floral per annum especially on the fragile Lekki peninsular. The geomorphic units identified within the barrier lagoon complex include 19 islands, 21 lagoons, peninsulas, sand bars, coastal planes and beaches. These morphological forms were found to have high ecosystem services including tourism and developmental values that is unprecedented in any part of West Africa sub region. Within the mud coast, the morphological units identified include; creeks, lake, and rivers. The mud coastline was also found to be undergoing serious coastal erosion and degradation due to oil exploration. The rate of coastal erosion has been estimated at about 25m per annum with some settlements and their livelihoods under threat. For sustainable developments of the fragile morphological systems of the South Western Nigeria coastline, anthropogenic activities resulting in biodiversity loss and landform alterations should be controlled while Oil exploration activities around the mud cost should adopt best practices.

HP1S4.01

HP1S4 - Deltas: landforms, ecosystems and human activities

Oral

Changes in hydrological regime and morphology of river deltas in the Russian Arctic

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The largest deltas on the Russian Arctic coast are located at the mouths of the Sev.Dvina, Pechora, Ob, Pur, Taz, Yenisei, Lena, Yana, Indigirka and Kolyma rivers. These deltas differ in size, morphology, environment and regime. But all these deltas are characterized by cool climate, permafrost, good supply of water resources, dense hydrographic network, low turbidity of river water, long period of freeze-up, poor land development, vulnerability of ecosystems.

At present, the Arctic deltas develop in conditions of: increase in river runoff; rise of air and water temperature; sea level rise; different vertical movements of the sea coast; man-induced deterioration of the river water quality. The hydrological regime of Yenisei and Kolyma deltas is subjected to water flow regulation by large reservoirs. In these circumstances, the main features of the regime of the deltas consist in slow redistribution of water runoff between delta branches, regular inundation of the delta plain, severe ice conditions. Morphological processes are characterized by the low intensity of the channel deformations and delta coast progradation, prevalence of sediment accumulation in the channel network and delta plain. Moreover, a degradation of permafrost and typical natural landscapes, appearance of anthropogenic systems take place.

In the XXI century, river runoff, sea level, impact of marine factors on delta coasts and regime, air and water temperature will increase. The scales of economic activity in the river basins and deltas will continue to grow, and the quality of river waters may worse. These changes will act significant impact on the morphology, regime and environmental conditions of the Russian Arctic deltas. Redistribution of water flow between branches will proceed; erosion of delta coasts will intensify; the area of permafrost and thermokarst lakes will decrease; the frequency and size of inundations will increase; ice extent and period of freeze-up may decrease.

HP1S4.02

HP1S4 - Deltas: landforms, ecosystems and human activities

Oral

Bioavailability of sediment-associated metals in the Slave River Delta, Northwest Territories, Canada

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The Slave River delta is a highly productive and biologically diverse ecosystem located on the south shore of Great Slave Lake in the Northwest Territories, Canada. There is concern regarding the water quality of the Slave River due to the transfer of sediment-associated contaminants from upstream sources and from long-range atmospheric transport. Previous studies report elevated metal levels in suspended sediment collected in the Slave River at Fort Smith and sediment deposited in the Slave River delta which either meet or exceed Canadian sediment quality guidelines but little is known about the bioavailability of sediment-associated metals to aquatic life in the delta. Such information is required to examine the potential risk to the nearby First Nations community of Fort Resolution and to the ecology of the delta. The present study examines the bioavailability of sediment-associated metals and their distribution across the delta. Surface sediment samples were collected and analyzed using ICP-MS for total metals (25 metals), grain size and organic carbon content. Membrane dialysis peepers were employed to quantify dissolved metal concentrations in pore-water near and at the sediment surface. Concentrations of 25 metals in pore water samples were determined. Four-week bioaccumulation tests were conducted on cultured Hyalella azteca using the Imhoff settling cone technique. Although levels of some sediment-bound metal levels exceeded National Water Quality Guidelines, relatively high rates of survival (mean = 80%) were observed during the four-week bioaccumulation tests, suggesting low sediment toxicity in these samples. Metal data are presented and interpreted in the context of current legislative and policy frameworks developed to manage northern environments of high ecological significance.

HP1S4.03

HP1S4 - Deltas: landforms, ecosystems and human activities

Oral

Regional Geochemical Mapping of Spitsbergen in the high Arctic based on overbank sediments of deltas and floodplains

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Overbank sediment from deltas and floodplains was sampled to obtain geochemical maps of the Arctic island Spitsbergen, in the Svalbard Archipelago in the high arctic. The purpose of the sampling programme was to produce geochemical maps that could be used for mineral prospecting and environmental research. In both cases the aim is to detect anomalies with geochemical element abundances higher than normal. The mapping programme results and the occurrence of this type of sediment in the arctic environment in Svalbard are discussed. It is concluded that overbank sediment is a representative sampling medium as it integrates sediments delivered from a number of different sources during floods. A review of sediment yield measurements showed that the glacier-fed rivers range from 160-2900 t/km^{2}yrs whereas yields of 28 – 83 t/km^{2}yrs have been measured in the non- glacial areas. Sandur deltas and river fans are the dominating depositional landforms. Overbank sediments samples were collected from 650 locations and analyzed for the content of 50 elements (total and acid soluble). The geochemical data are now available for public use and are actively being used in mineral exploration. High concentrations of Au were discovered on the northwestern side of Spitsbergen and a gold deposit was discovered and drilled. For environmental purposes the natural content and distribution of elements like arsenic, cadmium, copper, chromium, lead, mercury, nickel and zinc are documented.

HP1S4.04

HP1S4 - Deltas: landforms, ecosystems and human activities

Oral

Monitoring of flood propagation into the Niger Inner Delta: Prospective with the Low Resolution NOAA/AVHRR Data

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In this study, we use the low resolution AVHRR/NOAA14 satellite data, regularly collected by the Agrhymet Centre in Niamey (Niger), to characterize the space-time propagation of the flood and of the vegetation cover in the Inner Delta of the Niger river in Mali. We propose a methodology to identify the inundation front on satellite images, and to discriminate pixels of open water, flooded vegetation, vegetation on dry soil and bare soil. From the analysis of four images, taken at different dates well representing the whole of the hydrological cycle (from the filling to the emptying of the floodplain), we identify the four significant vegetative stages during the annual hydrological cycle: bare soil, vegetation on dry soil, flooded vegetation, open water. A selection of indexes sensitive to the presence of water surfaces and vegetation cover are presented. Then we propose an analysis of spectral signatures with a visual examination of coloured compositions to finally locate these four classes of pixels during the annual evolution of the flood.

HP1S4.05

HP1S4 - Deltas: landforms, ecosystems and human activities

Oral

Relationships between water heights at hydrological stations and inundated surfaces in the River Niger inner delta in Mali

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The River Niger inner delta is a wide natural seasonal flood plain in Mali, where the two main streams of the River Niger gather. This area is only poorly influenced by hydraulic managements, thus the inundation dynamic is mostly natural. Many people live in this humid area, and their activities depend on the date of arrival of the flood peak, and of its duration. But the inner delta is very large, and there is a long delay of several weeks or months between the arrival of the flood at the delta entry, and the occurrence of the flood at its exit. Previous studies using the low resolution AVHRR/NOAA14 satellite data, over the years 1990 to 2000 described the space-time propagation of the flood and of the vegetation cover. We use these images to study the relationships between the inundated surfaces and the water heights at several hydrological gauging stations, which data series are long enough and which cover several regions inside the delta. We then compare these relationships at the regional scale with global relationships with the whole delta from single gauging stations. Finally, we propose the reconstruction of possible past flooded surfaces from these relationships.

HP2PS.01

HP2PS - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Poster

Tracing terrestrial DOC in the Baltic Sea - a 3D model study

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The fate of terrestrial carbon in the marine environment and what role it plays in the carbon cycle is of great interest as rivers bring huge amounts of it each year to coastal seas. With global warming and an increased river runoff this discharge is expected to increase, therefore, it is important to understand the dynamics of the terrigenous carbon in the marine environment. In this study we have focused on the path of terrestrial dissolved organic carbon (DOC_{terr}) in the Baltic Sea by comparing results from a 3D circulation model, a NEMO configuration for the Baltic Sea, with stable carbon isotope observations of DOC. From this we could draw some conclusions regarding the processes affecting the removal of DOC from the water column and its effect on the inorganic carbon system of the Baltic Sea.

HP2PS.02

HP2PS - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Poster

Distribution and sources of suspended particulate matter in the Kara Sea

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Suspended particulate matter (SPM) is a fine material different in origin and composition. Its main features are formed in the result of the activity of planktonic organisms (biogenic matter) and supply of the mineral particles (abiogenic matter). The study of the SPM is essential for understanding the modern sedimentation processes, climate variability and the impact of pollution on the environment. The Kara Sea are powerfully affected river flow (annual runoff reaches 1300 km^3 per year), and with it - a significant influence of terrigenous sediment. Therefore, special attention in work is given the study of cross-shelf transport of terrigenous suspended material arriving with river runoff of the Ob and Yenisei, since these rivers account for about 90% of the annual freshwater flow into the sea. The researches were carried out during two cruises of R/V «Akademic Mstislav Keldish» in September - October 2007 and 2011. Climatic conditions over this part of the Arctic in these years were relatively similar. Ice cover was completely absent in the Kara Sea in the first part of autumn. The aim of our research is the study of features of SPM distribution and it main composition in the Kara Sea during the lowest sea ice cover period in the Arctic. There are five cross-shelf section were done during the expeditions. Two of them are the most important: from the mouth of Ob and Yenisei Rivers to St. Anna Trough. We studied concentration of SPM by three independent methods (vacuum filtration, Coulter Counter (Multisizer 3) and transmissometer), grain size distribution and content of the main chemical elements and components in the SPM - the real sours markers of particles (such as Al, Si, P, Corg, isotopic composition ($\Delta^{13}C$) of organic and carbonate carbon and other). There are carried out the study of biogeochemical processes participating in the transformation of the SPM into bottom sediments. We studied about 300 samples of SPM from the Kara Sea.

HP2PS.03

HP2PS - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Poster

The role of salt marsh vegetation on the heavy metals bioavailability

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Halophytes that colonize salt marshes have ability to withstand a sediment environment characterized by high salinity and have a well-developed aerenchyma system through which atmospheric oxygen is transported from the leaves to the roots. The oxygen not consumed by root respiration is available for diffusion into surrounding sediment, promoting change of chemical properties, mainly redox potential and pH, which condition the availability of trace metals. In addition, the solubility and availability of metals in marshes, in general, and for vegetation in particular, may be affected by several other factors such as concentration and speciation of metals, characteristics of the sediment (grain size, organic matter content, biotic aspects, concentrations of inorganic and organic ligands including plants exudates, cation exchange capacity, etc.). Therefore, mutual interactions between plants and surrounding chemical environment which determine the role-played by plants on trace metal distribution and uptake, may vary among plant species and, for a single plant, among locations with different characteristics. The aim of this work was to survey, comparatively, the role of S. maritima and S. fruticosa on minor and trace element (Ag, Cd, Cu, Cr, Mo, Ni, Pb and Zn) contents and distribution amongst sediment and plant tissues at salt marsh in Ria Formosa. Both S. maritima and S. fruticosa could fix metals from the surrounding belowground environment and accumulate metals, mainly in roots (and also in rhizomes in the case of S. maritima). Metal translocation to aerial parts of the plants were lower than 10%, except for Ag and Al in S. fruticosa and for Zn in S. maritima. This specie also presented Enrichment Factors lower than those for S. fruticosa for Cr, Ni, Zn, Fe and Al, and higher for Ag, Cd, Cu and Pb.

HP2PS.04

HP2PS - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Poster

Trace metals in biogeochemical processes in the Ob River and Yenisei River estuaries (the Kara Sea)

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Biogeochemical behavior of some trace heavy metals (Ag, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) in water column (soluble and particulate fractions) and benthic organisms along the two transects from the Ob River and Yenisei River estuaries to the Kara Sea was studied. All the samples were collected during cruise 54 and 59 of R\V “Akademik Mstislav Keldysh” in 2007 and 2011. Examined macrozoobenthic communities included the three dominant organism’ groups of the estuarine ecosystem with different trophic levels: 1. Bivalve mollusks (seston filter feeding); 2. Echinodermata (filter feeding and predators); 3. Crustacea (nonselective scavengers). Trace metal determination was made by AAS and ICP-MS analysis, certified reference materials were used to control an accuracy of methods. Alteration in the soluble and particulate fractions ratio of Fe, Mn, Zn, Cu, Pb, Cd and As and growth of non-detrital metal fraction in the near bottom suspensions in the mixing zones of the river and sea water were shown. In the Ob River and Yenisei River estuaries mussels were found to accumulate most of heavy metals at the background levels, while Zn and Cu contents were slightly higher. Different organisms and their organs showed large variability of heavy metal concentrations μg g-1 dry weight): Ag 0.05-0.67, As 0.21-130, Cd 0.09-4.21, Co 0.10-3.86, Cr 0.004-3.28, Cu 0.27-58.8, Fe 30-1940, Mn 0.8-1345, Ni 0.17-21.1, Pb 0.02-1.58, Zn 10-620. For each metal a minimum concentration was detected in the carbonate shells of bivalve mollusks, while the maximum ones – in the total body of crustacea or echinodermata. Peculiarities of the trace metal bioaccumulation in the dominant bottom organisms were revealed and bioconcentration factors were calculated based on the specific conditions of the environment. Comparison of the trace metal content in the similar taxa inhabited the Yenisei River and Ob River estuaries did not reveal a significant difference in the bioaccumulation.

HP2PS.05

HP2PS - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Poster

Assessing the hydrological impacts of land use changes upstream of the Tunisian World Heritage sea-connected Ichkeul Lake

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Land use and land cover changes have significant impacts on water quantity and quality. Land use is one major cause of diffuse source pollution. Land cover plays a key role in controlling the hydrologic response as well as the nutrients transfer (N and P). It is the case for the Joumine basin, discharging into the lake Ichkeul in northern Tunisia, a UNESCO World Heritage site since September 1980. The lake is characterized by a very specific hydrological functioning based on a seasonal alternance of water levels and salinity; through its link to the Mediterranean Sea via the Bizerte Lake. In this study three landsat satellites images and SWAT (Soil Water Assessment Tool) model were used to simulate stream flow and nitrate loads under different land use dates in the upstream watershed of Joumine Reservoir. Firstly, satellite images processing results showed an increase in cereal crop area from 50% in 1986 to 70% in 2010. The agricultural area was increased at the expense of maquis surface. The rural settlement area was increased from 0.7% in 1986 to 2% in 2010. These classified images were included into the SWAT model to assess the impact of land use changes on the hydrology and water quality in Joumine dam. The land use changes at the Joumine watershed between 1986 an 2010 did not affected monthly, mean annual and monthly streamflow results. It is explained by the values of Nash 0.68, 0.67, and 0.66 for corresponding land use of 2010, 2002 and 1986. On the other hand, land use changes had an impact on nitrate loads from agriculture practices.

HP2PS.06

HP2PS - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Poster

Prediction of streamflow from the set of basins flowing into a coastal bay

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Coastal basins of Brittany, France are hydrological hot spots. Many basins display a high level of nitrate pollution, 9 of them being pointed out by the European Commission since 2007, causing algal blooms in several coastal bays. To precisely diagnose and solve this issue, the fluxes of every contributing basin have to be considered. However, this faces a strong data-scarce situation due to the ungaugement of most of the basins.

In this context, we propose to transpose hydrological informations from one gauged basin to neighbouring points of interests. The methodology is based, firstly, on the development of a simple geomorphology-based transfer function on the gauged basin, describing the articulation of travel time over hillslopes and through channels. Secondly, the transfer function is inversed to assess the net rainfall time series through the deconvolution of the gauged discharge series. We obtain a standardized variable which is, thirdly, transposed and convoluted on the ungauged basin using its own transfer function in order to estimate discharge. The power of the approach is to benefit from the robustness and flexibility of the geomorphology-based transfer function without the need of a complex modelling of runoff production.

The methodology is applied on two highly controversial bays of northern Brittany, Saint-Brieuc's and Lannion's bays. We face the problem of lack of measurements (gap in measurement time series, too long time step or total absence of measurements) and the scaling issue in the transposition scheme. The importance of a well described transfer function is assessed, as well as the benefit of splitting the catchment dynamics between hillslopes and the river network compartments. Finally, this study enables the quantification of the whole volume of freshwater entering each bay.

HP2PS.07

HP2PS - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Poster

Changes in the French policy of natural risk management following the 2010 Xynthia coastal flooding catastrophe

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The Xynthia violent windstorm generated huge damages and fatalities across Europe between 27 February and 1 March 2010. Most of the 59 fatalities and most of the infrastructural damages in France have been caused by water flooding from the sea and rivers at some hot spots of the Atlantic Ocean coast. This catastrophe comes from the coincidence of a powerful storm surge and a high coefficient tide from the ocean, and river floods from the land. Various local phenomena occurred, including the breaking of sea walls. The synoptic crisis, across several administrative area, during the night, made it a major civil defense situation in France. This catastrophe had a major impact in France in terms of conscious arising and thus accounting for the marine submersion hazard and the associate forecasting, prevention, and protection issues. We review the changes in the French doctrine of the natural risk assessment and mitigation, as a consequence of the land-sea Xynthia event.

HP2S1.01

HP2S1 - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Oral

Effects of submarine groundwater discharge on coastal ecosystem

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Land-ocean interaction in the coastal zone is important for costal ecosystem and fishery production which are based on brackish water in the coastal area. Submarine groundwater discharge (SGD) is one of the pathways of water and dissolved materials from the land directly to the ocean. Constant and continuous transports of water and nutrients delivered by SGD provide sustainable ecosystem services to the coastal environment. Land-Ocean interaction are found in many coastal areas in Japan, in terms of ecosystem services though SGD including sea shell, sea grass and fishes. Numerical groundwater model including SGD is established in Saijo, Ehime prefecture, Japan, to compare with Rn which is one of indicators of SGD along the coastal line, and continuous data of Rn mooring and seepage meter. Observed fresh component of SGD separated from total SGD relatively agreed well with calculated rate of terrestrial groundwater discharge obtained from numerical model. The areas with larger SGD are located near the areas with sea grass farms.

HP2S1.02

HP2S1 - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Oral

Evaluating the contribution of rivers 222Rn activity and submarine groundwater discharge (SGD) in Yatsushiro Sea, Japan

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Submarine Groundwater Discharge (SGD) as a way through which solutes and nutrients travels from terrestrial areas toward the coastal areas has been recently considered highly as part of the hydrologic cycle. There are varieties of methods to estimate SGD in various scales. Among them, 222Rn has been developed with the viewpoint of accurate local estimations of SGD indirectly. Our research aims to measure the net SGD volume flux toward the Yatsushiro Sea, SW of Japan, using 222Rn method and considering rivers with high 222Rn activity discharging into the study area. The study area is an inland sea with high tidal fluctuations. Besides, there is a great contribution between sea water and groundwater which is highly affected by rivers. Continuous measurements of 222Rn have been done simultaneously with sea water EC. In addition, rivers grab samples were analyzed for level of 222Rn activity. Comparing estimated SGD volume using 222Rn method with seepage meters outputs had been done previously indicates overestimations in 222Rn method due to high 222Rn activity of discharging rivers.

HP2S1.03

HP2S1 - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Oral

From submarine to lacustrine groundwater discharge

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Submarine groundwater discharge (SGD) and its role for nutrient cycling are well known since the last decade. The freshwater equivalent, lacustrine groundwater discharge (LGD), is often disregarded although first reports of LGD are more than 40 years old. In total, we identified a dozen of different reasons for disregarding the groundwater path in water and nutrient budgets of freshwater ecosystems. Eutrophication is still a major threat to lakes in temperate climatic zones. Thus, it is necessary to determine the relevance of different nutrient sources to conduct effective management measures, to understand in-lake processes and to model future scenarios. A prerequisite for such nutrient budgets are water budgets. While most components of the water budget can be determined quite accurately the quantification of LGD is more difficult. There are several different measuring methods but all of them have limitations. In addition, modelling methods can be helpful, but there are other limitations like data sets, material parameters or plausible conceptual descriptions of the catchments. Nutrient concentrations in the groundwater approaching the groundwater-lake interface might also be quite heterogeneous and difficult to quantify. We investigated the fate of the nutrients nitrogen and phosphorus on their pathway from the catchment through the reactive aquifer-lake interface into the lake. We reviewed the international literature and summarized numbers reported for LGD of nutrients and compared LGD to SGD.

HP2S1.04

HP2S1 - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Oral

Spatial variability of lacustrine groundwater discharge (LGD) and its relevance for lake eutrophication

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Lacustrine groundwater discharge (LGD) is difficult to quantify, and thus, has often been handled as a residual in lakes´ water and nutrient budgets. But even if its contribution to the water balance is small, LGD can carry significant nutrient loads, namely when nutrient concentrations are high. In the present case study, we quantify the total annual LGD by the calculation of annual groundwater recharge in the subsurface catchment of Lake Arendsee in northern Germany. To assess the spatial variability of LGD, LGD rates are calculated based on temperature depth profiles of the lake sediment for subsections of the shoreline. The combination of total LGD and spatial LGD patterns allows calculating LGD volumes for each subsection. This reveals a main input of LGD within a limited part of the shoreline. Furthermore, varying phosphorus (P) concentrations in the near-shore groundwater contribute to the spatial variability of groundwater-borne P loads. Calculating P loads separately for each subsection reveals that groundwater-borne P loads vary extensively between subsections. The present study demonstrates the importance of (1) total LGD quantity, (2) spatial LGD patterns, and (3) heterogeneous groundwater nutrient concentrations for a reliable determination of groundwater-borne nutrient loads.

HP2S2.01

HP2S2 - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Oral

Investigation of groundwater-surface water interactions in shallow lakes using hydraulic head data and a groundwater net balance

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Lacustrine groundwater discharge (LGD) can play a major role in nutrient balances of lakes. However, studies focussing on nutrients are often neglecting this input path, or make use of groundwater net balances that are calculated using hydrological and meteorological data. Direct measurements of LGD with seepage meters are difficult and can be highly prone to errors. Indirect measurements using tracers deal with similar problems and are like direct methods point-measurements. This makes the application of these methods on a lake scale difficult, especially when information about the amount of groundwater entering and leaving the lake is needed. The subject of the present study is to evaluate the use of hydraulic head data and a groundwater net balance based on meteorological data to estimate the groundwater input and output of small lakes. The study sites are two shallow, groundwater fed lakes without any surface inflow or outflow. Spatially interpolated groundwater heads were combined with lake water levels to obtain vertical gradients between the aquifer and the water body of the lake which are separated by a thick mud layer with a much lower hydraulic conductivity than the aquifer. By fitting the hydraulic gradient of the mud layer to results of a simple mass balance we were able to estimate the groundwater input and output on an annual basis. Although our method needs some assumptions, the results are reasonable and give some more information about the exchange between the aquifer and surface water body, which can be helpful for the calculation of balances.

HP2S2.02

HP2S2 - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Oral

Application of process-based eco-hydrological model to northern Eurasia wetlands toward improvement in boundless biogeochemical cycles

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Wetlands have important influences on the hydrologic cycle, provides important role on biogeochemical process and transport, and helps preserve valuable species. In particular, boreal and subarctic peatlands store about 15-30% of the world's soil carbon as peat (Limpens et al., 2008), and affect the dynamics of greenhouse gases such as methane. The authors have so far developed the process-based National Integrated Catchment-based Eco-hydrology (NICE) model (Nakayama, 2008a-b, 2010, 2011a-b, 2012a-c; Nakayama and Fujita, 2010; Nakayama and Hashimoto, 2011; Nakayama and Shankman, 2013; Nakayama and Watanabe, 2004, 2006, 2008a-b; Nakayama et al., 2006, 2007, 2010, 2012), which includes complex interactions between the forest canopy, surface water, the unsaturated zone, aquifers, lakes, and rivers. In this study, the authors evaluated positive feedback between hydrologic, geomorphic, and ecological processes in the wetlands of northern Eurasia (Siberia, China, and Japan). The original NICE was further improved to implement map factor and non-uniform grid applicable to global scale through co-ordinate transformation. NICE also clarified the connectivity between groundwater and inundated flow, its effect on micro-topographic change through heterogeneous sedimentation, the relation to vegetation succession, and vice versa, which improved the clarification of nonlinear interaction in previous study (Reeve et al., 2000; Rietkerk et al., 2004). This simulation system will also play an important role in the improvement in biogeochemical activity in hot spots and hot moments (Frei et al., 2012) and boundless biogeochemical cycle along terrestrial-aquatic continuum for global environmental change (Cole et al., 2007; Battin et al., 2009).

HP2S2.03

HP2S2 - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Oral

Suspended particulate matter in the White Sea: the results of long-term interdisciplinary researches

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The aim of our researches is the study of the features of suspended particulate matter (SPM) distribution and formation of its grain size, mineral and basic chemical composition in the White Sea for understanding the modern sedimentation processes in the Arctic. We summarized the data on SPM concentration and composition of many expeditions (2001-2012) to the White Sea and to the Northern Dvina River mouth. Over these years we collected and studied about 2000 samples of the SPM in the surface water layer and in the water column. Special attention was given to research of biogeochemical processes in the fresh and saline waters mixing areas – the Northern Dvina River marginal filter. The study of SPM as a dispersion system of the sea requires the complex approach, i.e., consideration of biological, optical, and geochemical parameters of marine environments. The results of the study of various quantitative characteristics of the SPM (first of all, the area of the surface and the volumetric and mass concentrations, content of pelitic fraction) and the abundance of bacteriaplankton in the water are discussed. Chlorophyll «a» is not only a parameter used for primary production calculations. Chlorophyll «a» and its derivatives may be used as markers for the assessing the labile forms of organic carbon in both seawater, where these molecules characterize the impact of solely the phytoplankton on organic matter. We studied spatial and temporal variability of chlorophyll «a» in the White Sea. A positive correlation was found between the concentrations of chlorophyll «a» and SPM, as well as for chlorophyll «a» and organic matter. These relationships are primarily preconditioned by the same factor, i.e., by the riverine discharge, which carries both SPM and nutrients to the sea.

HP2S2.04

HP2S2 - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Oral

Partitioning sediment supply to Morro Bay, California

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Morro Bay estuary is an exploited lagoonal setting where commercial and recreational interests have a clear impact on the physical and geochemical ecological status of rare and sensitive habitats. In order to slow infilling and contaminant loading, the sediment supply from range and farmland areas of the Chorro and Los Osos Creeks has previously been the main focus of the Morro Bay National Estuary Program. This current project provides a quantitative sediment perspective on the supply of sediment from both fluvial and marine sources and their respective impacts on the estuary.

The mineralogical compositions of both sources are relatively immature. However, sediment transport and reworking during coastal transport accounts for significantly higher quartz contents in the fine-sand fraction of the marine samples (ca. 70%) compared to the fluvial sources (ca. 50%). Harbor samples near the mouth of the estuary have essentially the same composition as the spit (marine) samples. The quartz content decreases inward, but the marine contribution is significant in all samples, up to 5 km from the estuary mouth along the tidal channels. We expect that the fluvial supply is greater in the silt and clay fractions. But most of the channel samples are sandy, with insufficient fine sediment for analysis and budgeting. The predominance of the marine influx near the estuary mouth may be partly facilitated by frequent dredging in this area. Estuary infilling has also reduced the total tidal volume, which would reduce maximum velocities and further enhance sedimentation.

Measurements of total-sample metal contents show only a weak correlation with the fine fraction (<63 µm) contents and loss-on-ignition estimates of organic matter. We believe, therefore, that the location specific influences may be most important near quays, boat cleaning sites and stormwater discharges, in addition to the creek supply from of sources in the drainage area.

HP2S2.05

HP2S2 - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Oral

Morphodynamic changes in Mond River Estuary, the Persian Gulf

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The Mond River, which is considered as one of the Major Iranian rivers discharging in to the Persian Gulf, is bounded within the region from 51°10’ to 54°28’ E and 27°20’ to 29°51’ N, flowing in two provinces of Fars and Bushehr. The latest part of the river is completely meandered and the river mouth has been migrating twice during the past 50 years. Total sediment discharge of the river is estimated as 12 million cubic meter per year. Analysis of meandering river phenomenon and river mouth migration has long been one of the challenges in hydrodynamic discussions. This natural process usually takes place in rivers to provide energy equilibrium and its integration with human desires has posed as a management issue.

The sediment discharging to the Persian Gulf plays an essential role in formation of Mond River Delta and as well as a set of sand spits formed in downstream of the river mouth. The morpho-dynamic of entire environment of the Mond River – Mond Delta highly affects marine environment in the surrounding area.

The present study offers the results of a numerical and field investigation of various features of river-delta interaction on the Mond Delta area. A 3D model, namely SSIIM, has been utilized to investigate cases of flow and sediment behaviour in the meandered part of Mond River and future migration patterns of the River Mouth is estimated.

The results of the numerical model are compared with the field observations. It is concluded that the model achievements are capable to predict the observed phenomena.

Management guidelines and suggestions are deducted and drawn from the calibration and verification of the results with field observations and satellite image analysis.

HP2S2.06

HP2S2 - Land-ocean interaction Subtitle: Hydrodynamics and biogeochemistry

Oral

On the dynamics of high-density mud suspensions on modern continental shelves

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This work focuses on the dynamics of wave-generated, high-density suspensions (HDSs) of fluid mud on modern continental shelves using a state-of-the-art high-resolution numerical model, including k-ε turbulence closure. Our findings indicate the existence of two remarkable features inherent with such HDSs. First, under continued forcing, sediment concentrations tend to rapidly grow towards very high concentrations near the gelling point owing to a positive feedback between net erosion and hindered settling. This «gelling ignition», commencing at sediment concentrations above 30 g/L (value depends on sediment properties), is a natural consequence of the erosion's deposition behavior of mud suspensions at higher concentrations. Second, one-dimensional water-column modeling indicates that HDSs with concentrations >100 g/L can rapidly (within hours) develop into self-sustaining turbidity currents on mild bottom slopes as low as 2 m/km. Again, this remarkable feature is made possible via the well documented hindered-settling mechanism that almost shuts down deposition at high bear-bed sediment concentrations. The resultant turbidity currents quickly accelerate to speeds >25 cm/s due to the buoyant-slope force, in which a large density excess >80 kg/m3 (created via gelling ignition) compensates for a weak bottom slope. We postulate that such turbidity currents are common features on mud-dominated shelves such as the Eel Shelf, northern California, where 30-50% of the fate of the Eel River's sediment discharge is still unaccounted.

HP3PS.01

HP3PS - Implications of sea level change for the coastal zone

Poster

The Permanent Service for Mean Sea Level (PSMSL) in its 80th year

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The PSMSL was established as a “Permanent Service” of the International Council for Science in 1958, but in practice was a continuation of the Mean Sea Level Committee which had been set up at the Lisbon International Union of Geodesy and Geophysics (IUGG) conference in 1933. Now in its 80th year, the PSMSL continues to be the internationally recognised databank for long term sea level change information from tide gauge records. Here, we present a review of the past, present and planned future activities of the PSMSL.

The PSMSL dataset consists of over 2100 mean sea level records from across the globe, the longest of which date back to the start of the 19th century. Where possible, all data in a series are provided to a common benchmark-controlled datum, thus providing a record suitable for use in time series analysis. The PSMSL dataset is freely available for all to use, and is accessible through the PSMSL website (www.psmsl.org). We review the state of the PSMSL dataset, describing the historical evolution of the catalogue and highlighting some of the geographic regions where data coverage remains poor.

The PSMSL also provides technical and scientific outreach information to coastal stakeholders and the general public. It provides training and support to tide gauge operators across the globe. It plays an important role in the operation of the Intergovernmental Oceanographic Commission's Global Sea Level Observing System (GLOSS) and has participated in each of the Intergovernmental Panel on Climate Change assessment reports.

We also describe recent changes made to the PSMSL website, and describe some products added to allow users to explore the dataset interactively. We highlight some of the efforts being made to increase the quality and quantity of metadata available, and describe ongoing attempts to link our dataset with sources of higher frequency sea level data and other related data.

HP3PS.02

HP3PS - Implications of sea level change for the coastal zone

Poster

Coastal sea surface height variations as seen by GPS on a ferryboat

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Satellite altimeters have provided valuable sea surface height (SSH) observations in open oceans, but their use is unfortunately limited in coastal regions by many technical reasons, including contaminations by lands reflections and larger complicated tides. Moreover, even if those problems were solved, the temporal sampling interval of the satellite altimeters is too coarse for smaller-scale coastal phenomena. Thus, in this study, complementary observations of the coastal SSH using Global Positioning System (GPS) are examined.

Since August 2010, the SSH across the Tsushima Strait between Japan and Korea has been observed every 30 seconds using a real-time kinematic (RTK) GPS receiver mounted on a ferryboat *New Camellia* that serves daily round trips across the strait. The observed SSH includes high-frequency fluctuations that would be caused by wind waves. They can be smoothed out by averaging the SSH over the ship route, although the averaging periods are required to be longer than approximately eight minutes since ordinary wind waves are aliased by the 30-second sampling intervals as long-period waves.

By removing tidal and geoid heights estimated by best-available local models, we determined the sea surface dynamic height (SSDH). The obtained SSDH regularly includes undulations with approximately 20km wavelength, which is equivalent to that of the internal semi-diurnal tides in this region. The larger-scale SSDH variations are well agreed with the dynamic heights calculated from the de-tided velocity observed at the 18m depth by the acoustic Doppler current profiler (ADCP) mounted on the same ferryboat. Those comparisons are further used for the improvement of the local tidal and geoid models.

HP3PS.03

HP3PS - Implications of sea level change for the coastal zone

Poster

Sea level change in response to melting of ice sheets

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Relative sea level change is estimated with a combination of methods. First a melting scenario with reasonable fresh water input from Greenland ice sheet, glaciers in Alaska or West-Antarctica between 50 and 200 Gt per year are assumed and used as sources in a global Finite Element Sea-Ice Ocean Model (FESOM). The model calculates the evolution of ocean volume and mass using a non linear free sea surface. Other driving forces are atmospheric surface fluxes from NCEP reanalysis and river runoff from hydrologic modelling. The resulting sea level change due to inflow of mass, steric expansion and redistribution as a consequence of ocean dynamic reactions are calculated relative to the geoid. Geoid changes as a response to the changed mass distribution and the associated uplift are calculated in a second step and are augmented by rotational feedback. Finally glacio-isostatic adjustment is used to correct for ongoing vertical movements.

A significant fraction of the sea level variations at the North Atlantic coasts can already be explained by our reference experiment (no extra melting prescribed). Including ice sheet melting substantially improves the comparison between modelled sea level and PSMSL tide gauge records.

HP3PS.04

HP3PS - Implications of sea level change for the coastal zone

Poster

The GLOSS Delayed Mode Data Centre and the GLOSS Implementation Plan 2012

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The Global Sea Level Observing System (GLOSS) is an international programme conducted under the auspices of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the World Meteorological Organisation (WMO) and the Intergovernmental Oceanographic Commission (IOC). The main component of GLOSS is the 'Global Core Network' (GCN) of 290 sea level stations. The present definition of the GCN (the definition is modified every few years) is called GLOSS10.
A new GLOSS implementation plan was developed in 2012 to advise on technical standards for GLOSS tide gauge stations, as well as describing the basic terms and obligations for Member States participating in GLOSS.
Sea-level data are vital to scientists for studies of major ocean currents and global climate change, to engineers for the design of coastal installations, to the large community engaged in operational oceanography (e.g. provision of flood warnings from storm surges or tsunamis), and in local applications such as provision of tide tables. In many of these applications the rapid exchange of reliable data, nationally, regionally and even globally, can increase the value of the work.
The GLOSS Delayed Mode Data Centre is operated by the British Oceanographic Data Centre (BODC) in collaboration with the Permanent Service for Mean Sea Level (PSMSL). It has the responsibility for assembling, quality controlling and distributing the “final” version of GLOSS sea-level data sets, as well as all supporting metadata information, maintaining the GLOSS website and the GLOSS Station Handbook. We will discuss how we will meet the implementation plan requirement that the various centres optimize relational database tools and cross-referencing techniques to give the feel of a centralized GLOSS web server for all related data and metadata.
We will also discuss the data archaeology efforts that BODC is involved in, including providing advice to the GLOSS Group of Experts.

HP3PS.05

HP3PS - Implications of sea level change for the coastal zone

Poster

Interannual variability of the lakes level in Northwest Russia based on satellite altimetry

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Variability of the largest lakes level in Northwest Russia is characterized by alternating periods of rise and drop according to the altimeteric measurements of TOPEX/Poseidon (T/P) and Jason-1/2 (J1/2) satellites Water level was calculated with the use of an algorithm of regional adaptive retracking of Sensor Geophysical Data Record databases for the Lakes Ilmen, Ladoga. Onega and Peipus. Application of this algorithm considerably increases the amount of actual data records and significantly improve the accuracy of water level evaluation. The general principles of retracking of a complex domain (a coastal zone, an inland water body, etc.) are discussed. The principles are based on the calculation of signal with allowance made for the roughness of the reflecting surface, and they can be applied to different geographic regions. According to the results, temporal variability of the Lake Ilmen level is characterized by a wave with a period of 4-5 years (maximum in 2001, 2004, 2008 and minimum in 1997, 2003, 2008). Between 2000 and 2011, the lake level rised at a rate of 1,17 ±0,95 cm/yr. The level of the Lake Ladoga also showed a wave with period 4-5 years (maximum in 1995, 1999, 2005, 2010 and minimum in 2003, 2006, 2009). From 1993 to 2011 the lake level was decreasing at rate of 0,24 ±0,10 cm/yr. Similar wave is observed in the Lake Piepus level (maximum in 1995, 1999, 2005, 2010 and minimum in 1997, 2003, 2008). During the period from 1993 to 2011 its level was rising at a rate of 1,39 ±0,18 cm/yr. In the interannual variability of the Lake Onega level we found a wave with a period of 15 years(maximum in - 1995, 2009 and minimum in 2003). From 1993 to 2011 the lake level was decreasing at a rate of 0,18 ±0,09 cm/yr. This study was supported by a series of grants of the Russian Foundation for Basic Research (No 13-05-01125, 13-05-00728, 13-05-00256, and 13-01-00753)

HP3PS.06

HP3PS - Implications of sea level change for the coastal zone

Poster

Dynamic DEM and other aspects of subsidence in flood risk

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Subsidence is an important factor in coastal zones when it comes to ascertain flood risk. Obviously subsidence of coastal defences would add to the sea level rise, but subsidence of low lands behind these defences also increases risks. A number of developments make the visualisation and quantification of flood risk easier and quicker. In the Delta Programme,set up in the Netherlands to cope with expected scenarios of sea level rise and increased precipitation rates and river high stands, new subsidence prognosis maps were constructed that incorporate expected subsidence rates in different land use and climate scenarios. The reliability of these maps relies heavily on the accuracy with which the underlying parameters can be determined. The best source of information is found in subsidence observations, which can be used to calibrate model parameters. In the FP7 project SUBCOAST for the first time an integration of all available subsidence data has been combined. This includes data from levelling, airborne LIDAR and satellite InSAR, allowing also to separate the different causes of subsidence. Combining the observed subsidence with the calibrated prognosis now makes it possible to construct a dynamic DEM that can be used as a basis for the recently developed fast flood visualisation and quantification programs in the FEWS suite. This approach was applied to Ho Chi Minh City. Results show that the dependance on reliable ground truth data of observed subsidence is an alarming Achilles' heel in the combat against flood risk in most SE Asian deltas.

HP3PS.07

HP3PS - Implications of sea level change for the coastal zone

Poster

eSurge: Improving storm surge modelling with advanced satellite data products

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Storm surges, where water is pushed onshore by extreme weather conditions, are one of the deadliest and most devastating natural hazards, with large parts of the world's coastlines at risk. Well known examples include the 1953 North Sea floods, Cyclone Sidr in Bangladesh, Cyclone Nargis in Myanmar, and Hurricanes Katrina and Sandy in the Caribbean and USA. Any rise in sea level will increase the risk from storm surges, and any improvement in modelling and forecasting of such surges has the potential to save lives and save money. Satellite data already play an important role in storm forecasting, however much more could be done. In particular, advanced satellite products such as wind speed and direction from high resolution scatterometry and sea state information from coastal altimetry are not yet widely used in storm surge forecasting. Given the missions due to be launched over the coming years, in particular the Sentinel spacecraft, it is important to research how such data can be used operationally. Recognising this, ESA has initiated the eSurge project through its DUE programme, with the aim of improving the uptake of such satellite products by storm surge modellers and forecasters, by making it easier to access such data and by demonstrating their value to the community. eSurge makes a wide range of satellite and other data freely available through a dedicated web portal. We augment existing data with new data sets; in particular we are using techniques developed in the COASTALT project to provide measurements of water level where they were not previously available. The project will also perform a number of experiments to demonstrate the value of these data and to investigate how best to assimilate them into models. Starting in spring 2013, eSurge will provide a demonstration of a near real time service (eSurge Live) in the North Sea and North Indian Ocean, to demonstrate the feasibility of using such data operationally.

HP3PS.08

HP3PS - Implications of sea level change for the coastal zone

Poster

Estimation of Sea Level Rise and impacts in Vietnam coastal deltas - ONLY FOR POSTER PRESENTATION

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Located in the South East Asia, Vietnam has a long tropical coastal zone and two large low lying deltas-Red and Mekong rivers which are habitats of millions peoples and valuable ecosystems. Sea level rise due to climate change may cause impacts to life of people and the ecosystems. The presentation describes geographical conditions of the Vietnam coastal zone and some estimations of sea level rise based on historic tidal data and studies, and possible impacts. The National Target Plan to deal with climate change and sea level rise is also presented.

HP3S1.01

HP3S1 - Implications of sea level change for the coastal zone

Oral

Towards worldwide height unification using ocean information

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For the last two centuries, Mean Sea Level (MSL) has been used to define datums for national leveling systems. However, there are many problems with this. For example, the sea surface can be at a different geopotential in different countries due to the ocean circulation and/or will have been measured over a different period, so the question arises of how to relate one national datum to another. In addition, as time goes by, any datum will correspond less and less to the current MSL as ocean volumes and land levels change. The result is possible complications in impact studies that use heights related to national datums in different countries. This presentation will show how we are using ocean models together with sea level (tide gauge and altimeter) information, geodetic (GPS and levelling) data and new geoid models from GOCE and GRACE to understand how MSL varies from place to place along the coast. As a result we will work towards worldwide height system unification by expressing existing national datums in terms of the geoid, the only true datum. This work is within a number of GOCE-related activities funded by the European Space Agency and led by the Technical University of Munich. The study is focused on the North Atlantic where the various data sets are most copious. First results will be presented on the consistency between data sets and on the limitations, with regard to our objectives, of each data type in terms of accuracy and availability.

HP3S1.02

HP3S1 - Implications of sea level change for the coastal zone

Oral

Regional and global sea level variability derived from PSMSL data

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110 years of tide gauge records compiled, referenced and made available by PSMSL are analysed. We estimate sea level change at coasts and in the ocean interior by projecting the historic measurements onto global structure functions. Typically these are derived from EOF's based on 20 years of satellite altimetry. Several approaches are tested and compared, including filling of data gaps in the PSMSL resords by neural network techniques. This way we include coherence in measured sea level change in our estimate.

Results from different methods are analysed and compared to previous studies. Error levels are estimated. Our present best estimate for the global sea level rise since 1900 is 1.65 mm per year. Regionally the trend varies significantly and can be much higher. Maxima and minima are found in the Indian Ocean.

HP3S1.03

HP3S1 - Implications of sea level change for the coastal zone

Oral

Integration tide gauge and satellite altimetry for storm surge and sea level change prediction

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Tide gauge and satellite altimetry has vastly different spatial and temporal sampling. However the data can be integrated to take advantage of the high temporal sampling of the tide gauges with the high spatial sampling of the satellite. Combiningg the data, we have tried to investigate both high frequency signals (surges) but also annual to decadal sea level signal using data from the past 20 years to investigate existence of ability to capture surge and sea level along the Northwest European and Australian coastlines. The comparison demonstrates the importance of optimal tide modeling using the response method as well as careful use of the dynamic atmosphere correction delivered by the MOG2D model. Data from TOPEX/POESEIDON+Jason1/2 (T/P+J1/2) altimetry tide gauges recorders around both European and Australia coasts general exhibit temporal correlation of more than 90% for nearly all tide gauge stations.

We have selected several representative surge events on the two continents based on tide gauge recordings and investigated the capability of detecting these using satellite altimetry. On the European coast we find that when 2 or more satellites are available we capture more than 90% of the extreme sea level events. Finally we have investigated how satellite and tide gauge observations can best be combined with the aim of producing better sea level warning for the future for human safety. One method studied is a multivariate regression method and another is an optimum 3D interpolation method to integrate the detided sea level from T/P+J1/2 altimetry and tide gauge recorders. The performance of these models is demonstrated by examining the hindcast skill, which are greater than 90% around some tide gauge stations.

HP3S1.04

HP3S1 - Implications of sea level change for the coastal zone

Oral

Monthly to multi-decadal sea level variations from tide gauges in the German Bight from the mid-19th century to present

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FoKoS, Research Group Civil Security / University of Siegen, Civil Engineering, Germany

The recent interest on climate change impacts has led to a focus on long-term trend and acceleration patterns in mean sea level (MSL) on global as well as regional scales. However, these long-term changes are superimposed by a large inter-monthly to multi-decadal variability that hampers reliable estimates of longer-term changes and the distinction of climatic and anthropogenic signals. The present study describes the spectra of MSL changes from monthly to multi-decadal timescales at 13 tide gauge records located in the German Bight with record length between ~60 and 169 years. It is analyzed which forcing factors drive sea level on different timescales and whether they are important for the detection of longer-term trend and acceleration patterns. It is found that atmospheric forcing plays the most important role when analyzing MSL in the German Bight. Over 90%, 80% and 60% of the observed variability can be explained by atmospheric forcing (windstress, SLP, precipitation) when investigating intra-, inter-annual and decadal timescales, respectively. On multi-decadal scales the explanatory power of the forcing factors is rather small suggesting that remote forcing over the North Atlantic (integrated long-shore winds, Atlantic multi-decadal oscillation) is mainly responsible for the observed changes. However, the uncertainties of trend estimation can be considerably reduced when removing the atmospheric influences. A standard error (SE) smaller than 0.5 mm/yr requires 55 years of data when using observed MSL at tide gauge records from the German Bight. In contrast, a similar SE in the atmospherically corrected residuals is reached after 30 years. These results clarify the huge amount of natural variability on MSL that has to be considered when analyzing long-term changes. When determining acceleration patterns such fluctuations may considerably falsify the results, especially if only short time series are available.

HP3S1.05

HP3S1 - Implications of sea level change for the coastal zone

Oral

The present sea level rise - a natural process

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Tide gauges have recorded an ongoing eustatic sea level rise, which has been interpreted as manmade due to a global climatic change. This paper will show that the present sea level rise is due to a natural process, which have make sea level to fluctuate in an oscillatory way. The main reason why the present sea level rise has been interpreted as manmade is that the present eustatic rise has been assumed to have started c. 150 years ago from a period with stationary eustatic level. The idea of a more or less constant eustatic level since 8 000 years BP emanates from estimations of volumes of ice melted since the last ice age. These estimations are based on an assumption as the volumes of melted ice are impossible to verify.

A new eustatic curves, the one addressed in this paper, is from shore-level modelling in a formerly glaciated areas. Input data in this model include 92 shore-level curves, 4 detailed lake-tilting investigations, 1150 levels of the highest coastline, and 57 tide-gauge records from Scandinavia.

The main trend of the eustatic development follows the glacial cycle, with a low stand of c. -120 m, during the glacial maximum. In addition to the main eustatic rise, there are also small eustatic changes that make sea level oscillate in a more or less regular way. The peak amplitude of the oscillation was ±1.5 m during early Holocene. Today the amplitude has diminished to c. ± 20 cm. The oscillations can be traced backwards at least to c 10 800 years BP. The sea-level has oscillated with cycles of c. 600 year. The present eustatic rise follows the oscillation pattern established during the Holocene. The present eustatic rise will change to a eustatic lowering within c. 200 years. By then, sea level will have risen c. 20 cm above modern values. Predictions of future shore level displacements at different sites can be made by the present model.

HP3S1.06

HP3S1 - Implications of sea level change for the coastal zone

Oral

Origins of heat and freshwater anomalies underlying global regional sea level trends

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Regional sea level changes often differ from global mean changes due to geographic variations in surface fluxes and to changes in ocean circulation. Here we study such regional sea level trends from 1993 to 2004 using a synthesis of observations and an ocean general circulation model. Unlike the global mean, steric changes dominate regional trends with negligible contributions from column-integrated mass variations. Regional heat and freshwater anomalies underlying steric changes are in turn distinguished between redistribution of pre-existing anomalies within the ocean and contributions from additional surface fluxes external to the ocean. Internal redistribution accounts for most regional trends but exceptions are found, most notably in the western tropical Pacific Ocean where a warming of external origin dominates the trend. On average, external thermosteric sea level trends are found to be positive in temperate regions while negative at higher latitudes with opposite trends found in external halosteric anomalies.

HP3S2.01

HP3S2 - Implications of sea level change for the coastal zone

Oral

Sea level variability in Western Australia

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Coastal sea level variability occurs over a range timescales ranging from seconds to centuries. The action of the wind on the sea surface generates surface gravity waves with periods of the order of 10s. Although the swell waves are generated in the deeper ocean they have a major influence. Globally, the astronomical forces of the Sun and the Moon result in tidal variability with periods of 12 and 24 hours as well as tidal modulations with periods up to 18.6 years. In many regions, the effects of the tides dominate the water level variability – however, in regions where the tidal effects are small other processes also become important in determining the local water level. In this presentation, sea level data from Fremantle (tidal range ~0.5m), which has one of the longest time series records in the southern hemisphere, and other sea level recoding stations from Western Australia are presented to highlight the different processes ranging from seiches, tsunamis (generated through earthquakes and thunderstorms), tides, storm surges, continental shelf waves, annual and inter-annual variability. As the contribution from each of these processes is of the same order of magnitude – the study of sea level variability in the region is very interesting and reveals both local and remote forcing. A recent study to estimate extreme sea levels around Australia will be described which included prediction of extreme water levels under the influence of tides, tropical and extra-tropical storms around Australia.

HP3S2.02

HP3S2 - Implications of sea level change for the coastal zone

Oral

Estimating vertical allowances for Atlantic Canada under conditions of uncertain sea level rise

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Fisheries and Oceans Canada (DFO) has a substantial investment in coastal infrastructure including harbours, communication towers, lighthouses, office and storage facilities, and laboratories. An adaptation project has been initiated to provide science advice on the issue of sea level rise to DFO management sectors. This advice is given in the form of vertical allowances, which are defined as the amount by which an asset needs to be raised in order to maintain the same likelihood of future flooding events as that site has experienced in the recent past (Hunter, 2012). The allowances are determined by the combination of the statistics of present tides and storm surges (storm tides) and the regional projections of sea level rise and associated uncertainty. Tide-gauge data for nine pilot sites from Canadian Atlantic coast are used to derive the scale parameter of present sea-level extremes using Gumbel distribution function. The allowances in the 21st century with respect to year 1990 were computed at 10-year intervals for the Intergovernmental Panel on Climate Change (IPCC) A1FI emission scenario. For Atlantic Canada, the allowances are regionally variable and, for the period 1990-2050, range between -13 and 38 cm, while, for period 1990-2100, they range between 7 and 108 cm. The negative allowances in the Gulf of St. Lawrence are caused by land uplift due to the glacial isostatic adjustment (GIA) effect. The GIA model projections agree with the rate of vertical land motion measured from GPS data.

HP3S2.03

HP3S2 - Implications of sea level change for the coastal zone

Oral

Projections of Mediterranean mean sea level and extreme events for the 21st century

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All model projections show a warmer Mediterranean Sea by the end of the 21st century, which would result in a significant increase in the thermosteric component of sea level. Conversely, there is more disparity in the salinity projections and, moreover, the impact of a regional salinity increase on sea level is less clear. The reason is that the halosteric component only represents actual sea level variations under geostrophic equilibrium. When this is not ensured, the contribution of salt addition/subtraction to the mass component must also be considered in order to obtain total sea level. In this presentation we first formulate sea level variability in terms of the contributing physical processes, paying particular attention to the role of salinity changes in a semi-enclosed basin such as the Mediterranean Sea. Also the interpretation of regional model outputs deserves some attention in order to properly account for all sea level components. Our best estimate for Mediterranean mean sea level, excluding salinity effects, is that it will be 50-60 cm higher by the end of this century. We also present results for extreme sea level events. The projections of the meteorological component of sea level (the dominant component regarding extreme events in a microtidal environment) are obtained using a barotropic model forced with high-frequency atmospheric pressure and wind data under different climate change scenarios. On average, results indicate only small changes in the atmospheric component, so that positive/negative extreme events would increase/decrease by approximately the same amount as mean sea level.

HP3S2.04

HP3S2 - Implications of sea level change for the coastal zone

Oral

Observed mean sea level changes around the North Sea coastline from 1800 to present

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This study assesses historic changes in mean sea level around the coastline of the North Sea, one of the most densely populated coasts in the world. Typically, such analyses have been conducted at a national level, and detailed geographically wider analyses have not been undertaken for about 20 years. We analyse long records (up to 200 years) from 30 tide gauge sites, which are reasonably uniformly distributed along the coastline, and: (1) calculate relative sea level trends; (2) examine the inter-annual and decadal variations; (3) estimate regional absolute (or geocentric) sea level rise throughout the 20th century; and (4) assess the evidence for regional acceleration of sea-level rise. Relative sea level changes are broadly consistent with known vertical land movement patterns. The inter-annual and decadal variability is partly coherent across the region, but with some distinct differences between the Inner North Sea and the English Channel. Data sets from various sources are used to provide estimates of the absolute sea level changes. The long-term absolute mean sea level trend for the 1900 to 2011 period is estimated to be 1.6 ± 0.1 mm/yr for the entire North Sea region. The trend is almost the same for the Inner North Sea, and smaller but not significantly different on the 95% confidence level for the English Channel (i.e. 1.2 ± 0.1 mm/yr). The uncertainties in the estimates of vertical land movement rates are still large, and the results from a broad range of approaches for determining these rates are not consistent. Periods of sea level rise acceleration are detected at different times throughout the last 200 years and are to some extent related to air pressure variations. The recent rates (i.e. last two to three decades) of sea level rise are high compared to the long term average, but are comparable to those which have been observed at other times in the late 19th and throughout the 20th century.

HP3S2.05

HP3S2 - Implications of sea level change for the coastal zone

Oral

An assessment of sea level rise for a coastal wetland restoration project in the UK

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The Lyth Valley is located in the county of Cumbria in north-west England, bordering the Lake District National Park. The valley is bordered by uplands to the north, west, and east, and forms a broad coastal floodplain which has been heavily modified over the years. Today, a complex system of embankments, drainage ditches and pumping stations control water movements across the valley. One of the key ambitions of the England Wetland Vision (a programme to consider the role of wetlands over the next 50 years) is to restore existing wetland sites in the Lyth Valley, in what would be the second largest wetland restoration programme in the UK. Whilst the potential to deliver biodiversity benefits within the Lyth Valley is obvious, the current understanding of the flooding at a landscape scale, and the opportunities that this may present, is limited. In February 2010 a project was commenced to develop a greater understanding of water management in the Lyth Valley and how changes in sea level could affect the current agriculture and the ecological function to deliver biodiversity and wider ecosystem service benefits. An important component of this project was to consider the impact of breaching of sea defences, the extent and frequency of inundation and the continued cost of maintaining the level of defences. This paper describes the application of GIS and hydrodynamic modelling to test a number of breaching scenarios and their impact on the different land uses within the coastal environment. The results of the scenarios have been used to propose alternative land management strategies within the study area.

HP3S2.06

HP3S2 - Implications of sea level change for the coastal zone

Oral

Using chloride as an indicator of saline intrusion through basal sediments of slapton ley, Southwest England

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Slapton Ley consists of two freshwater coastal lagoons, separated from the sea by an elevated shingle barrier ~4m above the Ley surface water level and within ~1m of local Ordnance Datum. Short-term cyclic variations in conductivity and Cl^{-} were first observed in the Ley during automated high frequency water quality monitoring over three days in March 1999, four days in July 1999 and four days in April 2000. All time series appeared to positively correlate with the local tidal regime. Using Cl^{-} as a salt-water indicator, experiments were designed to establish the source of this saline water. Five spatial sampling and flow monitoring surveys were conducted over neap and spring tidal ranges. For each survey, two sets of samples were collected within an hour of the max. and min. tide level on the same day. The initial spatial survey showed that the Ley is not well mixed and that catchment surface waters do not contribute a significant amount of saline water to the Ley. River flow surveys showed that there was a significant increase in flow over the Ley outfall at high tide that could not be accounted for from measured inputs. A mass balance calculation has shown that an additional seawater influx of ~8 $l\ s^{-1}$ would be required to raise the Cl^{-} concentration in the Ley by the amount observed. Cores were taken within the Lower Ley and low lying wetlands within the contributing catchment, to establish the source of saline water in the Ley and establish the mechanism by which this water entered the Ley. Results from the analysis of interstitial pore waters from the basal sediments of the Ley, suggest that at ~3m depth seawater is forced beneath the barrier (probably through underlying peat layers) on a rising tidal cycle, passing up through the overlying gyttja to the water column above.

HP3S3.01

HP3S3 - Implications of sea level change for the coastal zone

Oral

Analysing impacts of sea level rise on coastal aquifers: A case study in the South-West Bangladesh

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One of the major consequences of global warming is sea level rise (SLR). Many recent research reports including IPCC's 4th Assessment report has predicted that the global mean sea level is likely to rise by more than 60 cm within this century. The consequences of SLR on coastal aquifer are long term and can be far reaching. One of the more apparent consequences is the increased migration of saline water into the coastal aquifers. There is an urgent need to enhance resilience of coastal aquifers to current sea level and to be better prepared to respond and adapt to SLR, which requires a comprehensive assessment of the potential impact of sea level rise on coastal aquifers. This study investigates the intrusion of saltwater interface in the coastal aquifer in the South West region of Bangladesh using a process-based model under several SLR scenarios. For this assessment, a 2D groundwater salinity model has been developed based on a conceptual understanding of the aquifer system and integrated with an existing 2D hydrodynamic model, which is capable of surface water salinity simulation. The model has been calibrated against the observed ground water level and salinity concentration data at several locations within the study area. Projected SLR from the latest IPCC report has been used for the assessment of its impacts on groundwater salinity. The study has revealed that SLR will impose long term rise in groundwater level which will lead to additional saltwater heads at the sea side and therefore, more saltwater intrusion to far upstream is anticipated. The paper introduces the 2D groundwater salinity model and its integration with the surface water salinity model, provides a brief overview of the study area and presents the key results from the calibration and validation of the model and the scenario analysis. Based on the simulated results, the possible impacts of the projected SLR on the aquifer system are discussed.

HP3S3.02

HP3S3 - Implications of sea level change for the coastal zone

Oral

Consequences of sea level variability and sea level rise for Cuban territory

Hernández

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The objective of the present paper was to determine the main impacts of sea level variability and long-term tendency, starting from direct measurements of 39 temporary and permanent tide gauges of the National Tide Gauge Network and of a Geographic Information System. Up-to-date and spatially positioned quantitative information was obtained about relative mean sea level rise, monthly anomalies, astronomical tide and sea level extreme values. In this sense, the anomalies, tendency and projection of relative mean sea level in Cuba during the present century were obtained, statistically updated up to 2012. The annual lineal rate of mean sea level rise in the Cuban archipelago, obtained from the longest tide gauge records, fluctuated between 0,214 cm/year at Siboney and 0,005 cm/year at Casilda. Return periods of sea level extreme values were characterized; the results were reflected in a map by means of geomatics technologies. It was determined that mean sea level rise due to Climate Change and global warming represents the main environmental hazard for Cuba, because of its great long-term socioeconomic impact. This process causes an increase in submerged areas by diminishing the emerged areas of the Cuban archipelago, with a widespread retreat of the coast line. Monthly and annual anomalies of mean sea level, some of which are similar or higher (approximately 40 cm) than the mean sea level rise estimated for halfway through the present century, reinforce the inland penetration of seawater due to the run-up of the predominant semi-daily tide. On top of this, it is added a gradual increase in coastal floods by sea penetration due extreme events. The combination of these different events will result in the loss of goods and services, causing expensive investments for adaptation. The sewer system and buried technical networks for settlements in coastal areas are among the most threatened services.

HPS1PS.01

HPS1PS - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Poster

A statistical method for improving continental shelf and near-shore marine climate predictions

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The Bluelink ReANalysis (BRAN) product provides daily estimates of ocean variability at 1/10 degree horizontal resolution around Australia. The large-scale patterns of sea surface temperature (SST) in deep water, such as those associated with the East Australian Current and the Leeuwin Current, are well represented by BRAN. Not surprisingly, however, BRAN performs poorly over the continental shelf. We develop a statistical approach that more accurately and robustly represents SST across the southern Australian shelf region, informed by satellite observations and BRAN data. We demonstrate that this statistical model approach generates more accurate estimates of the in-shore SST using: i) off-shore SST from BRAN, and ii) the statistical relationship between in-shore and off-shore SST observed remotely. SST variability is separated into the mean, seasonal cycle, and residual variability and separate models are developed for each component. The off-shore locations used to inform the model are determined by taking into account: i) the quality of BRAN at each location, ii) the strength between the in-shore and off-shore variability, and iii) the proximity of the in-shore and off-shore locations. Our approach uses accurate and robust ocean data from the larger-scale geographic domain (deep ocean) to provide estimates in the domain where the ocean model performs poorly (coastal ocean) based on the observed relationship between those two domains. Unlike statistical downscaling, this “statistical boundary-scaling” approach does not relate the local fine-scale variability to the local coarse-scale variability; it relates the local coastal variability to the non-local open-ocean variability. Model predictions are made for the continental shelf around southeastern Australia. We also discuss the role of the mean circulation in providing connectivity between the shelf and the off-shore regions and how this information is used to inform the choice of model predictor locations.

HPS1PS.03

HPS1PS - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Poster

Projection of future streamflow changes of the Pearl River basin in China using two delta-change methods

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Considering the considerable biases in precipitation simulations conducted by regional climate models (RCMs), the delta-change approach is often adopted in hydrological climate-change impact studies for the construction of future precipitation scenarios. However, different delta-change methods may yield various future precipitation scenarios that are likely to significantly impact projections of future streamflow. To quantify these effects, two different delta-change methods were compared in this study for future precipitation construction: the simple delta-change (SDC) method with a constant scaling factor and the quantile-quantile delta-change (QQDC) method with a non-uniform delta-change factor that is equal to the ratio of the RCM-simulated future to baseline precipitation quantiles. The Xinanjiang hydrological model (XAJ) was then applied using observed historical meteorological data and two future precipitation scenarios for river flow simulations in the Pearl River basin, China. The results show that the two delta-change methods significantly impact future precipitation and streamflow projections, especially in extremes. For instance, the QQDC method projects the 20-year extreme daily precipitation to be 8.1% to 98.6% higher than the predictions of the SDC method. As a result, the XAJ that uses QQDC future precipitation always produces a more severe flooding situation compared with the model that uses SDC precipitation by approximately 7.0% to 65.0% higher in the 20-year extreme daily streamflow. This result implies that precipitation transformation methods may be a source of uncertainly, which can affects future discharge projections. Moreover, such uncertainty should be considered in water resources management and flood control strategies to address future climate change.

HPS1PS.04

HPS1PS - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Poster

Modeling of flood watersheds in semi-arid regions of Algeria (Model 1)

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The study area encompasses three watersheds in semi-arid and arid south-eastern Algeria. IT is basins Melghir-Chott (68,751 km2), highland Constantine 07 (9578 km2) and El Hodna-basin 05 (25,843 km2). Wadis of these areas are endorheic drainage (wadis draining closed depressions) and quasi temporary.

Studies of protection against floods or design studies of hydraulic structures (spillway storm basin, etc.), require the flood data which is often unknown in several places especially at ungauged wadis these areas. This makes it very difficult to schedules and managers working in the field of hydraulic studies . The objective of this study is to propose a methodology for determining the absence of flood measurement data in the semi-arid and arid south eastern Algeria.

HPS1PS.05

HPS1PS - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Poster

Extrapolation of the rating curve with the neural network approach and multiple regression Case of the «Algerian Coastal» basin

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A quick and accurate determination of flow passing through a river section is fundamental for a large number of engineering applications, such as flood forecasting and real time water resources management. However, practically the great amount of discharge occurs during very brief flash floods, so getting gauging during these quick events is not easy. The rating curve remains the most frequently used method for continuous river discharge measurement. «Stage-discharge» is a time-dependent and very often they exhibit random fluctuations caused by modifying gauging cross sectional during the various flood, their relationship is not always unique. One of the solutions is give the discharge as a unique function of the stage as following a power curve, in the present paper the observed stage-discharge data of two hydrometrics stations in the «Algerian Coastal» watershed are put to the test by an artificial neural network and by using linear multiple regression. The results show the interest of these approaches, particularly in the curves extrapolation, when the «Stage-discharge» relationship is not a single one.

HPS1PS.06

HPS1PS - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Poster

Network technologies of spatio-temporal processes research

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We present new results on geoinformation technology for natural process research, which is incorporated into two dynamic web-GIS's: GeoTime 3 and Geo-ESIMO. Free online access to them and a set of demo GIS-Projects are available at http://www.geo.iitp.ru/GT3 and http://www.geo.iitp.ru/esimo. Both Web-GISs are implemented as Java applications. They encompass network access to geographical data and plug-ins, which may be distributed over network servers as well as stored on the user PC, and GIS-interface to launch calculations on remote servers and grid. The technology combines visual exploration, spatial and spatio-temporal modeling, finding empirical relations and special object-oriented methods. Visual research methods include (1) animation analysis of one or more processes; (2) comparison with standard processes and WMS tile map image; (3) interactive graphic modeling and measurement. The methods of modelling allows to extract new properties of spatial and spatio-temporal data: (1) the fields of local thematic, spatial and spatio-temporal properties of the processes; (2) the fields of functions from one or several processes; (3) the fields of statistical properties of processes. Finding empirical relationships allows: (1) to select spatial areas with similar dynamics; (2) to detect spatio-temporal anomalies in the fields; (3) to estimate the parameters of the anomalies. Subject-oriented techniques include: (1) computation of seismic flow fields; (2) separation and analysis of cluster component in seismic flow; (3) spatial segmentation of GPS and InSAR time series; (4) analysis of spatio-temporal characteristics of ocean processes. The case studies on spatio-temporal analysis of earthquake fields, analysis of ocean processes, processing of GPS and InSAR time series, and express analysis of the forecast data on oil pollution at sea will be presented. The research is supported by RFBR projects 10-07-00204-à and Targeted Federal Program “World Ocean”.

HPS1PS.07

HPS1PS - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Poster

Water resources in semi-arid zones (climatic and anthropic impacts): The case of the Essouira aquifers system (Mogador,Morocco)

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The water resources of the Essaouira basin are characteristic of a semi-arid climate, and are severely impacted by the climate (quantity and quality). Considering the importance of the Essaouira aquifer in the groundwater supply of the region, a study was conducted in order to comprehend this aquifer groundwater evolution. It is a coastal aquifers located on the Atlantic coastline, southern (Morocco), corresponding to a sedimentary basin with an area of near 200 km2.

A water sampling from forty wells, drillings and sources belonging to the plioquaternary and turonian aquifers was realised. The electric conductivity and temperature were measured on the ground. Waters belonging to the plioquaternary aquifer present very variable electric conductivities from 1590 us/cm to 5040 us/cm. In spite of this variability, they form the same family and are characterized by sodium-chloride facies. There exists, however, a good correlation between the electric conductivity and chloride and sodium contents. The lower electric conductivities are situated in the North-Est quarter immediately in the south of the Ksob River.

Potable water supplying the Essaouira city and its neighbouring rural agglomerations is presently based on exploiting underground waters, notably those of the plioquaternary aquifer. This aquifer is submitted to several constraints. Less deep, this aquifer is sensitive to drought episodes, more frequent in Morocco; the most severe one was happened in 1995. It has been shown by this study that the recharge rate of the deep turonian aquifer is too low. This may cause a lack of water for supplying the Essaouira city and its region. Nevertheless, if we return to the drought context of the past years as prevented by the present world tendency, Moroccan authorities must envisage to build small dams on the Ksob river for a better management of flooding waters which are presently thrown in the Atlantic ocean.

HPS1PS.08

HPS1PS - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Poster

Snowfall return time estimation using precipitation and temperature time series

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The issue of snow events return time estimation is of relevant importance in places characterized by a lack of observations. Where these events are infrequent, areas are usually not equipped to measure snowfall. In this framework a statistical analysis concerning snowfall return time estimation is an issue that makes post-event effects, regarding electrical, hydraulic and road infrastructures, difficult to be managed.

In this study, the task of snow events return time estimation is faced analyzing pairs of rainfall and temperature data. The direct return time estimation of snow events is compared to an indirect return time evaluated using rainfall and temperature bivariate analysis. First, the statistical dependence of snow, rainfall and temperature is analyzed, second, the rainfall sample is selected conditioning values to a specific range of temperature and its return time is computed. Finally, both return times are compared.

In order to verify the proposed approach, case studies where rainfall, snow and temperature observations are available, are selected. The indirect return time of rainfall and temperature can be easily estimated, thanks to the procedure applied for selecting rainfall sample in respect to a given temperature range. Results obtained with the two approaches are compared, presenting encouraging perspective in terms of return time value equivalence.

HPS1S1.01

HPS1S1 - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Oral

Implications of strong-rate-weakening friction for the length-scale dependence of the strength of the crust; Why earthquakes are so gentle

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The thinness of fault slipping zones and the paucity of observed melts implies very low dynamic friction compared to the overburden pressure (less than 0.05 for a meter of slip at 10 km). However, if static friction was comparably low, then the crust could not support observed topographic relief. Strong-rate-weakening friction seems to be a plausible explanation for these seemingly conflicting observations. Strong-rate-weakening friction leads to slip-pulses with extremely complex failure dynamics; strong positive feedback between the slip and the friction produces multi-scale chaos. Unfortunately, 3-d continuum problems with strong-rate-weakening friction are numerically intractable. Therefore we investigated the much simpler problem of 1-d spring block sliders with strong-rate-weakening-friction. We show that the system produces power-law complexity. That is, the pre-stress evolves into a state that is heterogeneous at all scales. Since the pre-stress and the events are spatially heterogeneous, we must generalize our definition of "strength." We define stress based strength to be the spatial average of the pre-stress in a failure region, and we define work-based strength to be the average work per unit of deformation. We show that these strengths are not the same. Furthermore, we show that the larger the event (or system), the smaller the strength. We show that the strength decreases as a power with the size; the exponent of this relation is related to the dynamic heterogeneity of the system. Since the model is homogeneous, all complexity is dynamic. Earthquakes are so gentle because the Earth is so big.

Finally we show a surprising new energy transport equation that reproduces the chaotic behavior of the full numerical simulation. The equation is multi-scale and many orders of magnitude faster than the full numerical system.

HPS1S1.02

HPS1S1 - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Oral

Comparing and contrasting earthquake, flood and storm disaster statistics: Real and spurious trends

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We compare statistics for different types of natural disasters. There is a clear upwards long-term trend in the reported number of hydro-meteorological and geological natural disasters, such as floods, storms, and earthquakes. While it is well known that this is partial due to improved reporting over the last century, it is often considered that for the most recent decades data is rather reliable. We look at various statistical properties of data for reported floods, storms, and earthquakes. We apply various statistical methods, including frequency-magnitude analysis, in order to investigate the internal consistency of the data from different time periods and investigate trends. Our analysis reveals that conclusions based directly on the registered number of fatal earthquake, storm and flood disasters are misleading. This is because even for recent years inadequate reporting has large effects on the number of such events. In fact, improved planning, physical infrastructure and emergency response mean that society has been far more successful at reducing the total number of fatal flood and storm disasters than the data apparently suggest. For earthquakes things are worse, presumably because of the lack of short-term warnings. Even here, however, in relation to population growth there have been major improvements. We also investigate the total number of fatalities, as opposed to the total number of fatal events. The hydro-meteorological disasters investigated show a very long-term downward trend, but the figures for earthquakes are relatively constant. Total fatality is dominated by rare, large events and pseudo-random variations in these means that on shorter, e.g. decade, time scales no underlying trend can be reliably confirmed. However, if the number of fatal events is stable or decreasing it is plausible that there is also an underlying downward trend in total fatalities related to storms and floods.

HPS1S1.03

HPS1S1 - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Oral

Estimating noise in climate simulations: Which significance test performs the best

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Externally-forced climate change simulated by general circulation model needs to be compared with model noise (model internal variability) in order to assess the robustness of climate change signals. Significance tests are performed to establish the robustness of the signal, and the core step in a significance test is to quantify the noise. Student's t-test has been the most popular significance testing technique, despite more sophisticated techniques developed over the years. Some of these techniques were tested before, but only on artificial data that cannot fully capture all the features of general circulation model output. We evaluate how well five different significance testing techniques (including Student's t-test) quantify noise on 10 to 100 continuous-year simulations, and validate the performance using much longer (220 to 1000 years) model simulations, instead of using artificial data. We find that Prewhitening Bootstrap test tends to perform slightly better than the other techniques for strongly-autocorrelated simulations while Effective Sample Size t-test is generally the worst performer regardless of autocorrelation. Overall, the sophisticated techniques fail to significantly improve over Student's t-test. With 20-year (50-year) integrations, the average errors in estimated noise by the techniques (except Effective Sample Size t-test) are in the range of about 25~50% (20~50%).

HPS1S1.04

HPS1S1 - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Oral

Variability of hydrologic regime for the last millennium in five continents

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Tree rings data is valuable proxy data, which is usually used to explore the hydrologic conditions of an area in the past. There is a very good correlation between the tree rings measurements and the amount of precipitation for each given year. Low frequency components of tree rings data for over 50 stations in five continents are explored using singular spectrum and wavelet analysis techniques. The results show that long term events such as Little Ice Age and Medieval Warm Period are evident in all continents, whereas short term events are specific only to certain continents. In other words, the effect of long term events is more global rather than being regional or local. This type of comparative analysis across different geographic locations will help enhance our understanding of hydrologic systems with prolonged missing data periods. Non-linear trend pattern in tree rings data from different regions show that the change of water availability can be studied in local, regional, and global scales. The extraction of nonlinear trend in tree rings data series could serve as a basis in prediction of the long term and large scale variability of water availability in local, regional, and global scales. The nonlinear trend in most of tree rings time series in the present study explains more than 60 percent of the variance; therefore, based on its strong correlation with precipitation, its prediction would reveal the main pattern of available water variability for decades and centuries to come.

HPS1S1.05

HPS1S1 - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Oral

The functional framework for hydrological variables

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River flows records, continuously measured and analyzed, are essential for the prevention of flood risks and the effective planning and management of water resources. A hydrograph is a graphical representation of the temporal variation of flow over a period of time. A flood hydrograph is commonly characterized by its peak, volume, and duration. Recent multivariate approaches in hydrological frequency analysis (FA) considered these features jointly in order to take into account their dependence structure. However, all these approaches are based on the analysis of a limited number of characteristics and do not make use of the full information provided by the hydrograph. The objective of the present talk is to propose a new framework for FA using the hydrographs as curves: functional data. In this context, the whole hydrograph is considered as one infinite-dimensional observation. This context allows us to provide more effective and efficient estimates of the risk associated with extreme events. The proposed approach contributes to addressing the problem of lack of data commonly encountered in hydrology by. A number of functional data analysis tools are introduced and adapted to flood FA with a focus on exploratory analysis as a first stage toward a complete functional flood FA. These methods are illustrated in a real-world flood analysis case study from the province of Quebec, Canada.

HPS1S2.01

HPS1S2 - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Oral

Effect of time discretization and finite record length on continuous-time stochastic properties

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Natural processes evolve in continuous time but their observation is inevitably made at discrete time. The observational time series formed are either series of instantaneous values of the natural phenomenon at a certain time step or aggregated quantities during this time step. In addition, the observation period is apparently a finite time period. Both time discretization and finite length may strongly affect the stochastic properties inferred from the data. In particular, time discretization distorts the stochastic properties at small time scales, while the finite length affects the properties at large time scales. Modelling of natural processes is typical made assuming discrete time and parameter estimation is usually done using classical statistical estimators which assume that observations are random samples. All these are inadequate practices and result in inappropriate and biased models. A different modelling strategy is proposed, in which the stochastic model is by definition a continuous-time process and the distortion due to discretization and finite-period observation is explicitly taken into account in model calibration. An additional benefit of the proposed strategy is that it avoids the too artificial, often non-parsimonious, families of discrete time stochastic models (like the ARIMA(p,d,q) models).

HPS1S2.02

HPS1S2 - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Oral

Universal multifractals characterization of the rainfall runoff relationship in urban and peri-urban hydrology

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Scaling laws, and more specifically Universal Multifractals (UM), have been extensively used to analyse and simulate geophysical fields extremely variable over wide range of spatio-temporal scales such as rainfall or river discharge. However not much attention has been devoted to surface runoff. Here we suggest performing a multifractal analysis of surface water depth and velocity maps to improve understanding of the rainfall-runoff relationship. The studied field consists in the outputs of a fully distributed urban hydrological model currently under development called Multi-Hydro. It consists in an interacting core between open source software packages, each of them representing a portion of the water cycle in urban environment. Two catchments of the Paris (France) area are tested: a 144 ha flat urban area in the Seine-Saint-Denis County, and a 250 ha urban area with a significant portion of forest located on a steep hillside of the Bièvre River. Three rainfall events that occurred in 2010 and 2011, for which the Météo-France radar mosaic with a resolution of 1 km in space and 5 min in time is available, are analysed. They generated significant surface runoff and some local flooding. The model is tested with pixels of size 5, 10 and 20 m. The rainfall data is stochastically downscaled to higher resolution simply by continuing the underlying cascade process which is observed on the available range of scales. It appears that the outputs (maps of water depth and velocity, and discharge in conduits) of the hydrological model exhibit a scaling behaviour both in space and time. The three UM parameters of the various processes at stake are then compared which enables to analyse how the extremes are either dampened or enhanced. This hints at innovative techniques to quantify the extremes at very high resolution (typically 1 m) without having to run the model at these resolutions which would require to much time especially for real time applications.

HPS1S2.03

HPS1S2 - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Oral

Testing for trends in multivariate hydrologic frequency analysis

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Hydrological frequency analysis (HFA) relies on a number of assumptions on the data series, in particular stationarity. In the univariate setting, these assumptions are generally checked before the modeling step. During the last decade, multivariate HFA approaches have gained popularity in the field of hydrology. However, the step of checking the assumptions remains neglected in the multivariate HFA literature. For a reliable analysis and accurate results, the above required assumptions should also be checked prior to modeling in the multivariate setting. The present talk attempts to start bridging this gap in the application of multivariate HFA. We only focus here on the application of nonparametric tests for monotonic trends in HFA. A first application of the tests described herein is given on the basis of a multivariate data set characterizing flood attributes from two stations. A multi-site application for different locations is also presented. In both applications, univariate and multivariate trends are detected in some situations. It is recommended to jointly apply univariate and multivariate trend tests for an overview of different trend components which guides the selection of accurate and appropriate models.

HPS1S2.04

HPS1S2 - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Oral

Hydrologic drought characteristics analysis of Xijiang basin, China

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Drought is a recurring phenomenon that has plagued civilization throughout history in xijiang basin. Streamflow analysis has vital importance in water uses and management, including domestic water supply, irrigation scheduling, reservoir operation, in-stream flow maintenance, etc. We used the 59 years (1951»C2009) daily streamflow data of twelve sites on the Xijiang basin, China. An independent hydrologic drought event was classified using standardization runoff index (Z). The mean of seven days' Z values instead of the original value to exclude small drought events and IT method was used to combine related drought events, respectively. The year 1963 was selected as extreme drought year to verify the identified drought events. Z values were adopted to reveal the temporal and spatial drought characteristics. The drought duration and intensity are subjected to exponential and gamma distributions, respectively. With the application of Clayton copula, Frank copula and Gumbel-Hougard copula and other four different two-dimensional copula functions to model the joint drought duration and severity distribution. Meanwhile, maximum likelihood method and Kendall coefficient method were selected to estimate joint distribution parameters, respectively. The results show that the severe hydrological drought events in history can be well indentified and southwest of xijiang basin experience frequent, persistent hydrological drought, while the north lasted shorter. The copula fitting results of drought duration and severity are quite satisfactory and the frank copula function shows the minimum error when compared with empirical value. The relationship among hydrological drought, meteorological drought and agricultural drought are reported on.

HPS1S2.05

HPS1S2 - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Oral

Impacts of ENSO on the southern African rainfall as revealed by self-organizing maps

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Using a relatively new statistical method called self-organizing maps (SOM), impacts of El Nino/Southern Oscillation (ENSO) on the southern African rainfall are examined. For the present analysis, we have used observational data and outputs from three versions of an atmospheric general circulation model. The SOM have successfully captured synoptic precipitation patterns along with their interannual variability. It is shown that nodes associated with tropical temperate troughs (TTTs), which provides a substantial portion of summer rainfall in southern Africa, in the southern (northern) part of the domain are observed less (more) often during El Nino years, while nodes associated with TTTs occur more frequently during La Nina years. Also, nodes with dry condition over southern Africa are more (less) frequently observed during El Nino (La Nina) years.

HPS1S2.06

HPS1S2 - Advanced Statistical Methods for Hydrology, Oceanography and Seismology

Oral

A new approach to calibrating hydrological models: Using cross wavelet transforms to select calibration and validation periods

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We propose a new approach to model calibration, one that employs the use of cross wavelet transforms to identify relationships in time frequency space between climate and discharge time series. Hydrological models often have a calibration and validation period that is defined by data availability alone, even when a more deliberate calibration approach is employed there is seldom much effort to account for the climate variability. The choice of the periods used in the calibration process has an effect on the model's performance and developments in this field will be beneficial to most modelling endeavours, especially for forecasting and climate studies. Climate data that includes information about the climate variability, for example teleconnection indices, are used together with discharge time series to calculate the cross wavelet transform which is used to choose the calibration and validation periods. The cross wavelet transform gives information regarding the frequency, period and power of the relationships in the two data sets which allow the user to choose appropriate periods for calibration and validation, regardless if they are employing a multi period calibration approach or a more traditional single period approach. The benefit of this new method is that it is able to provide the user with objective information regarding the climate and hydrological variability that can be used to better select calibration and validations periods. This would translate to models that are better calibrated for modelling the full range of variability of the system.

Hw03PS.01

Hw03PS - Characterizing water quantity and quality: new approaches and future directions

Poster

Analysis of baseflow recession for estimation of hydrogeological parameters in the vertically heterogeneous aquifer

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The baseflow recession process from ground water is controlled by the basin hydrogeological characteristics. The characteristics of baseflow can be described by the Brutsaert-Nieber equation, which was usually applied in the homogeneous aquifer. Rupp and Selker (2005) proposed an analytical solution of quick and slow recession flow equations in the vertically heterogeneous aquifer that a saturated hydraulic conductivity decays in a power law. We used this analytical solution to estimate hydrogeological parameters of saturated hydraulic conductivity, specific yield associated with soil depth and vertical variation of the soil permeability. The method was applied in a small catchment of Xingfeng in Dongjiang watershed of southeast China. The results demonstrate the estimated hydrogeological parameters, particularly saturated hydraulic conductivity, are greatly influenced by vertical heterogeneity of soil. As the index of n for describing soil heterogeneity in the Rupp and Selker method (2005) increases from 0 to 4, the average saturated hydraulic conductivity Kave increases 2.2 times and the specific yield increase 1.4 times. If base flow and watershed features, such as width and length, are known, this method offers a reasonable result of the hydrogeological parameters.

Hw03PS.02

Hw03PS - Characterizing water quantity and quality: new approaches and future directions

Poster

Hydrogeochemistry of aquifers in active fault areas: Carboneras-Palomares Fault Zone (SE Spain)

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The character of the hydrological changes that follow major earthquakes has been investigated and found to depend on the type of faulting. Our study areas are located in different zones, but in this abstract we present results from the Palomares Fault and Carboneras Fault Zones, in the eastern part of the province of Almería (Spain).

A monitoring network has been designed to study the physical and chemical parameters of water in relation to seismic events in the Palomares–Carboneras Zone. We are trying to establish a groundwater circulation model and to identify the sources of aquifer fluids (exogenous/endogenous). Finally, it is important to determine the influence water flow can have on the nucleation of new earthquakes, so the sources directly related to the most significant failures in the study area need to be characterized.

The chemical composition of the waters reflects different types and degrees of water-rock interaction. Due to the geological complexity of the Palomares–Carboneras Zone, and taking into account the different hydrogeological paths recognized in the area, several geochemical families have been found: a) Extreme electrical conductivity (from 4000 to 9700 µS/cm) with very high salinity: Na-Ca-Mg-SO4-Cl and Na-Mg-Cl-SO4 types, related to Pliocene marine marls in the Vera Depression and Pulpí Corridor.

b) High electrical conductivity (from 2000 to 3500 µS/cm): Na-Ca-Mg-SO4-Cl and Na-Mg-HCO3-Cl-SO4 types, related to the dissolution of evaporites and carbonates along deep faults.

c) Low electrical conductivity from 300 to 730 µS/cm: Ca-Mg-Na-HCO3-SO4 type in relation to the dissolution of carbonates from Sierra Cabrera and Cerro del Alamo.

Hw03PS.03

Hw03PS - Characterizing water quantity and quality: new approaches and future directions

Poster

Drinking water quality problems in arid and semi-arid area of central Rajasthan

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Rajasthan is well known for its Great Thar desert. Central Rajasthan has arid to semi-arid environmental. Such area faces either scarcity of water or poor quality of drinking water. Groundwater is major source for drinking purpose due to unavailability of surface water. There is a lack of groundwater quality knowledge to the community and data available are hard to understand by non-technical community. The CCME Water Quality Index is a tool for simplifying the reporting of water quality data. It provides meaningful summaries of overall water quality and trends, which is accessible to non-technical lay people. In the present study it is objected to examine the groundwater quality of 6 districts (viz. Ajmer, Bhilwara, Pali, Rajasamand, Nagaur and Jodhpur), centrally located to Rajasthan with arid and semi-arid conditions. CCME WQI is also evaluated to produce quality data in a form to understand by community. 4369 groundwater source of 1680 villages from 6 districts (76,959 Km2.) are collected and examined for 9 major physic chemical parameters (i.e. pH, TDS, Chloride, Nitrate, Fluoride, Total Hardness, Calcium, Magnesium and Alkalinity). Results are framed in BIS: 10500, 1993 and found 2952 samples unfit for drinking purposes. According to CCME WQI groundwater of 93 villages is poor, 343 villages is marginal and 369 villages is fair in quality. Toxicological studies of unsafe drinking water and their remedial measures are also discussed. A tentative correlation between prevailing water-borne diseases and quality parameter has also been shown. It is also concluded that WQI can be used as a tool in comparing the water quality of a village. It gives a general idea of the possible problems with drinking water in a particular region. The index is most effective ways to communicate the information on water quality to the public or to the policy makers.

Hw03PS.04

Hw03PS - Characterizing water quantity and quality: new approaches and future directions

Poster

Factors controlling the evolution and changes of freshwater chemistry constituents in Langat River Basin, Malaysia

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In Malaysia, freshwater ecosystems play a significant role in providing water to domestic, agricultural and industrial purposes. At present, these ecosystems have been facing numerous threats that challenge the local authorities' ability on tackling down the water security (quantity and quality) issues and management. Various guidelines and protocols were set up to represent a desired level of elements and contaminants in water bodies. However, the natural content of elements may not always meet or equal to the desired levels. The quality of surface water is an essential component of the natural environment and is considered as the main factor for controlling environmental health and potential hazard the surrounding ecosystem. Langat River Basin in Selangor, Malaysia is among the river basins that serve as one of the most important freshwater ecosystems in not only limited to Selangor state but also to few other states where the basin lies are highly developed. This river is exposed to natural and anthropogenic interference while beset by unforeseen evolution of water quality. A study was done to clarify the hydrogeochemical processes and potential sources of interference in the river. An environmental forensic investigation via the use of geostatistical and geochemical approaches and different standard criteria revealed two sources controlling the evolution of Langat River Basin water chemistry: (i) anthropogenic (agricultural and industrial activities) and (ii) natural processes (seawater intrusion and geological weathering). In addition, the suitability of river water for various purposes was determined based the application of selected indicator and indices. The findings will serve as an essential platform for the protection of water resources and in the assessment of water quality for creating the threshold ions compositions in natural water. Therefore this study have an important practical and strategic significance to the surrounding area.

Hw03PS.05

Hw03PS - Characterizing water quantity and quality: new approaches and future directions

Poster

The Local Polynomial Method: A processing tool to quantify surface-subsurface exchange flows using temperature times series

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The quantification of surface-subsurface exchange flows is important for the assessment of water resources or the investigation of pathways and fate of contaminants and nutrients. Field monitoring in time and space is indispensible for process understanding of hydrological interactions and their variability. Not only is the complexity of the examined processes asking for novel data processing and characterization tools, it is also the vastness of acquired information which urges for new solutions. New techniques therefore should be easily applicable, allow fast computation and a flexible output including uncertainties and should use a maximum amount of information for the analysis. Sensing of temperature profiles in riverbeds in conjunction with numerical and analytical heat transport simulation tools is becoming a standard in the characterization of vertical exchange fluxes. For this type of investigations we propose the application of the Local Polynomial Method (LPM) in conjunction with a Maximum Likelihood Estimator (MLE).

The LPM determines the frequency response function between measured temperatures time series at the water-sediment interface and within the riverbed. Then, a non-linear optimization technique is applied (i.e. a MLE), which allows the determination of the model quality and parameter uncertainty. Finally, the optimized model parameters are transformed from the frequency domain to the time domain where they hold information regarding the vertical exchange flux and thermal soil parameters.

The presented methodology is flexible and fast and is able to create time series of exchange fluxes and their uncertainties. Advantage of LPM In comparison to other methods is that it uses all measured frequency information for data processing. For validation we compare results of the LPM with measurements from conventional techniques like seepage meters, hydraulic head gradients as well as other numerical and analytical heat transport simulation tools.

Hw03S1.01

Hw03S1 - Characterizing water quantity and quality: new approaches and future directions

Oral

An evaluation of selected inorganic surface water quality monitoring practices: are we doing it right?

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Successful environmental/water quality-monitoring programs usually represent a balance between analytical capabilities, the collection of representative samples, and available financial/personnel resources. Currently, monitoring programs are under pressure to do more with less. Hence, a review of current procedures should be undertaken to see if they are achieving program objectives cost-effectively.

An evaluation of many widely used sampling, processing, and analytical procedures indicates that they may be generating non-representative/non-comparable data. The differences resulting from using alternative procedures clearly indicate that databases require metadata files so that users are aware of how the data were collected and/or generated and its limitations.

The common practice of calendar-based sampling needs to be re-examined, and possibly replaced by hydrologically-based sampling. This accrues because there is a linkage between water discharge (flow) and many common water quality parameters. The extensive use of surrogates (e.g., turbidity), as well as empirical or process-oriented models has become common because they represent less costly alternatives for generating water quality-data. However, these approaches depend on accurate calibrations based on manually collected representative measurements/samples. Further, because the concept of stationarity appears to be fallacious, those initial calibrations must periodically be re-examined to ensure that the relationship(s) that form their bases are still valid.

As a result of these findings, all monitoring programs should incorporate periodic technical/programmatic reviews to ensure that monitoring objectives continue to be met. If they aren’t, or if the objectives change whilst monitoring continues, some programs may require redesign, some procedures may need updating, and some model/surrogate relationships may require recalibration.

Hw03S1.02

Hw03S1 - Characterizing water quantity and quality: new approaches and future directions

Oral

Estimating riverine fluxes and their uncertainties from discrete surveys

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Data on riverine fluxes are essential for calculating element cycles (carbon, nutrients, and pollutants) and erosion rates from regional to global scales. At most water-quality stations throughout the world, riverine fluxes are calculated from daily flow data (Q) and discrete concentration data (C), the latter being the main cause of sometimes large uncertainties. This presentation offers a comprehensive approach for predicting the magnitude of these uncertainties for water-quality stations in medium to large basins (basin area>500 km^2) based on eight commonly used method (averaging, regression and hydrograph separation methods) for suspended particulate matter, dissolved solids, dissolved and total nutrients, metals, and pesticides. The performance of each method was analyzed first by type of riverine material, which appeared to be much less pertinent than the flux variability matrix. The latter combines the river flow duration in two percent of time (W2%) and the truncated exponent (b50sup) defining the C vs. Q relationship at higher flows . As flux variability increases (high W2% and/or high b50sup), averaging methods and rating curve methods become less efficient compared to hydrograph separation methods. A large data base of daily surveys, 125 station variables of suspended particulate matter (SPM), total dissolved solids (TDS) and dissolved and particulate nutrients, was used to determine uncertainties from simulated discrete surveys and to establish relationships between indicators. The flux variability matrix can be used in three ways. Firstly, flux biases and imprecisions can be plotted in the [W2%, b50sup] matrix for different sampling strategy (monthly, ..) for each method. Secondly, the best method can be highlighted in the matrix variability, depending on hydrological and hydrochemical/hydrosdimentological variability. And thirdly, the matrix variability can be used to predict the sampling effort required to achieve a specified level of precision.

Hw03S1.03

Hw03S1 - Characterizing water quantity and quality: new approaches and future directions

Oral

Assessing the effectiveness of different monitoring strategies on the identification of a hydrologic water quality model

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Eutrophication of fresh water is a widely reported aquatic problem in the world. The Selke catchment is a small tributary of the Elbe river, which shows high heterogeneity in catchment characteristics. The objectives of this study were to (i) assess the new conceptual process-based hydrologic water quality HYPE model (HYdrological Predictions for the Environment) for simulation of runoff and nitrogen emission at the Selke catchment, and (ii) evaluate the effect of different water quantity and quality monitoring strategies on the model identification. To this end, HYPE was calibrated against measured daily discharge and regular sampling (biweekly/monthly) of IN (Inorganic Nitrogen) concentration. PEST was used to implement parameter sensitivity analysis, multi-objective automatic calibration. Parameter sensitivity analysis showed that potential evapotranspiration rate is most sensitive for runoff simulation, while the nitrogen leaching is mainly controlled by plant uptake and denitrification. HYPE reproduced hydrographs quite well for both calibration and validation periods at all three gauge stations with the lowest Nash-Sutcliffe Efficiency (NSE) of 0.86. The model reproduced well the hydrologic responses to the extreme climate conditions in terms of discharge and soil moisture storage. Observed IN concentrations showed increase in magnitude but decrease in dynamics along the descending of stream slope. Monthly IN loads dynamics were well represented for both calibration and validation periods with the lowest NSE of 0.69. Temporal and spatial variations of IN loads reflect proportionality between IN loads and runoff, indicating that IN emission is mainly controlled by runoff. Currently, high resolution water quality constitutes are measured at 15-minute step. The MCMC is being combined with HYPE model to implement uncertainty analysis for comparison the new monitoring system with conventional regular sampling scheme on model identification.

Hw03S1.05

Hw03S1 - Characterizing water quantity and quality: new approaches and future directions

Oral

Managing water resources on the basis of their ecological status

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Human activities in industrial and agricultural production, hydroelectric power generation, forestry, fisheries, recreation, municipal water use and transportation negatively affect both the quantity and quality of water resources. Recently, these drivers are being also coupled with and amplified by the cumulative effects of global warming and, in a broader sense, climate change. As one of the vital conditions of societal development, water resources require that in selecting managerial strategies, a future status of aquatic environments be adequately forecasted. The status of aquatic ecosystems is formed by the interplay of natural factors and the impact caused by anthropogenic stress. An anthropogenic component in an aquatic ecosystem dynamic behaviour is important as it alters rate of ecosystem development, dramatically speeding it up in most of the cases and because human-caused disturbances are "unfamiliar" to the ecosystem, which means that there are no evolution-developed compensatory reactions or adaptive mechanisms within the ecosystem to cope with and sustain the stress. We consider a set of invariant transformations which any aquatic system displays under anthropogenic stress and the corresponding patterns in the ecosystem's reactions to stress. These reactions operate at each level of life organization from cellular and sub-cellular mechanisms to populations and communities. At the same time, an ecosystem reacts to stress synergistically, as a whole, and this can be traced down through the changes in its structural organization. The latter is interpreted as the ecological status of the aquatic ecosystem. Predictions of ecological status require specific data on aquatic chemistry and toxicology, climate, hydrology and hydrobiology as well as special methods and techniques of data collection, storage and processing. These issues are discussed within the task of water body assessment and management under various kinds of anthropogenic impacts.

Hw03S2.01

Hw03S2 - Characterizing water quantity and quality: new approaches and future directions

Oral

Subsurface characterization: Some recent developments and future prospects

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Virtually every hydrogeologic investigation requires information about the processes and properties affecting the flow of water in the subsurface. In this presentation, we will provide an overview of a cooperative program of data-driven research directed towards the development of new and/or refined methods for the physical characterization of subsurface flow systems.

At sites of groundwater contamination, we need information about the fine-scale hydrostratigraphic details (i.e. spatial variations in hydraulic conductivity (K)) that are often a critical control on contaminant movement. Recently, significant progress has been made in utilizing direct-push (DP) technology to characterize K variations in unconsolidated settings. The newest generation of DP tools allows characterization of vertical variations in K at a resolution as high as 0.015 m.

High-resolution K information is often used to estimate groundwater flux and its variation in space. Ideally, however, we would measure groundwater flux directly. Recently, progress has been made on the development of a tool for high-resolution characterization of vertical variations in groundwater flux. Information at a 0.014-m vertical resolution has been obtained using fiber optic distributed temperature sensing technology to monitor the temperature response to active heating in a well.

Given recent technological advances, monitoring of head responses to natural stimuli (e.g., fluctuations in stream stage and barometric pressure, plant water uptake) should play an increasing role in subsurface characterization. For example, water-level responses to barometric pressure changes can provide important insights into issues such as degree of confinement, sufficiency of well development, and bulk properties of the vadose zone. A particularly promising avenue for estimating evapotranspiration and other components of the water balance is through monitoring of pore pressures in clay units (geolysimeter).

Hw03S2.02

Hw03S2 - Characterizing water quantity and quality: new approaches and future directions

Oral

Real-time eco-hydrology: Investigating groundwater - Surface water exchange combining different technologies

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Groundwater discharge entering rivers and lakes has often been neglected due to some measurement difficulties and the intense spatial heterogeneity of the groundwater discharge. On the contrary, measurement of river water infiltration into the hyporheic zone is also complicated because of small-scale flow patterns due to river bed morphology. Therefore, fast, easily applicable methods to detect groundwater-surface water exchange pattern are required for different purposes and scales. We applied techniques based on temperature differences between subsurface and surface waters. First, a new technology based on heat-pulse sensors is presented which enables to estimate small-scale hyporheic flow directions and flow velocities in this zone. The measurement of groundwater exfiltration or stream water infiltration with distributed temperature sensing (DTS) is an efficient method to identify specific exchange locations. Temperature profiles of sediments might be subsequently used to quantify the fluxes. This combination allows for estimating groundwater-surface water exchange at a medium scale. To scale up airborne measurements of thermal infrared radiation (TIR) might be applied. As a result of previous field investigations based on ground-based methods the groundwater discharge pattern of the study site Lake Arendsee is well established. A TIR image taken in spring 2012 agrees with our previous findings and shows that warm groundwater entering the lake in some near-shore areas is visible as plume floating on top of the lake. Prerequisites for the application of TIR to detect exchange pattern are identified based on the balance between positive buoyancy of the groundwater and intensity of vertical mixing produced by heat and momentum fluxes at the lake surface. The quantification of groundwater-surface water exchange is of great ecologically relevance, e.g. considering the aspect of nutrient import into lakes or rivers. Due to intense spatial heterogeneity of nutrient conc

Hw03S2.03

Hw03S2 - Characterizing water quantity and quality: new approaches and future directions

Oral

Soil moisture observations by micro TDR coil probes in the surface thin soil layer from 0 cm to 5 cm depths in the Steppe of Mongolia

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Micro TDR coil probe (CP) developed for soil moisture measurement can be considered to be effective to the soil moisture measurement in the thin soil layer near the soil surface. It is indispensable for using CP to know actually the durability, the stability and applicability of CP in the field. The soil moisture measurement in the surface thin soil layer from o cm to 5 cm depths is also important to make a validation of soil moisture measurement algorithm of some satellite sensors (eg. AMSR2). The CP was made of brass and enamel wires and the sensor size was 45mm in diameter and 40mm in length. We made a severe test of CP in the cold steppe of Mongolia after laboratory tests of probe error and temperature effect. Six CPs, two wire type TDR probes and some meteorological instruments were installed in Sanzai site covered with grass and highly wet soils and made a field tests for the period from 2002 to 2007. We had much snowfall in winter and air temperature changed widely from + 38 to - 36 there. After the field tests, we set the same CPs with two wire type TDR probes and some meteorological sensors at the Mandalgobi site (MGS) in the MAVEX (Mongol AMSR-E/AMSR2 Validation Experiment) study area on the Mongolian plateau in 2008. Air temperature varied between + 38 to - 35 there. Each two CPs were horizontally installed at the 1 cm, 2 cm, and 3 cm depths, respectively. The CPs succeeded in stable and precise soil moisture measurement in the surface thin soil layer above the 4 cm depth and showed more dynamic behaviors than would be expected.

Hw03S2.04

Hw03S2 - Characterizing water quantity and quality: new approaches and future directions

Oral

A modified Spearman rho test for autocorrelated hydrological series

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Spearman rho test is a widely used nonparametric rank-based statistical test to detect monotonic trends in hydrological time series, so as another technique the Mann-Kendall test. Both tests assume that data are independent in series. However, autocorrelation commonly exits in hydrological series, especially in monthly series. Concerning the fact that the existence of autocorrelation would influence the significance answer of trend detection, the original Spearman rho test is modified by correcting the variance of the test statistic so as to suit autocorrelated series. Firstly, this paper derived a theoretical relationship to calculate the variance of Spearman rho for autocorrelated data; Then, in order to reduce computation time consumption, an approximate formula to the theoretical relationship is presented based on numerical simulation of two special cases e.g. AR(1) and MA(1) dependence series. By statistical simulation, comparison of the modified and original test methods is carried out, and the results demonstrate that the modified Spearman rho test is more accurate than original one in significance level without loss of power. Moreover, the modified Spearman rho test has the similar power as modified Mann-Kendall test proposed by Hamed K.H. in detecting trends. The modified test is applied to monthly streamflow data of 5 stations in upper reaches of the Yangtze River. The performance of the modified Spearman rho test is demonstrated and compared with original one.

Hw03S2.05

Hw03S2 - Characterizing water quantity and quality: new approaches and future directions

Oral

Using periphyton as an indicator of bioremediation of mine water pollution

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Water quality assessment often relies heavily on chemical and macro-biological (e.g. macro-invertebrates and fish) indicators. The use of periphyton – mats containing bacteria, algae and detritus which are attached to submerged surfaces in most aquatic ecosystems - has been overlooked. The analysis of periphyton samples by scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) allows the accumulation rates and removal pathways of potentially toxic metal pollutants to be determined in aquatic systems. The results can inform the design of effective water treatment systems and the understanding of the fate of metal pollutants in aquatic systems. In this study iron (Fe) accumulation in periphytic mats was examined in a settlement lagoon receiving mine drainage containing c. 7 mg L^{-1} total Fe, in Scotland, UK. Quantification and mapping of Fe concentrations within and on the surfaces of cells within periphyton samples using SEM-EDS suggested that Fe accumulation was dominated by the association of Fe-rich precipitates with the extracellular polymeric substances matrix, rather than biotic uptake. Intracellular Fe concentrations were significantly higher in periphyton samples exposed to the highest dissolved Fe concentrations. There was no evidence that Fe removal by the periphyton was affected by the community composition. Mean Fe concentrations in the periphyton samples after 3 months of exposure to the mine water were 6.8 ±2.1% Fe on a dry weight basis. However, the dominant removal process of Fe in the lagoon was settlement. Scale-up calculations based on the mean measured Fe accumulation rate by periphyton substrates of 0.021 g m^{-2} d^{-1} showed that exposure of large surface areas of periphyton substrate in the settlement lagoon would only increase the Fe removal efficiency of the lagoon by c.1%.

Hw03S2.06

Hw03S2 - Characterizing water quantity and quality: new approaches and future directions

Oral

Development and evaluation of an LED based fluorescence instrumentation for in-situ estimation of water quality

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An innovative and rapid way to potentially monitor the quality of water is to exploit its natural fluorescence. Previous research has identified relationships between fluorescence and water quality, specifically fluorescence emitted at 340-370nm under excitation at 220-240nm or 270-280nm (tryptophan-like fluorescence) is indicative of microbial activity (peak T), whilst fluorescence emitted at 400-480nm under excitation at 300-360nm (fulvic-like fluorescence) is indicative of the presence of organic carbon (peak C). Such work was reliant on expensive laboratory based equipment, producing intricate excitation emission matrices.

This work involves the design, build and testing of a dual wavelength, all-LED, battery powered instrument, capable of detecting microbial and fulvic-like fluorescence at levels potentially found in potable water. A fully functional device has been constructed and applied to a range of samples from 3 UK water company supply systems. Results from the new device, a bench top fluorescence instrument and standard analysis for TOC and microbial surrogates are being compared. Results so far demonstrate excellent correlation with the bench top instrument for both peaks ($R2 > 0.95$). Good correlation with TOC measurements have also been observed ($R2 \sim 0.72$). Definitive relationships between Peak T measurements and microbial surrogates have not yet been found, perhaps because the fluorescence response is to a wide range of microbial matter. The device has not provided any false positive readings. Overall the potential of the new instrument to provide real-time, in-situ initial assessment of potable water quality has been presented, with significant implications for proactive management. Further development of the device will permit the continuous monitoring of fluorescence intensities, therefore offering the opportunity for the device to be installed in distribution systems as an early warning device for elevated organic and microbial levels.

Hw03S2.07

Hw03S2 - Characterizing water quantity and quality: new approaches and future directions

Oral

Automated high-frequency sampling in water quality monitoring – from pattern recognition to biogeochemical process inference

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To date, high-frequency water quality sampling has revealed a far more complex catchment biogeochemical behaviour than inferred from low-frequency sampling and model predictions, including fractal and self-organization properties, non-stationarity and non-linearity.

We will discuss novel methodological and epistemological challenges introduced by emergent high-frequency monitoring strategies including detection and recognition of biogeochemical patterns in what seems to be noise data, establishing causal effects in coupled biogeochemical time series, integration of data between low-frequency and high-frequency water quality time series, feeding a new process-understanding into existing water quality models.

To understand the biogeochemical functioning of a small agricultural catchment subjected to diffuse pollution an automated nutrient lab for in-situ analysis of stream water samples was set up in 2009. The aim is to capture temporal dynamics of highly reactive nutrients, P and N during both high-magnitude (export during storm-events) and low-magnitude conditions (functioning of stream ecosystem under baseflow conditions).

High-frequency data show small-scale complexities of fate and transport of the reactive nutrients controlled by hydrological and biogeochemical forcing. The non-stationary and non-linear effects are dominant features of nutrient time series at the whole range of stream flows. Evidence of both transport- and supply-limitation is observed. The predominance of hysteresis effects in the concentration-discharge relationship suggests the presence of a temporally varying apportionment of nutrient sources. Stream metabolic activity exerts a significant role on nutrient concentrations during both baseflow conditions and minor storm events.

We will also demonstrate practical aspects of handling, analysing and interpreting high-frequency data - a MATLAB-based database and toolbox for quality control and interrogation of water quality time series.

Hw03S3.01

Hw03S3 - Characterizing water quantity and quality: new approaches and future directions

Oral

Environmental virtual observatories: managing catchments with wellies, sensors and smartphones

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Data availability for hydrological research is expanding at a rapid pace. From the constant stream of high-resolution satellite images to the local efforts of citizen scientists, there is growing stream of heterogeneous data that can be turned into useful information. One promising way to harness these new data sources is the use of web-based technologies. Web-enabled data processing and modelling can help processing large and distributed data sets, and providing tailored products for a variety of end-users. It will also allow hydrological models to be used as building blocks in larger simulation systems to study the relation of the water cycle with other environmental processes such as biodiversity and soil fertility.

Recently, several large funding initiatives such as the UK's Environmental Virtual Observatory (EVO) program and the U.S. National Science Foundation's Earth Cube, have been launched to explore the use of web-based technologies for environmental data processing. Here, we present findings of the UK EVO pilot and discuss the relevance for characterising water quantity and quality. The EVO pilot project has set up interactive web applications for a diverse set of hydrological problems, ranging from local water quality and flooding issues to regional hydrological prediction. Using web-enabled data sets, open standards for data exchange, and cloud computing technologies, these applications provide real-time visualisation of environmental variables, and simulation of various land-management scenarios. At the same time, the modularity of the various components makes it straightforward to reuse them in new, tailor made applications for very different end-users.

Using network technologies and cloud computing has the potential to revolutionize environmental science and management. Yet, we identify several major challenges that still need to be solved, including developing better models, uncertainty quantification and visualisation methods.

Hw04S1.04

Hw03S1 - Characterizing water quantity and quality: new approaches and future directions

Oral

Effects of pollution on macro-invertebrates and water quality bio-assessment

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Many large rivers in China are receiving a huge amount of contaminated water. Water pollution has become an increasingly important issue for water resources management, and a stress on aquatic ecology, which was assessed using macro-invertebrates as indicators. The biodiversity of the macro-invertebrate community is affected, and the species composition changes from natural to tolerant species due to water pollution. Different species compositions of aquatic animals may reflect different water pollution levels. A combination of chemical and biological methods constitutes the best approach for biological monitoring studies to indicate water quality. In this study, samples of water and macroinvertebrates were taken from several large rivers with different pollution levels in China. Macroinvertebrates were identified to genus or family level. Macroinvertebrate taxa richness decreased with increasing pollution levels. Extremely non-uniform distributions of functional feeding groups of macro-invertebrates were triggered as a result of pollution. The density of macroinvertebrates was not affected by organic pollution for the abundant tolerant taxa. Different taxa can be used as indicators for different pollution levels. Leptophlebiidae, Siphlonuridae, Arctopsychidae, Perlidae, and *Antocha* sp. were indicator taxa for very good or good water quality. Chironomidae, Lymnaeidae, *Tubifex* sp., *Limnodrilus* sp., *Limnoperna lacustris*, *Corbicula* sp., *Macrobrachium* sp., Planorbidae, Naididae, Glossiphonidae, and *Branchiura* sp. were indicator taxa for very poor water quality.

Key words: pollution; aquatic ecology; macro-invertebrate; water quality bio-assessment

Hw06S1.01

Hw06S1 - Anthropogenic radionuclide contamination of water and sediment: short-term and long-term consequences

Oral

Terrestrial Trasfer of fallout radionuclides by geomorphological process by Fukushima NPP accident

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Experimental catchments have been established in Yamakiya district, Kawamata Town, Fukushima prefecture, located about 35 km from Fukushima power plant, and designated as the evacuated zone. Approximate Cs-137 fallout in this area is 200-600kBq/m2. We established 3 forest sites: broad leaf tree forest and two Japanese cedar forest plantation (young and mature). Ineach site we installed towers of 8-12 meters. Using these towers, we sampled tree leaves, and measure Cs-137 and Cs-134 in the laboratory, and also we have measure Cs-137, Cs-134 content at various height in each forest using a portable High Purity Germanium (HPGe) detector (Ortech; Detective-EX). We also measured the throughfall, stem flow and litter fall inside of the forest.

Experimental catchments have been established in Yamakiya district,Kawamata Town, Fukushima prefecture, located about 35km from Fukushima power plant, and designated as the evacuated zone. Approximate Cs-137 fallout in this area is 200-600kBq/m2. We established 3 forest sites: broad leaf tree forest and two Japanese cedar forest plantation (young and mature). In each site we installed towers of 8-12 meters. Using these towers, we sampled tree leaves, and measure Cs-137 and Cs-134 in the laboratory, and also we have measure Cs-137, Cs-134 content at various height in each forest using a idetector (Ortech; Detective-EX). We also measured the throughfall, stem flow and litter fall inside of the forest. 5 runoff plot from USLE standard plot have been constructed, and also experimental paddy field has been established. Also total 6 suspended sediment samples, turbidity meters were installed in the Kuchibuto river and 2 sites in downstream Abukuma river.

At the presentation, total almost 2-year of monitoring results will be presented.

Hw06S1.02

Hw06S1 - Anthropogenic radionuclide contamination of water and sediment: short-term and long-term consequences

Oral

Transport of Cs-134 and Cs-137 in river waters from Fukushima Prefecture in Japan during 2011-2012

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It is important to elucidate the short-term to long-term impacts of the Fukushima Daiichi NPP accident on ecosystems of river watershed environments. This study was conducted to investigate the transport of Cs-134 and Cs-137 in five river systems (Abukuma River, Uta River, Niita River, Natsui River and Same River) running through Fukushima Prefecture in Japan. The transport behavior of radiocesium in river waters was studied at normal flow condition during May 2011-November 2012. Field experiments were conducted at Shirakawa (upper), Motomiya, Date (middle) and Iwanuma (lower) in the Abukuma River. We also collected river water samples as a site from a small river such as the Uta River, the Nitta River, the Natsui River and the Same River. The radioactivity of Cs-134 and Cs-137 in the river waters before and after the filtration was measured with gamma-ray spectrometry using ammonium molybdophosphate/Cs compound method. Radioactivity of Cs-134 and Cs-137 in the river waters ranged from 0.046 to 1.43 Bq/l, and from 0.052 to 1.53 Bq/l, respectively in July 2011. Highest value was found at the monitoring site of the Nitta River, which is running through higher contaminated area in the upper site. The radiocesium concentration is low in the order of Niita Rver> Date-Abukuma River> Uta River> Shirakawa-Abukuma River> Same River> Natsui River. The radioactivity decreased to 1/2-1/4 of the July samples in September 2011, and then decreased to 1/3-1/12 in August 2012. The decrease rate depends on each watershed conditions. However, this spatial distribution is observed during the sampling period and corresponds to those of radiocesium inventory in surface soil. Therefore, these results indicate that the transport processes of radiocesium from watershed to river vary with each river system and depend on their watershed environment such as deposition pattern of radiocesium, geographical features and river flow condition.

Hw06S1.03

Hw06S1 - Anthropogenic radionuclide contamination of water and sediment: short-term and long-term consequences

Oral

Radioactive contamination in Fukushima: What do we know of its dispersion by rivers two years after the accident?

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Fukushima nuclear power plant accident led to the release of important quantities of radionuclides into the environment. Several of those substances (e.g., Cs-134; Cs-137) strongly sorb onto soil particles. This leads to important consequences for human activities in strongly contaminated areas where the most affected fields should not be cultivated anymore during long periods of time, depending on the half life of the emitted radionuclides (i.e., Cs-137, with a half life of 30 yrs, will remain in the environment during the next three centuries). Furthermore, radioactive sediment concentration and transfer by rivers can lead to the dispersion of contamination into larger areas over time. This paper deals with a pilot study conducted in the coastal catchments of the Rivers Nitta, Mano and Ota (ca. 600 km^2) draining the main part of the radioactive pollution plume that deposited across Fukushima Prefecture. Three field campaigns were conducted to collect riverbed sediment along those rivers after the summer typhoons and the spring snowmelt (i.e., in Nov 2011, April 2012 and Nov 2012). Based on their analysis in gamma spectrometry, we show the rapid dispersion of the inland contamination and its export by coastal rivers towards the Pacific Ocean. This is confirmed by measurements of the Ag-110m: Cs-137 ratio across the region. Analysis of sediment sequences that accumulated in reservoirs of the region provides additional information on the magnitude on sediment transfers in this area.

Hw06S1.04

Hw06S1 - Anthropogenic radionuclide contamination of water and sediment: short-term and long-term consequences

Oral

Numerical modeling and estimation of radioactive cesium movement at the kuchibuto river basin, Fukushima

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Serious radioactive substances have been released from the Fukushima No.1 Nuclear Power Plant Unit No. 1 and 3 to the atmosphere as we know. Among the radioactive substances released to the hydrologic cycle, the radioactive cesium (Cs-134 and Cs-137) is strongly attached to suspended sediment. Cs-137 has a long half-life of about 30 years. Thus, we made attempt to estimate a movement of Cs-137 with suspended sediment in the Kuchibuto River basin (139 square kilometer), which is an upper part of the Abukuma River basin in the Fukushima prefecture where the radioactive substances were widely spreading. A simulated runoff of Cs-137 in the Kuchibuto River was compared with the observed one from June 21st to August 24th in 2011. To reproduce a runoff of Cs-137, a distributed rainfall and sediment runoff model was constructed. A distributed rainfall runoff model is based on a kinematic wave flow model considering subsurface flow component. The friction velocity calculated by a rainfall runoff model is used to simulate distributed suspended sediment runoff. In addition to sediment runoff, the origin of suspended sediment in basin was also traced numerically to reflect spatial distribution of Cs-137 attached to the suspended load. Attachment of Cs-137 to suspended load was modeled using a particle size distribution of suspended load to reflect the property that Cs-137 attaches to the sediment with smaller diameter particles. Finally, estimated Cs-137 runoff is predicted using simulated concentration of suspended and the attachment model of Cs-137 to suspended load A constructed simulation model reproduced an observed rainfall runoff as well as an estimation of sediment runoff considering the origin of the source of sediment generation and an estimation of Cs-137 movement contained in the suspended load.

Hw06S2.01

Hw06S2 - Anthropogenic radionuclide contamination of water and sediment: short-term and long-term consequences

Oral

Pathways of Chernobyl-derived 137Cs migration in areas of Central Russia with different levels of contamination

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There are some areas of the Central Russia located on relatively large distance from Chernobyl Nuclear Rower Plant, which were contaminated by radionuclide fallout in April-May 1986. Level of radionuclide contamination in the most case was controlled by two main factors: intensity of rain and topography. The latter was even more considerably influenced on radionuclide fallout because it is also had an impact on rain intensity. In the results there are few strips of Chernobyl radionuclide contamination with different inventories of initial fallout are located on the west part of Central Russian (Srednerusskaya) Upland, which is the main watershed divide between the main river basins of southern part of Russian Plain: the Volga River, the Don River and the Dnieper River basins. Studies of lateral redistribution of Chernobyl-derived 137Cs were undertaken in three sites located in areas with different level of Chernobyl contamination. There are Plava River basin, the Chern River basin and the Vorobza River Basin. Both erosion and deposition areas were investigated for understanding of Chernobyl-derived 137Cs loss/gain along the different chains of fluvial systems. It was found some similarities for the all study sites, as well as some differences. The most similarities are associated with local relief features and climate changes during last 20 years. The proportion between Chernobyl-derived 137Cs deposition on cultivated slope, uncultivated slope toes and in dry valley bottoms are relatively similar for all sites. Also all these geomorphologic units are the main sinks for 137Cs. Only about 7-12% of Chernobyl-derived 137Cs was delivered to the river valley bottoms. However differences in proportion of cultivated field from total basin area and different set of crops in crop rotation used affects the 137Cs lateral redistribution rates. It was found that dry valley bottoms are the main sink of Chernobyl-derived 137Cs.

Hw06S2.02

Hw06S2 - Anthropogenic radionuclide contamination of water and sediment: short-term and long-term consequences

Oral

Tracing the origins of sedimentary masses in transit in the Lower Rhone River using activities ratios 238Pu/(239+240)Pu and 137Cs/(239+240)Pu

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The aim of this work was to examine the potential use of artificial radionuclides as tracers to determine the sources of suspended particulate matter in the Lower Rhone River. The Rhone River is the most significant source of freshwater and sediment flowing into the North western Mediterranean Sea. Floods play a major role in the annual suspended sediment load and associated contaminants. As the Rhone River catchment is characterized by a high climatic and geological heterogeneity, floods can be distinguished according to their geographic origins. Long term time series of particle bound radionuclides acquired in the framework of radiological monitoring in the Lower Rhone River provide relevant data sets to investigate the variability of radionuclide contents. In the Rhone River, Plutonium isotopes have two main origins: washout of the river catchment contaminated by the atmospheric Global Fallout (GF) and releases from one reprocessing plant. These two sources display a specific 238Pu/239+240Pu Activity Ratio (AR), allowing the identification of the contribution of catchment vs. bed sediments to Plutonium fluxes. Our results show that the remobilization of sediments deposits labelled by radioactive discharges occurs during most floods events, whatever the flood type. 137Cs derives from the washout of the river catchment labelled by the GF and the Chernobyl accident, and releases from the nuclear industry. The AR 137Cs/239+240Pu has been widely used for tracing Cs and Pu in sediments and freshwaters. Our results show that suspended sediments derived from floods occurring at the meridional western part of the Rhone catchment are characterized by the lowest 137Cs/239+240Pu AR values. This observation is in accordance with the values registered from flood sediment deposits collected in meridional tributaries and could be explained by a lesser contribution of the past Chernobyl fallout in 137Cs supply to the river from this part of the Rhone watershed.

Hw06S2.03

Hw06S2 - Anthropogenic radionuclide contamination of water and sediment: short-term and long-term consequences

Oral

Transformation of Cs-137 soil contamination in the Upper Lokna River basin 25 years after fallout

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At the result of the Chernobyl NPP accident in 1986 some regions of Russia were contaminated by Cs-137. The deposition of Cs-137 was very heterogeneous due to significant impact of changing weather conditions during the accident, as a result of the radioactive material was spread in different directions and then fell down to the vast territories. Investigation of the structure and transformation of radioactive soil contamination fields of agricultural landscapes become the important scientific problems due to contact with contaminated products in the human diet.

The Upper Lokna River is located near the Plavsk town in the Tula region at a distance 500 km from Chernobyl and have area 35 km2. This area is a so-called «Plavsk Cs-137 hotspot» here Cs-137 soil contamination of some areas was 185-555 Bq/m2. The river Lokna Plava (with a drainage basin area of about 178 km2, and a main river length of 21 km) is one of the main tributaries of River Plava. The spatial variation of the inventory Cs-137 in the upper 30 cm of basin soil was studied. The Cs-137 sampling program was conducted during 2011-2012 and included: six undisturbed reference locations (72 bulk cores) and individual 70 bulk cores relatively uniform distributed within the upper part of the Lokna River basin. The Cs-137 activity was measured at 661.66 keV, using a high-resolution, low-background, hyperpure germanium coaxial gamma-ray detector with a maximum relative error of the isotope activity determination of ±5-10%. Map of contemporary level of soil contamination by Cs-137 was constructed. The level of Cs-137 soil contamination ranged from 40 to 350 kBq\m2. It was also reconstructed level of Cs-137 soil contamination fallout at 1986 based on reference values. Transformation of initial Cs-137 soil contamination was mostly associated with agricultural activity, which is lead to water and tillage processes development on cultivated field and Cs-137 transport to uncultivated slope toes and valley bottoms.

Hw06S2.04

Hw06S2 - Anthropogenic radionuclide contamination of water and sediment: short-term and long-term consequences

Oral

Sources and behaviour of fallout radionuclides in High Arctic peats

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Peatlands constitute a poorly investigated component of the Arctic. This work is a systematic study on sources of fallout radionuclides (^{137}Cs, Pu and ^{241}Am) in peats from the poorly investigated in this regard High Arctic environment. Six 18 cm to 24 cm long peat cores were collected from the near-shore peatlands in SW Spitsbergen. Radionuclide levels, activity ratios of ^{238}Pu/$^{239+240}$Pu, ^{241}Am/$^{239+240}$Pu, $^{239+240}$Pu/^{137}Cs were determined by gamma and alpha spectrometry. Additionally atom ratios of ^{240}Pu/^{239}Pu were assessed by ICPMS. The activity and atom ratios indicate global fallout as the dominant source of the studied radionuclides. Concordant positions of all radionuclide peak activities in peat profiles and the reasonable values of peat accumulation rates based therein suggest good fixation of the studied radionuclides to peat. On the other hand, occurrence of the multiple activity peaks and large variability of radionuclide inventories among the profiles indicate the possibility of post-depositional mobility of radionuclides from water-logged peats.

Hw06S2.05

Hw06S2 - Anthropogenic radionuclide contamination of water and sediment: short-term and long-term consequences

Oral

Enhanced levels of fallout radionuclides in the proglacial environment

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Retreating glaciers uncover areas that are sites of intense biogeochemical and geomorphic activity. There is no information on levels and behaviour of radionuclides in this dynamic environment. This study presents observations of anomalously high activities of the fallout radionuclides in proglacial zones of two High Arctic glaciers from W Spitsbergen (Scottbreen and Werenskioldbreen). Up to 15 cm thick sequences of fine-grained deposits were collected in the vicinity of the glacier fronts. These deposits consist of material washed-out into the small depressions of the bottom moraine. Detailed mineralogical, granulometric and chemical investigations reveal vertical homogeneity of properties of these initial soils. Despite this, the depth profiles of radionuclide activities show pronounced peaks of 3000 Bq, 1 Bq and 20 Bq, respectively. Total inventories of ^{137}Cs, ^{238}Pu and $^{239+240}Pu$ reach very high values of 100000 Bq/m^2, 50 Bq/m^2 and 900 Bq/m^2, respectively. A primary source of the highly active material found in the studied soils are cryoconite holes that develop on glacier surface and temporarily accumulate airborne material. Melting of glacier surface leads to release of this material and its downstream transport until it reaches deposition sites in the proglacial zone. Development of plant cover over these areas will lead to incorporation of the accumulated radionuclides into the food chain of the fragile Arctic ecosystem.

Hw06S2.06

Hw06S2 - Anthropogenic radionuclide contamination of water and sediment: short-term and long-term consequences

Oral

Physicochemical forms of strontium-90 and caesium-137 in bottom sediments of Glubokoye Lake within the Chernobyl exclusion zone

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Lake ecosystems are efficient ‘collectors’ for the wide range of radionuclides, which accumulates by abiotic and biotic components after their intake in aquatic environment. As a result of a chemical exchange with water, bottom sediments are considered to be the source of a secondary water contamination by radionuclides. The study of radionuclide forms in bottom sediments allows evaluating the ability of radionuclides to migrate in aquatic ecosystems. We studied the physicochemical forms of Sr-90 and Cs-137 in the bottom sediments of Glubokoye Lake, located within the Chernobyl exclusion zone and considered there as one of the most radionuclide contaminated lake. The examinations of Sr-90 and Cs-137 physicochemical forms in bottom sediment samples were determined by consecutive extraction. Samples were divided into five fractions of the main physicochemical forms of radionuclides: exchange; carbonate; fixed with oxides and hydroxides of metals; organic form and mineral residue. The conducted studies showed that the greatest variability of Cs-137 is found in the organic-mineral fraction and the smallest one – in the fraction fixed with oxides and hydroxides of metals. The greatest variability of Sr-90 is observed in the exchange form, while for the carbonate form and form fixed with oxides and hydroxides, variation coefficient was similar and the least. According to the research data, Sr-90 and Cs-137 are distributed unequally in bottom sediments layers. Both radionuclides are accumulated in bottom sediments mainly in an ion-exchange form and in the form associated with organic matter. Since Sr-90 is characterized by a weak capability of generating fixed settled forms, its content in exchanged forms is considerable. Cs-137 generates settled forms with bottom sediments, thus its content is much greater in insoluble form relatively to Sr-90. Unlike Cs-137, Sr-90 turns less into hardly accessible forms for geochemical migration and is mainly located in a mobile state.

Hw07PS.01

Hw07PS - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Poster

Interaction between surface water and groundwater in Baiyangdian Lake watershed, North China Plain

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China achieved rapid modernization. As technology develops, water demand in many aspects for example agriculture, industry, daily life has increased. Because of lack of surface water, groundwater is the most important water resource in northeast China. However, excessive pumping and untreated drainage have brought serious groundwater table depression and deterioration of water quality. In order to appropriately manage the water resources for sustainable water use, it is urgently necessary to improve an understanding of hydrological process. The objectives of this study are to clarify the characteristics of the water quality and the groundwater flow processes by multi-tracers approach in Baiyangdian Lake watershed. An intensive field survey and water sampling were conducted in June, 2011. Stable isotopic compositions of $\Delta^{18}O$ and ΔD and major solute ion concentrations were determined on all water samples, and a principal component analysis and cluster analysis were applied to classify the waters into several groups. The surface water is divided into 3 kinds of categories (Baiyangdian Lake, Fu River and Tang Reservoir). Spatial variation of solute concentrations and $\Delta^{18}O$ / ΔD show 1) the groundwater around Tang Reservoir is mainly recharged by Tang Reservoir and flow toward a direction of northeast, 2) the groundwater around Baiyangdian Lake is mainly recharged by Banyangdian Lake which is influenced by high evaporation effect, and 3) an interaction between the surface water and the groundwater is not so dominant in Fu river region as compared with that of Tang and Baiyangdian regions. In addition, a detection of nitrate concentration in deep groundwater indicates that an intrusion from shallow to deep aquifers occurs due to the huge deep groundwater pumping. Consequently, communication between different water bodies has been enhanced by anthropogenic activities in North China Plain.

Hw07PS.02

Hw07PS - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Poster

Residence time and hydrogeochemical evolution of natural spring water in the Kirishima Volcano, southern Japan

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Chlorofluorocarbons (CFCs) has been widely used by many researchers as one of the good groundwater age tracers over the world. Volcanic fields are known as spring-rich areas in tropic-semi tropic climate areas and very important as clean water supply sources. Residence time in such volcanic springs is generally short (< 50 yr) and CFCs have been preferably used as suitable age tracer. In a calculation processes, temperature of recharge water is a key to obtain absolute age values. Since temperature in recharge zones is generally difficult to point out, absolute values of CFCs ages are difficult to estimate and this uncertainties become critical when obtained age variation in study area would be small. However, range and degree of such uncertainties has rarely been discussed in previous study. To verify above question, spring areas around Kirishima volcanic mountain (1,700 m, average annual precipitation around this area is 2800 mm/yr) in southern Japan was selected as ideal study field. To clarify most possible spring ages, we compared temperature effect estimated from three different ways, (1) spring water temperature in the sampling site, (2) estimated temperature from isotopic (Δ^{18}O and ΔD) analysis, and (3) that from watershed area analysis. After consider the range of spring water ages, we discuss spring water flow dynamics and chemical weathering mechanism and rates in the study area.

Hw07PS.03

Hw07PS - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Poster

Groundwater Flow System revealed by multi-tracers approach in Tay Island, Dong Thap Province, Southwest Vietnam

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We performed a study to clarify the process of interaction between groundwater and the Mekong River water in relation to the seasonal fluctuation of the Mekong River level in Tay Island, southwest Vietnam. A field survey was conducted in January (dry season) and October (rainy season) 2012, and water samples were collected from the groundwater in shallow and deep aquifer; the Mekong River water and the channel water to analyze stable isotopes of Hydrogen ($\Delta^{2}H$) and Oxygen ($\Delta^{18}O$) and solute ions concentrations for the water samples. Analyzed tracing elements were classified with multiple aquifers which were identified based on the hydrological classification. Chemical composition of shallow aquifer is characterized by Ca-HCO_3 type in the 1st aquifer, by Na-Mg-HCO_3 type in the 2nd aquifer, and by Na-Cl type in the 3rd aquifer. The deep aquifer is clearly classified into the 4th and 5th aquifers being characterized by Na-HCO_3 type. The stable isotopic compositions of groundwater suggests that groundwater flows from the central area of the island to north and south of the island due to the effect of pumping for irrigation during the dry season. In addition, interaction process between groundwater and the Mekong River water was clearly observed by the isotope and solutions tracers along with a seasonal fluctuation of the Mekong River water level. During the dry season the groundwater table of Tay Island was higher than that of the Mekong River leading to the groundwater discharging out to the river, whereas, the groundwater was recharged by the Mekong River water due to the lower groundwater level than that of the Mekong River during the rainy season. Especially, the surface water and the groundwater interaction were dominant in the 1st and 2nd aquifers and partly in the 3rd aquifer in Tay Island.

Hw07PS.04

Hw07PS - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Poster

Quantifying of water and solute transport through unsaturated zone using artificial 3H and Br-: A lysimeter study

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The results of lysimeter tracer experiment aimed at quantifying water and solute transport through the unsaturated zone are reported. The experiment was performed at the lysimeter station located in Krakow, Poland. 4 lysimeters having one (A) - the length of 1 m and the cross-section of 1 m2 and three (I-III) having the length of 1.5 m and the cross-section of 0.2827 m2 were used. They were filled with three types of sand of similar granulometric characteristics but differing in the mineralogical composition. All lysimeteres were instrumented to collect the percolating water for isotope and chemical analyses. One lysimeter (A), was weighable which yielded the cumulative water content in the soil as a function of time. Lysimeters were not covered with plants.

In August 2011 two artificial tracers were injected: tritium solution (CT=105 TU) and KBr solution (CBr = 2000 mg/L). In addition, the most common herbicide (Glyphosate) was introduced with the initial concentration of 45 mg/L (MPC for usage in agriculture). Migration of the injected tracers through lysimeter was controlled by precipitation and evaporation rates which in turn were function of season. Lack of plant cover resulted in relatively high infiltration rate in the lysimeters, reaching approximately 80% of the annual rainfall. Concentrations of the injected tracers were measured in the drainage water. After 12 months from the beginning of the experiment, approximately 90% of the injected tritium and Br was recovered at the bottom of lysimeters. In contrast, neither Glyphosate nor its decay products could be traced in the drainage water. The residence time distribution (RTD) functions were derived for 3H and Br concentration data and the mean transit times of tracers through different soils were quantified.

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Hw07PS.05

Hw07PS - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Poster

Origin of nitrate pollution in a fissured-karstic aquifer: An isotopic study

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The fissured-karstic aquifer system located in southern Poland is the main source of potable water for the Czestochowa city and the surrounding villages. Pollution with nitrates is the most important water quality problem in this system. The concentration of nitrate in some wells exceeds the maximum permissible level of 50 mgNO3/L and is still growing. Although technological measures (removal of nitrates and mixing of water originating from different wells) were introduced to maintain quality of groundwater being supplied to the local drinking water distribution system, the source(s) of nitrate pollution have to be identified and appropriate action have to be taken to reduce the load of NO3 in the recharge of this aquifer. The existing hypothesis links the elevated nitrate levels in groundwater with the leaking sewage system in the Czestochowa city. A dedicated study employing environmental tracers was launched with the main aim of quantifying the pathways and dynamics of groundwater flow in the aquifer. Tritium was found throughout the system. This points to active recharge and characteristic time scales of groundwater flow in the order of years to several decades. In addition, 15N and 18O content of dissolved nitrate was analyzed in number of wells. The isotopic composition of dissolved nitrates does not confirm the hypothesis on the decisive role of urban sewage in nitrate pollution of the aquifer. The isotope data point to agriculture as the main source of NO3. No hint for natural denitrification in the aquifer could be found in the isotope data. In contrast, the nitrates subject to artificial denitrification in the local water treatment plant revealed 15N and 18O enrichment in the proportions expected for this type of process.

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Hw07PS.06

Hw07PS - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Poster

Numerical simulation of accidental pollution wave in small streams

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The environmental problems caused by the increasing of pollutant loads discharged into natural water bodies require a complex amount of the information for setting out frameworks of regulation and control. For that reason the cognition of transport mechanism and mixing characteristics in natural streams is very important. The mathematical and numerical models have become very useful tools for solving the water management problems. The mathematical simulations based on numerical models of pollution mixing in streams can be used (for example) for prediction of spreading of accidental contaminant waves in rivers. The paper deals with the estimation of the longitudinal dispersion coefficients and with the numerical simulation of transport and transformation of accidental pollution in the small natural streams. We used the numerical model called SIRENIE. This model is based on analytical solution of two-dimensional advection – diffusion equation. The longitudinal dispersion coefficients were estimated on set of the field measurements in small streams: Jalovecky brook and Rybarik brook (Slovakia). Transport and transformation of different pollutant concentration waves along the streams were simulated using the model SIRENIE. Keywords: water pollution simulation, surface stream, longitudinal dispersion Acknowledgement: This work was supported by project VEGA 0010/11.

Hw07PS.07

Hw07PS - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Poster

A novel tracer based on the observation of fluorescent particles

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Tracing systems are powerful techniques to investigate environmental phenomena such as pollutant diffusion, sediment transport, and drainage formation. In this context, the deployment and observation of enhanced fluorescent particles have been studied to non-intrusively estimate flow velocities and travel times in complex hydrological environments. Such insoluble and buoyant fluorescent particle tracers are not affected by adsorption issues and are detected through commercially available inexpensive digital devices. In this work, we study and complement previously developed unsupervised particle detection tools with Large Scale Particle Image Velocimetry (LSPIV) analysis for flow estimations in natural settings. Specifically, several experiments are executed by deploying few grams of fluorescent beads in natural streams and analyzing acquired videos with both unsupervised image analysis tools and LSPIV. Results from both methodologies suggest their complementary use for enhanced and real time flow monitoring. In addition, the use of environmentally friendly highly visible fluorescent particles would sensibly improve the joint performance of such non-intrusive sensing systems. Applications of the proposed methodology are foreseen to contribute to higher accuracy rating curve development and to improved large scale characterization of watershed response.

Hw07PS.08

Hw07PS - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Poster

Role of entrapped pore air in rainfall-runoff process in a small headwater catchment underlain by volcanic rock

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The important issue in catchment hydrology is how do pre-event water stored in the catchment will discharge rapidly during the rainstorm event. One of proposed possible conceptual model to explain the rapid outflow of old water was role of entrapped pore air. Despite its potential importance to runoff generation, only a handful of studies have done in the field to show the effects of entrapped pre air on rainfall- runoff processes. In order to investigate the behavior of entrapped air in the field, hydrometric, tracer, subsurface water potential, airflow and air pressure observations have conducted in a small headwater catchment in Shiranui town Kumamoto prefecture, Japan. The catchment is underlain by Tertiary volcanic rock: Andesite. Air outflow volume from the borehole and inner pressure in the borehole were measured at three boreholes with different depth (depth of 25 m, 60 m and 120 m). By integrating the behavior of subsurface water flow and behavior of pore air during rainstorm event in June 2006, it is suggested that air entrapment have occurred at the lower part of the slope. It is suggested that during large rainstorm event with enough antecedent precipitation, drastic rise of groundwater level occur. In such rainstorm event, ridging shaped groundwater level appears and it will be connected to the strongly saturated area of soil-bedrock interface. Therefore pore air in the slope seems to be entrapped at lower part of the slope by combination of ridging shape groundwater level at lower part of the slope, saturated area at soil-bedrock interface and rising groundwater level. The air will be compressed by the rising groundwater level and assumed to effect on discharge. By comparing the rainfall event with air entrapment and rainfall event without air entrapment, the peak discharge showed almost 1.5 times larger at rainfall event with air entrapment.

Hw07PS.09

Hw07PS - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Poster

The temporal-spatial variation of runoff component in a permafrost watershed of Qinghai-Tibet plateau

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In order to improve understanding hydrological processes in permafrost watershed, the spatial-temporal variation of stable isotopes in precipitation, soil water, ground water and river water was investigated in Fenghuoshan watershed, one of the permafrost watersheds in Qinghai-Tibet plateau. The results indicated that the distribution of stable isotopes in river water was influenced by the seasonality variation of river recharge (from soil water and underground water) and the spatial difference of vegetation coverage. Along with the movement of freeze-thaw front of active soil layer, the recharge sources of surface river water were changed. This suggests that the freeze-thaw of active soil layer plays an important role in rainfall-runoff process in permafrost watershed. In addition, evaporation played important role in the fractionation of water isotopes. Runoff segmentation results show that groundwater (including soil water) is the main source of surface runoff in June spring flood period. Precipitation contribution rate is larger in sub-basin with higher vegetation coverage than other basins. In autumn period, groundwater is also the main source of surface runoff, but contrary to spring flood period, precipitation contribution rate is lower in higher vegetation cover sub-basin than that with lower vegetation cover. The influence of vegetation coverage variation on soil freeze-thaw processes might result in different runoff component. This implies that frozen soil degradation and vegetation degeneration, caused by climate change, will significantly change the flow pattern in permafrost regions.

Hw07PS.10

Hw07PS - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Poster

Unraveling groundwater and surface water interaction in Central Kenya Rift lakes: Implications for management

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Groundwater is increasingly becoming an important resource for rural communities especially in arid and semiarid regions. Knowledge of the occurrence and state of this resource is important for sustainable management. For along time groundwater and surface water budget estimations and response to climate changes have been treated separately. However, aquifers surrounding lakes can modify how lake levels and solute balance respond to climate changes. Understanding ground and surface water connection is important to lake basin managers and inform on future changes linked with climate changes.

Lakes in the East Africa Rift have been intensively studied to better understand the influence of climate change on hydrological systems. The exceptional sensitivity of these rift lakes has been noted from paleoclimatic studies. However the baseline needed for future management in the scenario of more humid or arid situations is not highly resolved. Groundwater is an important component in the hydrology of these closed lakes and has received very negligible monitoring and planning.

In this study, we try to understand groundwater dynamics within the Central Kenya rift basins of lakes Naivasha and Nakuru by combining tracer methods of chemical, isotopic and noble gasses approaches (Major Anions and Cations, 3H-3He, 4He). Water samples from wells, springs and lake in the catchment are analysed to determine the flow, age and origin of the groundwater in the study area.

The study is on-going and plans to present the reconstruction groundwater flow pathways and interconnectivity with the lakes and modern recharge rates and flow paths in the unsaturated zone. Further we'll attempt to provide important quantitative foundations for sustainable management of these water resources.

Hw07PS.11

Hw07PS - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Poster

Estimation of mass transport of suspended sediment using fluorescent x ray analysis in terms of snowmelt

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Suspended sediment (SS) can have significant impacts on ecological system, and there are many examples of the damage on human life caused by high SS concentration. In June of 2007, extreme high turbidity water was pumped from the Tokoro River into the domestic water supply system, which resulted in the cessation of water supply for 4 days in Kitami city of Hokkaido, Japan. In this region, it is possible in snowmelt season to occur the overland flow at the fields because of reducing infiltration capacity of ground surface by soil freezing. As a result, it contributes to the production of high turbidity water even if in term of snowmelt.

This study aims to clarify the mechanism of the production and transport of SS in the Oromushi River basin, which is a sub-basin of the Tokoro River basin, during snowmelt season by using fluorescent X-ray analysis.

Chemical composition analysis is applied to estimate the production and transportation of SS in river basins where surface erosion is the dominant process. By using X-ray Fluorescence Analyzer, we measured chemical composition of soil with diameter less than 63 μm at 18 domains over the Oromushi River basin in order to pay attention to SS. When the chemical composition obtained from a river basin point is similar to the downstream end of the river, the sampled soil was considered to be a significant source of SS for the downstream end.

Although the predominant composition was the same in a river basin including the downstream end, significant differences were found in the pattern of chemical composition. We applied the modified correlation method for evaluating the transport rates from each small domain to the downstream end by using the production rate of SS obtained from field observations in term of all season. As a result, spatial patterns of SS transportation rate are found to be strongly related to surface soil type even if in term of snowmelt.

Hw07S1.02

Hw07S1 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Evaluation of the groundwater recharge rate for different land use by using stable water isotopes profiles in unsaturated soil

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Kumamoto area has recently started the groundwater pumping permission regulated by the holding rate of open land which is effective to recharge the local aquifer as a countermeasure for the groundwater pumping. For this regulation, the undestanding the actual groundwater recharge and the evaluation of the groundwater recharge rate for many type of land use is important for the suitable groundwater management. The unsaturated soil core has been sampled to extract the soil water and its stable isotope ratio (D and 18O) has been confirmed. The long term stable isotope fluctuation in the local precipitation has been used to evaluate the sampled soil isotopic profiles by using the Displacement flow model and the groundwater rechagrge rate for the different land surface use has been evaluated; farm land and decedeous forest on the flat upland, grassland and coniferous forest on the mountain slope. Those evaluated groundwater recharge rate has been compaired with the results of regional scale 3D groundwater flow simulation including unsaturated recharge process for the different surface land use.

Hw07S1.03

Hw07S1 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Tracing aquifer recharge from large-scale regional flow systems (Empordà basin, NE Spain)

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Groundwater from local alluvial and fluvio-deltaic hydrogeological systems has been largely exploited to fulfill human needs. In the Empordà basin (NE Spain), generated during the distensive period that followed the Alpine orogeny during the Neogen, groundwater flow through faults gives place to thermal and non-thermal springs. The nearby occurrence of the Pyrennes range, as a main recharge area, and the normal faults that define the boundaries of the basin determine an appropriate framework where upward fluxes may develop. Therefore, it can be assumed that such fluxes may also feed the surface aquifer formations and constitute an alternative resource in the area. This study looks for identifying such recharge in the uppermost aquifers using hydrochemical and isotopic data. Samples from approximately 60 supply wells, which are the deepest available in the area, are used to identify the occurrence of those fluxes linked to the geological context of the region, especially fault zones and the dipping of the main sedimentary formations. Specific major elements, as HCO_3, Cl or Na, are used to identify odd ratios in groundwater samples. Environmental isotopes (oxygen 18 and deuterium) complement hydrochemical data for groundwater facies characterization. Such data are discussed with the aim to assess the occurrence of a large-scale regional recharge.

Hw07S1.04

Hw07S1 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Study of heterogeneity characteristics of vertical hyporheic flux using a heat tracing method

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As an important tracer of water flow movement, heat tracing method involved with water temperature has been applied to the calculation of hyporheic flux. The temperature data of three river cross-sections in DaWen River, Shandong Province were monitored during 4th June to 7th June, 2012. In the basis of the analytical solution of one-dimensional steady-state heat transport governing equation under the vertical groundwater discharge conditions, the hyporheic flux and surface water temperature were obtained via curve fitting method. Statistic analysis of the hyporheic flux at different locations was conducted. This study is focused on the spatial heterogeneity characteristics of hyporheic flux, and the determination of the depth of hyporheic zone. The results show that the hyporheic flux has a gradually increasing trend from the riverbank to the center of river, and the hyporheic flux varies significantly within the same section. The distribution of strong discharge zones is well agreed with the heterogeneity of streambed. Moreover, the heterogeneity of hyporheic flux in the center of river is much more remarkable than that of the riverbank. The hyporheic zone depth has great spatial difference by the effect of hyporheic flux and the heterogeneity of streambed sediments. The small depth of the hyporheic zone usually accompanied with the large hyporheic flux.

Hw07S1.05

Hw07S1 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Runoff generation derived from multi-tracer approach

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Compilation of approved physically-based runoff generation concepts reveal deficits in the field of multiply tracer hydrological conceptions considering screening hydraulic features, for isolation of connected partial processes is a tricky task especially in hydraulically complex hard rock basins. This presentation refers to 40 years of tracer hydrological research and focuses on progressive refinement of experimental methods and design practice. Hence, hydrograph separations and mean transit time computations with the aid of environmental isotopes were rather successful. Since isotopes are suspicious of violating statutory study requirements in terms of temporal and spatial homogeneity and disregards fractal nature of mixing, additional artificial tracers were applied to confirm isotopic and hydraulic findings. Experiments and results are reported from forested Alpine and low mountain range basin in Europe with partially confined aquifers, and compared to agricultural lowland basins with unconfined porous aquifer. The entire multilateral tracer approach is reported from Lange Bramke basin, Harz Mountains, Germany where basic hydrological and hydraulic information like direct and indirect streamflow components, mean transit time, volume of mobile water and effective porosity were derived with the help the environmental isotopes and related modelling techniques. In that basin hydrogeology allowed performing well-directed trials with artificial tracers with respect to subsurface hydraulics in major cross faults and groundwater exfiltration-streamflow dynamics' links, with the piezometric table-discharge relations being frequently hysteretic, and where on average 10% of total is direct flow of event water and 90% is groundwater discharge which need to be recharged. Hence, the results seem proving the correctness of the pursued research strategy which is found to support traditional water balances and the calibration and validation of hydraulic basin models at best.

Hw07S2.01

Hw07S2 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Assessing groundwater fluxes and storage capacity in non-steady aquifer system with transient mixing cell modeling approach based on spatial and temporal variations in hydro chemical and isotopes compositions

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A Mixing Cells Modeling (MCM) approach has been developed to elaborate on complex and vague groundwater non steady flow systems. It provides the user with the ability to assess the groundwater fluxes in a complex transient hydrological system in which the spatial distribution of dissolved minerals (and pollutants) vary with time. In such a system, the boundaries and hydrological conditions along the boundaries are not sufficiently clear or distinct, and there is a lack of hydro-geological information on the precise flow pattern. Thus it is impossible to construct, solve and calibrate a transport hydrological model based on the continuity approach. The proposed alternative MCM algorithm is based on a more simplistic, yet practical approach, in which the flow domain is sub-divided into pseudo- homogeneous flow cells forming a multi-compartmental MCM flow model. The creation of the multi-compartmental structure is based on spatial and temporal distribution of dissolved contaminants, environmental isotopes and hydrochemistry in the transient hydrological system.

This presentation demonstrates the use of the MCMtr (transient flow) mathematical algorithms for identifying and quantifying hidden fluxes of pollutants into an alluvial aquifer in the Arava Valley. The MCM modelling scheme is solved by an optimization scheme which is based on linear programing where water, dissolved minerals and chemicals are served as constraints.

Hw07S2.02

Hw07S2 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Residence time distribution of young groundwater derived from tracer data and 3D flow and transport modeling

Dulinski, M. 1; Bartyzel, J. 1; Kania, J. 1; Wachniew, P. 1; Sliwka, I. 2; Mochalski, P. 2; Rozanski, K. 1; Witcczak, S. 1

1 AGH University of Science and Technology, Poland; 2 Henryk Niewodniczañski Institute of Nuclear Physics, Polish Academy of Sciences, Poland

Here we present the results of a comprehensive study aimed at quantifying mean residence time of groundwater in the recharge area of a porous sandy aquifer located in the southern Poland. It provides potable water for public and private users. To quantify residence time distribution (RTD) functions for water pumped by the production wells located in the recharge area of the aquifer, tritium along with several gaseous tracers was employed. The bomb-tritium has been used for several decades as a tracer of choice to detect recent recharge and to quantify groundwater residence times on time scale extending from several years to several decades. In this context, the lumped-parameter modeling has been the most often used approach. Nowadays, atmospheric concentrations of tritium are approaching natural levels in most parts of the world and the usage of this tracer has become more problematic. Therefore, there is a growing interest in alternative indicators of groundwater age in shallow aquifers. Anthropogenic trace gases present in the atmosphere, such as freons (CFC-11, CFC-12, CFC-113) and sulfur hexafluoride (SF_6), have been applied in numerous case studies as substitutes of tritium. Apart of well-established tracers such as SF_6 and CFC-12, also other trace gases present in the atmosphere such as SF_5CF_3 and H-1301 were tested as age indicators of young groundwater in the framework of this study. Time series of tracer concentrations in the sampled boreholes were interpreted with the aid of lumped-parameter models. In parallel, the arrival times of tracers to the selected wells were calculated with the aid of 3D flow and transport model available for the studied groundwater system and compared with the RTD functions obtained from the lumped-parameter modeling.

Hw07S2.03

Hw07S2 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Linking environmental tracer derived stationary and non-stationary hyporheic travel times with hyporheic reactivity

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The distribution and temporal variability of hyporheic travel times of water and their relation to the biogeochemical processes in the hyporheic zone are amongst the key parameters for assessing the self-cleaning potential of rivers. In this study we used time series of specific electrical conductivity (EC) of water to delineate the flow paths and travel times of water undergoing exchange between a stream and the adjacent riparian aquifer. The main objective was to interrelate hyporheic travel times with transformations of oxygen and nitrate monitored within the hyporheic zone. The study is part of a multi-disciplinary monitoring program at a river bend constituting the Steinlach Test Site near Tübingen in Germany. The sandy gravel aquifer below the river bend is equipped with piezometers containing automatic probes to record pressure, temperature, EC, and dissolved oxygen. Additional water samples for the analysis of oxygen, pH, major ions, and DOC were taken from Mar 2012 to Jan 2013.

Travel time distributions were derived using common lumped parameter models. In addition to this stationary approach, we also applied a windowed cross-correlation to assess short-term changes in travel time governed by variations of stream discharge. Mean travel times of 0.5 to 8 days were derived at selected piezometers using a dispersion model. Application of the non-stationary modelling approach revealed a doubling of travel times between high and low flow conditions. Although no clear relationship between hyporheic travel time and concentrations of dissolved oxygen and nitrate could be observed for the test site in total, we found an increase in oxygen consumption and nitrate reduction with increasing travel time for a small subregion of the test site. We attribute this different biogeochemical behaviour of the otherwise relatively uniform hyporheic sediments to different exposure times to zones with bioavailable organic matter which apparently do not map integral travel times.

Hw07S2.04

Hw07S2 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Mean ages of groundwater obtained from a multi-tracer study (18O, 3H/3He, 85Kr, CFC, SF6) from a spring in the Vienna Basin

Kralik, M. 1; Humer, F. 1; Sültenfuß, J. 2; Purtschert, R. 3; Gerber, C. 3; Darling, G. 4; Gooddy, D. 4; Wyhlidal, S. 5; Rank, D. 6

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A systematic investigation of Mean groundwater Residence Times (MRTs) in six Austrian porous aquifers by isotope and tracer gas analyses was undertaken. The study showed all CFC measurements of groundwater from densely populated basins in Austria are affected by local contamination. In addition generally longer MRTs were found for SF6 than for 3H/3He. In order to resolve the reasons for these differences between the two tracers, the Fischa-Dagnitz Spring system in the Southern Vienna Basin and a lysimeter site in Styria were investigated further. These sites were selected as they have been studied by tracer methods previously (Stolp et al. 2010; Kralik et al. 2011) and represent a relatively simple hydrogeological system. Measurements of 3H/3He and 85Kr in the Fischa-Dagnitz Spring system yielded model-ages between 8 – 10 years similar to the investigations of Stolp et al, (2010). SF6 concentrations indicated a significant older age of 21 years. In the second porous aquifer close to the lysimeter site Wagna in Styria the 3H/3He and 85Kr method yielded very young model ages of less than one year, but the SF6-data indicate a significantly higher model age of 16 years. Possible reasons for these differences will be discussed along with a suggested methodology for carrying out future investigations of groundwater MRTs. Kralik, M., Wenter, F., Humer, F. & Grath, J. (2011): Grundwasseralter ausgewählter Grund-wasserkörper, 2009/2010: Grazer Becken, Jauntal, Leibnitzer Feld, Rheintal, Unteres Sal-zachtal, Wulkatal. 205 p., Rep., S259, Environment Agency Austria, Vienna. (http://www.lebensministerium.at/publikationen/wasser/grundwasser.html). Stolp, B. J., Solomon, D.K., Suckow, A., Vitvar, T., Rank, D., Aggarwal, P.K. & Han, L.F. (2010): Age dating base flow at springs and gaining streams using helium-3 and tritium: Fischa-Dagnitz system, southern Vienna Basin, Austria, Water Resour. Res., 46, 1-13.

Hw07S2.05

Hw07S2 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Geochemical and isotopic evidence for the potential impacts of climate-induced sea level change on coastal groundwater systems

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Climate-induced long-term changes in sea level can have impacts on groundwater systems especially in coastal areas. This study investigates the evidence for such influence in a coastal sedimentary plain, namely the Kamikita Plain and its surrounding areas located in northeastern Japan. The area's underlying basin is filled with Neogene to Quaternary sediments including «Green Tuff» formations of lower to middle Miocene ages. Deep groundwater samples were collected from deep boreholes distributed all across the investigated area. The obtained samples were analyzed for major ion chemistry, and stable isotopes of hydrogen, oxygen, and carbon. Selected samples were further analyzed for helium isotopes, tritium, C-14, and Cl-36 to constrain the age of groundwater. Concentrations of major ions indicate that the groundwater originates from the mixing of meteoric groundwater and seawater. This trend is confirmed by the ∆D vs. ∆O-18 diagram, with most of the samples plotted on a mixing line between the origin (seawater) and the local meteoric water line. The relative composition of Cl, B and Li suggests that the seawater component has been somewhat altered in aquifers. This is consistent with relatively low He-3/He-4 ratios indicating rather long residence time of groundwater. The ages of meteoric groundwater and seawater components were further examined using He-4, C-14 and Cl-36. Carbon-14 ages indicate that the meteoric groundwater component would have been recharged after the last glacial maximum. In contrast, estimated Cl-36/Cl ratios of seawater component suggest old seawater ages up to several hundred thousand years. Overall, calculated seawater ages become older from coastal to inland areas with relatively young seawater ages in the central plain. The distribution of old seawater may imply hydrogeological controls on the flow of old seawater and on the intrusion of young seawater during transgression in a sedimentary rock area.
Acknowledgement: Main part of this research project has been conducted as the regulatory supporting research funded by Secretariat of Nuclear Regulation Authority (Secretariat of NRA), Japan.

Hw07S3.01

Hw07S3 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Dynamic change of residence time in surface and subsurface waters with hydrological processes revealed by multi-tracers approach in mountainous headwater catchments

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Headwater catchments in mountainous region are the most important recharge area for surface and subsurface waters, and time information of the water is principal to understand hydrological processes in the catchments. However, there have been few researches to evaluate a residence time variation of water in time and space at the mountainous headwaters especially with steep slope. We performed an investigation on age dating and tracing of the hydrological flow processes in mountainous catchments underlain by granite and gabbro, Yamanashi and Tsukuba, central Japan.

We conducted hydrometric measurements and sampling of spring, stream and ground waters in high-flow and low-flow seasons from 2008 through 2012 in the catchments, and CFCs, stable isotopic ratios of ^{18}O and deuterium, inorganic solute constituents concentrations were determined on all water samples.

Residence time of spring, stream and ground waters in the catchments ranges from a few years to more than 40 years in time and space, and shows a younger age during the high-flow season, whereas it shows an older age in the low-flow season. The results suggest that a high groundwater level in the mountainous body causes a dominant contribution of shallow subsurface flow with younger age to the spring and stream during the high-flow season, whereas a deeper subsurface flow with an older age contributes dominantly to them during the low-flow season. Also, the storage volume of the groundwater was evaluated using the age information and mass balance model, leading to a temporal change of the volume. Consequently, the hydrological processes dynamically cause a variation of the water age and volume in the mountainous catchments.

Hw07S3.02

Hw07S3 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Interaction between shallow and deep aquifers in Baiyangdian Lake Watershed, North China Plain

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In arid/semi-arid regions, consumption of deep groundwater resource is increasing due to increasing water demand for every sector. An intensive groundwater survey was performed in Baiyangdian Lake Watershed (BLW), central area of North China Plain, because BLW is suffering serious water issues in quantity and quality due to high economic growth and agricultural activities. The objective of this study is to clarify the groundwater flow regime in research area, especially focusing on an interacted relationship between shallow and deep groundwater.
For this purpose, in total 127 water samples from surface water and groundwater in different aquifers (1st aquifer ranging from 0 to 120m depths; 2nd aquifer ranging from 120 to 300 m depths; 3rd aquifer ranging to more than300 m depths approximately) were taken, and major tracing elements of solute ion concentrations and stable isotopes of $\Delta^{18}O$ and $\Delta^{2}H$ were determined for all water samples. Chemical compositions of water show that the water taken in mountainous area and Dingzhou area (southwest of the plain) was characterized by Ca-HCO_3 type, which is different from those in Baoding area (northeast of the plain). Solute ion concentrations and stable isotopic compositions indicate a possible interaction of groundwater between different aquifers, whereas nitrate was not detected in the deep aquifers. The stable isotopic compositions of the groundwater show that the 1st and 2nd aquifer were affected by an evaporation before infiltration, and the 3rd aquifer was mainly recharged by the precipitation falling on the mountainous area.
In a specific area near the urbanized city, an anthropogenic activity might induce a recharge from the 1st and 2nd aquifers into the 3rd aquifer proved by similarity of the chemical tracers of ions and isotopes.

Hw07S3.03

Hw07S3 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Groundwater flow system revealed by stable isotopes and solute constituents tracers in semi-arid region, northern Tunisia

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Groundwater and surface water are major water resources for every sector in Tunisia which located in north Africa, so this region seems to be vulnerable to the decrease of precipitation. Therefore, we investigated spatial and seasonal distributions of tracing elements in surface water and groundwater and to clarify hydrological processes of groundwater-surface water continuum system in northern part of Tunisia.

An intensive field survey was performed in Siliana, an inland area, and Sousse, a coastal area of northern Tunisia, in March and July, 2012. Physico-chemical components were observed in situ, and ^{18}O and ^{2}H and ion concentrations were determined on water samples taken at approximately 40 sites of dams, rivers, deep wells, shallow wells, springs, and a sewage plant.

The $\Delta^{18}O$ isotopic ratio of the water sampled in Sousse were higher as compared with those in Siliana, showing amount effect and inland effect of stable isotopes in precipitation.

In Siliana, the $\Delta\ ^{18}O$ isotopic ratio observed at higher elevation showed a lower value than that at lower elevation in both seasons. Also, a geochemical evolution of groundwater and river water was observed from the upstream to the downstream regions, thus there might be multiple groundwater-surface water cycle systems combining of local scale and regional scale in Siliana.

The stable isotopic compositions and ion concentrations of shallow groundwater taken in Khairat aquifer, south part of Sousse area, showed a middle value of groundwater in mountainous area around it and Khairat Dam water. A contribution ratio of the dam and the mountainous groundwater to the shallow groundwater was estimated to be 44 % and 56% by end-member mixing analysis using $\Delta^{18}O$ isotopic ratio and electrical conductivity, which indicates an importance of the recharge from the dam to the aquifer.

Hw07S3.04

Hw07S3 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Hydrological fonctionning and water exchanges through an alluvial plain: A Loire meander (Central France)

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The presentation focuses on a protected zone («Guilly meander», 4.27 km^2) in the middle Loire valley, the longest French river, where several actions of wetland preservation are conducted. The meander is a part of a particular anthropogenic system which has been impacted by changes of land uses in the floodplain. The aim of this large-scale study, which combines geomorphology, hydrogeology and geochemistry is twofold: i) characterizing the water exchanges and the transfer times in an alluvial plain; ii) identifying the role played by the morphological and sedimentary heritages in the meander hydrology. In the meander and in the alluvial plain, pressure sensors have been installed in several wells in the unconfined aquifers (time interval of ½ hour). The potentiometric data reflect the propagation of the hydrological signal from the Loire River towards the alluvial aquifer. In addition, water has been sampled monthly during a hydrological year for both chemical and isotopic (18O, 2H) analyses. The chemical and isotopic compositions of the groundwater from the shallow, alluvial aquifer are helpful to demonstrate that the groundwater of the alluvial aquifer comes from a mixing between the groundwater of the regional aquifer (Beauce Aquifer) and the Loire river water. The water exchanges between the different water-bodies in the meander display an important temporal variability and an unequal response time. This is confirmed by simulations of a hydrogeological model within the meander. We observe important variations of water-table elevation according to the discharge of the Loire River: fast recharge events from the river towards the alluvial aquifer are observed especially during flood periods. These recharges show significant spatial variations characterized not only by the distance to the river, but also by morphological and sedimentary heritages.

Hw07S3.05

Hw07S3 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Application of isotopic tracers as a tool for understanding hydrodynamic behavior of the highly exploited Diass aquifer system

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The Diass horst aquifer system located 50 km east of Dakar (Senegal) is exploited in two main aquifers: (1) the confined/unconfined paleocene karstic limestone reservoir and (2) the confined Maastrichtian sandstone aquifer underneath.This system has experienced intensive groundwater abstraction during the last 50 years to supply increasing water demand, agricultural and industrial needs. The high water abstraction rate (about 109,000 m3/d) has caused a continuous groundwater level decline (up to 30 m), a modification of the groundwater flow and salinization in parts of the aquifers. The objective of the study is to improve the understanding of groundwater dynamics and to infer origin and timing of recharge using mainly stable ($\Delta^{18}O$, $\Delta^{2}H$, ^{13}C) and radioactive (^{3}H and ^{14}C) isotopes. Values of $\Delta^{18}O$ and $\Delta^{2}H$ for the Paleocene aquifer range from -5.9 to -5‰ and from -39 to -30‰, respectively comparing to that of the Maastrichtian aquifer which are between -6 and -3.7‰ for $\Delta^{18}O$ and between -40.3 and -24‰ for $\Delta^{2}H$. Plotted against the conventional $\Delta^{2}H$ vs. $\Delta^{18}O$ diagram, the three campaigns displayed three different trends parallel and slightly below the GWML reflecting old and different water masses characterized by different isotopes signatures. These different water masses confirm drastic changes in groundwater flow induced by the high pumping rates. The very low tritium (generally < 0.7 TU) and 14C (between 0.7 to 57.2) contents indicate predominance of older water being recharged during the Pleistocene and Holocene periods. However, few boreholes which exhibit high tritium (1.2 to 4.3 TU) and 14C (65.7 to 70.8 pmc) values indicate some mixture with recent water likely through faulting and vertical drainance. These results show that pumping influences primarily flow dynamics induces reverse hydraulic gradient were vertical drainance is observed from the shallow to deeper aquifers. Also lateral flow along flow paths occur to the piezometric depressions created by pumping.

Hw07S3.06

Hw07S3 - Tracer hydrology as a tool for understanding and quantifying flow-paths and biodegradation processes in groundwater systems

Oral

Use of environmental tracers to understand groundwater surface water interactions in the wetland terrain in NE China

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Water resources management is the key to sustainable agriculture and wetlands ecosystems. Understanding the interaction between groundwater and surface water is sometimes difficult due to complex hydrological conditions, e.g. in the case of a wetlands terrain. We have chosen a wetland and paddy rice fields co-existing area with groundwater-dominated irrigation scheme in the Sanjiang Plain, NE China, which has been reclaimed from natural wetlands, to investigate this issue. Sanjiang Plain is the largest area of fresh water mash and the largest food supply base in China. It is the largest wetlands reclamation program in China and maybe also in the world, for paddy rice. In some of the areas, water table has been declining rather fast. Water quality deterioration is also observed in some of areas. Using a multi-tracer approach involving water chemistry and isotopes (2H, 18O, 3H, 13C, 14C), integrated with data on groundwater regime, we demonstrate that it is possible to delineate hydraulic interactions between groundwater, river, ponds and paddy rice fields. Regional variations in hydrogeology have been found to be the main factors controlling groundwater recharge and regime. We found that groundwater in the confined Quaternary aquifer is recharged by lateral flow from nearby mountains with ages over 50 years and evidenced by depleted heavy isotopes. It is in general not affected by changes in the wetlands and/or rice fields and therefore is less vulnerable to the pollution from fertilizer overuse, however, its yield is limited. On the contrary, the unconfined Quaternary aquifer is recharged by rainfall or riverbank infiltration, especially at localities near the rivers. It is more likely for the groundwater to be affected by nutrients released from the intensive agricultural activities in general, though its yield is rather abundant.

Hw08PS.01

Hw08PS - Subsurface warming, heat energy and groundwater

Poster

Agneyodgara (Lava Energy) - Implications for sustainable heating solutions in Himalaya

Arya, R. 1

1 Arya Driller, India

Water is blood of mother earth we need proper doctors to operate on our system lest we may end our Lives

Agneyodgara(Lava Energy) concept developed by Dr Ritesh Arya with the aim for RIGHT to FREE SAFE SUSTAINABLE Water & Energy for all by tapping heat energy at shallow depth and utilise the same for heating and energy production.

Areas in the remote inaccessible areas in Indian Himalaya where electricity and heating demand at present is met by fossil fuel are immediate beneficiaries. Waste water and untapped Lava Energy are the main raw material.

Idea helps to develop hot groundwater sources where none was known before by exploring and drilling into geologically favorable locations. Present paper sites example of Hot groundwater discovered by the author in Siachen base camp in the high altitude cold mountain deserts f Ladakh Indian Himalaya and its implications in space heating,bathing,washing and green house on one hand besides decreasing the expenditure on fossil fuel (transportation of which is costly proposition) besides harming the glacial environment. Paper also helps to highlight significance of utilisation of the naturally occurring hot waters in Chumathang, Tatapani, Manikaran to be promoted as geothermal tourist destinations.

Pilot projects identified under Agneyodgara IndNor programe (2011) funded by research council of Norway have yielded results and 120C temperature was recorded at 100m depth in pilot project drilled at Chumathang (2012).

Utilisation of these untapped perennial hot water resources as free energy source is the key to provide sustainable solutions for happy living in the tough terrains of Himalaya.

Hw08S1.01

Hw08S1 - Subsurface warming, heat energy and groundwater

Oral

Subsurface warming due to global warming and heat island effects in Asian mega cities

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Subsurface warming due to global warming and heat island effects is found all over the world in many cities. The increased temperature reaches up to more than 100 meter below the surface in some Asian cities, and thermal storage can be potentially used as new energy sources. In this study, the current status of subsurface warming in Asian cities including Tokyo, Osaka, Bangkok, Jakarta, Taipei and Seoul is presented as well as potential uses of increased thermal storage due to subsurface warming. Reconstructions of surface warming histories due to urbanization in each city from subsurface temperature-depth profiles show the different stage of urbanization within the cities. Comparisons of subsurface warming in Asian cities show the histories of urbanization in Asia.

Hw08S1.02

Hw08S1 - Subsurface warming, heat energy and groundwater

Oral

Variations in groundwater temperatures due to urbanisation and its theoretical influence to groundwater energy utilisation

Arola, T. 1

1 Golder Associates Oy, Finland

Finland has 5957 categorised and mapped groundwater areas eg. soil and bedrock aquifers. Approximately 56 500 hectares of Finnish aquifers, 801 groundwater areas, are under urban or industrial land use. These aquifers can be a significant local energy source. The main target of this study is to research if urbanisation, so called urban head island effect, has elevated groundwater temperatures in Turku, Lohja and Lahti towns in Southern Finland.

Open loop ground source heating and cooling systems extract thermal energy from and/or discharge waste heat to water bodies such as aquifers and lakes. The effects of groundwater temperature changes to the open loop energy utilisation system are also quantified in this work.

The research is done by measuring groundwater temperatures in rural and in urban areas within same aquifer after winter and summer time. The usable heating and cooling energy load to buildings is calculated based on observed groundwater temperature changes.

The study concludes that urbanisation has elevated groundwater temperatures in research areas. Heat loss from buildings had the most significant effect on groundwater temperature rise.

Due to warmer groundwater, approximately 50% more heat load could be utilised from urban than rural areas. As heat load increase, cool load decrease. Approximately 50 % less cool load can be utilised from urban than rural areas. However, groundwater heat exchange system for cooling is still cost effective energy utilisation process in Nordic countries, even in heated areas.

Hw08S1.03

Hw08S1 - Subsurface warming, heat energy and groundwater

Oral

Tracking temperature changes from rooftop down to deep hole: first year observation of the thermal environmental monitoring observatory of the Xi'an Jiaotong University, China

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A good understanding of temperature changes across the atmosphere and land boundary is of great importance to our understanding of the transportation and storage of the earth system energy and the interaction between land thermal environment and boundary layer development. However, there have been very few reports on systematically monitoring the temperature variations across air, ground surface, soil, and rock on a permanent spot. The Thermal Environmental Monitoring Observatory of the Xi'an Jiaotong University (TEMOX) in central China has been constructed to join the effort to fill this critical observational gap. The TEMOX is located within the campus of the Xi'an Jiaotong University. It is comprised of a standard ground based meteorological station, two rooftop meteorological masts 25 m and 50 m above ground surface respectively, four 5-m soil temperature/moisture probes, and more specially, a 500 m deep observation borehole. The environmental parameters monitored include air temperature, soil temperature, rock temperature, air humidity, air pressure, precipitation, radiation, wind speed and direction, daylight duration, net radiation, soil moisture, carbon dioxide content, and atmospheric electricity. The TEMOX is a facility of the Geothermal and Environmental Research Laboratory of the Xi'an Jiaotong University. The construction of the Observatory was completed in June 2012. It has been operating under the collaboration of the Geothermal and Environmental Research Laboratory and the Meteorological Bureau of the Xi'an Municipal City. Observational data are sampled at a 6-second interval. In this paper, we will present the first year record from the TEMOX.

Hw08S1.04

Hw08S1 - Subsurface warming, heat energy and groundwater

Oral

Spatial mapping of the potential for ground source heat pump systems in the UK

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The UK Government expects that by 2020 12% of the UK's heat demand will come from renewable sources, and is providing incentives to help achieve this. Ground source heat pumps (GSHP) could make a substantial contribution to this provided that obstacles to the uptake of GSHP's can be overcome. One such obstacle is the perception of risk associated with unknown ground conditions or hydrogeological and economic conditions. This paper presents recent approaches (ThermoMap, open-loop GSHP tool) to map and summarise relevant parameters to show where suitable conditions exist for the installation of GSHP systems.

The main focus of the paper will be on a recently developed web-based tool for open loop GSHP systems which, for larger size installations (> 100kWth), can be more economic than closed-loop systems. An approach is presented that maps relevant hydrogeological and economic parameters in England and Wales to assess the potential /suitability of the area for open-loop GSHP installations. Data are collated, grouped and summarised within a GIS environment and integrated in a web-based viewer. Suitability for GSHPs is displayed in the form of maps and tables. Ranking and weighting of the data was deliberately avoided as these methods conceal the actual parameter values which are of great importance for the planning of GSHP schemes. As such the tool provides an effective instrument for the initial assessment of suitability of a location (at the given scale) thereby increasing confidence at the early planning stage.

Hw08S1.06

Hw08S1 - Subsurface warming, heat energy and groundwater

Oral

Using the HYPE model to investigate the catchment-scale influence of air temperatures on soil and water temperatures

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Changes in shallow subsurface temperatures as well as in surface water temperatures through changing atmospheric forcing have the potential to alter ecological conditions and nutrient concentrations in streams and lakes. A rise in ambient temperatures may enhance bacterial metabolism, change solute-solid matter equilibria, or alter lake circulation patterns. Such changes in turn directly influence the fate of nutrients in the water cycle and may become important under climate change conditions.

However, the importance of these changes in the context of larger catchments is not yet fully understood. Here, we use a soil depth dependent heat exchange conceptualisation within the HYPE (Hydrological Predictions for the Environment) model to track changes in water temperatures, as well as phosphorus and nitrogen cycling at the catchment scale on cold-temperate catchments in Sweden. The HYPE model is a semi-distributed hydrological and nutrient transport model. It builds on the catchment similarity paradigm, and sub-catchments are configured and parameterized along landscape properties.

Using scenario-type changes in temperature forcing, we investigate the influence on stream and lake temperatures as well as concentrations and loads of nitrogen and phosphorus. Preliminary results show notable changes in inner-annual in-stream temperature dynamics as a result of changing air temperatures.

Hw10PS.01

Hw10PS - Adaptative water resources management – system design and operation

Poster

Application of Bayesian MCMC method for estimation of design maximum floods in water management

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In recent decades with the constant increase of technology, more and more attention has been given to the analysis of existing, as well as soon to be designed dams with respect to their failures. New statistical methods and approach allows for more advanced hydrological design as well for revaluation of existing reservoars and dams. In the presented paper it is proposed to use historical information in the frequency analysis of the marginal distributions in the framework of Bayesian Monte Carlo Markov Chain (MCMC) simulations. Generally, a Bayesian approach allows for a straightforward combination of different sources of information on floods (e.g.flood data from systematic measurements and historical flood records, respectively) in terms of a product of the corresponding likelihood functions. On the other hand, the MCMC algorithm is a numerical approach for sampling from the likelihood distributions. The Bayesian MCMC methods therefore provide an attractive way to estimate the uncertainty in parameters and quantile metrics of frequency distributions. The applicability of the method is demonstrated in a case study of the hydroelectric power station Orlík on the Vltava River. This site has a key role in the flood prevention of Prague, the capital city of the Czech Republic. The record length of the available flood data is 126 years from the period 1877-2002, while the flood event observed in 2002 that caused extensive damages and numerous casualties is treated as a historic one. Finally the estimated flood peaks were compared with those obtained by the traditional method used in the practice of water management specialists.

Hw10PS.02

Hw10PS - Adaptative water resources management – system design and operation

Poster

Impact of streamflow data uncertainty on the calibration of river models

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Modelling of regulated river systems requires a combination of hydrological components, e.g. rainfall-runoff models, and components dealing with diversion and storage of water. The resulting models often include a large number of calibrated parameters and multiple prediction points, which can only be calibrated if constrainted by multi-site streamflow data. However, this approach is often challenged in semi-arid catchments where remoteness and flashy responses reduce the opportunity for flow gaugings and lead to poor quality of flow data. This study investigates the impact of streamflow data uncertainty on river model calibration. The case study is a the Flinders catchment located in Northern Australia and covering an area of 110,000 km2. An uncertainty analysis of streamflow data was conducted for 30 gauging stations across the catchment. The analysis produced a set of 50 replicates of streamflow time series capturing the uncertainty from the rating curve at each station. Finally, a river model was calibrated for each replicate. Flow statistics along with performance metrics were analysed for each replicates and compared with the statistics obtained with the model calibrated against original data. The results suggest that the uncertainty in streamflow data does not have the same impact on headwater areas, where they affect mostly high flow regimes, than on lower part of the model, where they introduce uncertainty on low flows. The impact on bias can be large, reaching 20% in some parts of the model.

Hw10PS.03

Hw10PS - Adaptative water resources management – system design and operation

Poster

Land use and the impacts on water and sediment quality: Pitimbu river case study

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River basin management is a key factor in the sustainable development of a society as population growth increases water demands from competing sectors. A management framework tool is of crucial importance to permit an integrated 'holistic' consideration of the water and environment system, in which quantity and quality variables are interlinked, stakeholders requirements are balanced and water use is optimized. In most Brazilian urban areas, river basin management is a real challenge as local level public institutions implement their own policies without a common agreement. Pitimbu river basin (126.76 km2) spans three municipalities in the metropolitan region of Natal. It is strategically important, as the river supplies 35% of the population with potable water. The fluvial regime shows a wide seasonal variation (0.62-10.6 m3s-1) and a flashy streamflow distribution caused by convective storms. The aim of this study is to analyze the impact of land use on water and sediment contamination as indicated by selected metals. Bottom sediment and water sampling campaigns were conducted during a monitoring period spanning both dry and rainy seasons (2011-2012). Sediment samples were collected and analyzed by flame atomic absorption espectrometry. Samples were analysed to determine concentrations of Al, Cu, Cd, Zn, Fe, Pb, Ni and Mn. Higher metal concentrations were observed in the sediments than in the water. Metal concentrations above reference levels were observed for Pb, Zn, Fe and Ni in the sediment and for Fe and Al in the water. High Fe and Al levels in the sediment and water are due to fertilizers and pesticides used in agriculture in headwater areas. The development of large residential areas contitutes a source of contaminants through base flow. In summary, the current state of unsustainable land use in the Pitimbu River basin points to the need of reviewing and improving the management strategy.

Hw10PS.04

Hw10PS - Adaptative water resources management – system design and operation

Poster

Assessment sedimentation rate in the Mosul dam reservoir, Iraq

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Mosul dam is one of the biggest hydraulic structures in Iraq that was built on the Tigris River 60 km north-west Mosul city north of Iraq. The water surface area of its reservoir is 380 km2 with a storage capacity of 11.11×109 m3 at a maximum operation level (330 m.a.s.l). The dam became operational in 1986. No study has been conducted to determine the sedimentation rate, storage capacity and new operational curve since that date. To develop an up to date operational curve, a new bathymetric survey was conducted in 2011. The results indicated that the reduction in the storage capacity of the reservoir was 14.73%. This implies that the annual sedimentation rate within the reservoir was 45.72×106 m3.yr-1 (0.59%) that is less than the average worldwide rate. Consequently, a new operational curve was constructed.

Hw10S1.02

Hw10S1 - Adaptative water resources management – system design and operation

Oral

Integrated water resources management in the local implementation practice

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The riparian states of the Lower Jordan River face immense pressure and competition on their natural freshwater resources. Integrated Water Resources Management (IWRM) is an attractive concept to obtain more sustainable, equitable and efficient water management. Its implementation, however, appears an intricate challenge in itself as the international water sector community strives for ways to translate the theoretical construct of IWRM into operational guidelines for local application. Following these insights, the presented study contributes to the contemporary IWRM research by presenting a sub-basin-scale approach on IWRM and scenario planning with an application for a Jordanian side wadi of the Lower Jordan River Basin (Wadi Shueib, ~190 km^2). Primary water sector challenges in the Wadi Shueib are related to municipal supply, as well as to the management of the resulting waste water return flows. In a comprehensive analysis of the existing data from local institutions and previous studies, holistic monthly water balance time series were constructed. The conceptual system understanding was represented using a water allocation and balancing model (WEAP). National water strategy objectives and the official local action plan were used as normative guideline to craft a set of planning alternatives and performance indicators with relation to the local challenges. Exemplary scenario simulations with a planning horizon of 2025 showed that the current implementation practice in the study area may fall short of achieving several national objectives. Room for improvement was identified especially in water resources protection and water loss reduction issues. The modelling exercise demonstrates a possibility to provide decision makers with local planning support that is equally based on national IWRM policies as well as on sound science, and thus can be a useful instrument in the progress towards operational IWRM.

Hw10S1.03

Hw10S1 - Adaptative water resources management – system design and operation

Oral

Recent developments in dynamic network flow optimization

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In water resource management networks of reservoirs and water courses play an important role. From sewer systems to river networks we find similar components. Evaluation and control of the transport capacity of such networks for time varying loads and capacity is naturally of interest to water managers. We discuss some recent developments in algorithms for the solution of time dependent and dynamic network flow problems. These techniques allow for changes in configuration or capacity.

Hw10S1.04

Hw10S1 - Adaptative water resources management – system design and operation

Oral

Application of spatial time series data for management of water resources in small watersheds

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The exponential growth in infrastructure development, industry, agriculture including food production, urbanization in developing nations has triggered climatic changes leading to an unprecedented demand for water resources. Development and management of water resources with inadequate scientific backing and ad-hock policies have added additional complexity. Lack of proper understanding on the interactions between different components of water resources viz., atmospheric, surface and sub-surface is a major constraint in drawing suitable management strategies. Implementations policies on rainwater harvesting, conjunctive use of ground water and surface water, selection of proper cropping pattern, appear to yield better results in water resource management. An integrated water resource management incorporating both quantity and quality perspectives have resulted in the generation of critical spatial time series data on various water resources components in the watershed. The morphometric characteristics represented by lineament density, drainage characteristics along with geoelectrical imaging have provided vital information on the mapping of groundwater potential zones, while the rain fall-run off relationships, information on occurrence and seasonal dynamics of ground water have provided vital information on the availability of water resources in time and space. The conceptual numerical model adopted to simulate the groundwater behavior has provided critical inputs in conceiving strategies for optimum development and effective management of water resources in the watershed.

Hw10S1.05

Hw10S1 - Adaptative water resources management – system design and operation

Oral

Estimation of deposited sediment loads in Mosul Dam reservoir based on a two dimensional model

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Mosul Dam is one of the biggest dams in Iraq. It is located on Tigris River about 60Km north of Mosul City. The total storage capacity of the dam is about 11.1 billion cubic meters. It is a multipurpose dam, for flood control, irrigation, water supply, and power generation. The dam was in operation since 1986. The main irrigation project supplied by water from Mosul dam reservoir is North Jazira irrigation projects. It is located within the upper part of the reservoir. Sediment accumulation within the reservoir is causing problems, especially near Jazira pumping station. This is affecting the pumping efficiency and quantity. The sources of sediment accumulated within the reservoir are from the Tigris River as well as those brought by the side valleys on both sides of the reservoir. There are seven valleys on the left bank and three on the right bank.

Measured flow and sediment load of Tigris River, in addition to the estimated values of flow and sediment load based on Soil and Water Assessment Tool (SWAT) model was considered for the operation period (1988-2011). The total inflow rate and sediment load arrived to the reservoir and the released values based on operation schedule of the dam to satisfy the downstream requirements were considered to describe the flow and sediment load. The course of the river and the topography of the bed of the reservoir before dam operation were the geometrical data feed to the 2-D hydrodynamic and sediment models. The Surface Water Modeling System (SMS) was applied after model calibration based on field measured data of previous studies to estimate the deposited sediment load distribution for the operation period. The results give an idea for the main source of sediment to present a probable solution of the pumping station problem.

Hw10S1.06

Hw10S1 - Adaptative water resources management – system design and operation

Oral

Application of satellite data for estimation of lineament density to identify ground water potential areas

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Remote sensing (satellite data) is extremely useful in assessment of ground water potential areas through estimation of lineament density. SPOT and IRS-1A data was used to assess ground water potential areas which falls between latitudes 28o 29’ to 28o 35’ E and longitudes 77o 3’ to 77o 16’ N. Lineament densities were estimated using satellite data to identify ground water potential areas. Development and exploration of ground water require sustainable use and recharge approach. Based on drainage pattern and slope of the study area, remote sensing data is helpful in estimation of lineament density which provide suitable site for exploration of ground water and selection of check dam sites for ground water recharge/ conservation. Total 14 check dam sites were identified using satellite (remote sensing) data in the study area. Mean reflectance values at suggested check dam sites were 1.06 % to 4.53 %. Lineament density is directly proportional to ground water availability in an area. Study area is highly variable in terms of lineament densities at different locations. Areas indicating high lineament densities are highly potential (good aquifers) to possess ground water availability. The water demand vis-a-vis water resources availability is evaluated based on hydro-geological set up, field investigation and interpretation of satellite (remote sensing) data.

Hw10S1.07

Hw10S1 - Adaptative water resources management – system design and operation

Oral

Spatial distribution of potential water-bearing zone in the mountainous region of Taiwan

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Ensuring the availability of groundwater has long been the concern from the government and the locals. In Taiwan, significant efforts have been made in the past decades to understand the hydrogeological context of downstream alluvium plain areas. Extensive reports have shown that, along with the ever-increasing population, excessive demand and conflicting usage, these areas are currently (or will be) highly stressed. Being the primary source of groundwater recharge, the hydrological systems at the upstream mountainous regions have yet received sufficient attention. Their greater complexity, compared to plain areas, is reflected in the varying nature of different hydrogeologic units. Knowledge gaps are often present due to limited data, let alone predictions and making decisions. In our view, the spatial distribution of water-bearing zones in the mountainous region is, by far, among the most important issues needs to be consciously clarified. A clear insight into their hydraulic properties and geophysical processes is essential for implementing adaptive management. For this, the Central Geological Survey of Taiwan has commenced an extensive hydrogeological investigation programme in 2010. Until now, three major river basins of central Taiwan have been studied. In total 65 boreholes are drilled (depth: 100 meters) and a series of experiments are conducted, including core inspection, geophysical logs, packer tests, pumping tests. Based on data generated by these techniques, the statistical inference allows a better description of the hydrogeological context and its corresponding water-bearing characteristics. Higher productivities (300-600 litres/min) are found in the metamorphic rock units associated with well-developed fracture network, which are way more sufficient to provide the needs of a 500-people village. The overall findings are integrated in a GIS-based system and the zoning can be used for different scenarios of water supply and demand management.

Hw10S2.01

Hw10S2 - Adaptative water resources management – system design and operation

Oral

Incorporation of future water resources predictions in adaptive management

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An improved understanding of geophysical processes allows obtaining enhanced predictions of the characteristics of hydro-climatic variables, the states of water resources systems and the associated uncertainties. These predictions can in turn be used to derive adaptive water resource management schemes that integrate all available information in an optimal manner. Non-stationary hydro-climatological models allow to take into consideration all information about changes in the environment and quantify the resulting uncertainties in design and management variables. In these models, the distribution parameters change in time and so do the estimates of exceedance probabilities on which are based the design and management of water resources structures structures. Ignoring existing non-stationarities could lead to significant waste of valuable economic resources and even catastrophic consequences in case of underestimation. These models can also handle low-frequency oscillatory variations and can be applied to more general and more complex procedures where parameters are formulated as non-linear functions of covariates. Covariates can represent relevant climate indices, the state of the system (for instance percentage of the area that is urbanised) or time (trend). We present herein a discussion of recent developments in the field of non-stationary prediction models and the results of the application of these models for water resources design and management. Several non-stationary frequency analysis models are discussed and their advantages demonstrated. Parameter estimation for such models is discussed. Results are also presented with the use of B-spline models to account for the dependence of parameters on more than one covariate. Examples are provided for water resources management in both arid and non-arid environments. The consequences of making the wrong choices or ignoring the inherent uncertainties are discussed for these examples. Words of caution are also

Hw10S2.02

Hw10S2 - Adaptative water resources management – system design and operation

Oral

An integrated modelling framework for simulating human decisions in water resources management at the regional-scale

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Global change and options for adaptation and mitigation has become a central target of water resources research. Responses of environmental and technical systems to global change have received a lot of attention, while changes of the behavior of humans and the feedbacks between the environmental changes and human decisions was less in the focus of natural scientists and engineers. But, water resources, human actors and climate change are related in many complex ways. The GLOWA-Danube research cooperation has developed the integrated simulation system DANUBIA to simulate water-related influences of global change in different spatial and temporal contexts. DANUBIA is a modular system comprised of 17 dynamically-coupled, process-based model components and a framework which controls the interaction of these components with respect to space and time. This contribution describes approaches and capabilities of DANUBIA with regard to the simulation of global change effects on human decisions using the example of agriculture and water supply. In agriculture, market prices and legislation can be equally or even more important than water availability in determining farmers’ behavior and thus in determining the agricultural impact on water resources quantity and quality. The DANUBIA framework and the DeepActor-framework for simulation of decision-making by human actors are presented together with the model components most relevant to the interactions between agriculture and groundwater. The approach to combining climate and socio-economic scenarios is explained. Exemplary scenario results are shown for the Upper Danube Catchment in Southern Germany.
Barthel, R., et al. (2008): An integrated modelling framework for simulating regional-scale actor responses to global change in the water domain. Env. Mod. .Softw., 23, 1095-1121

Barthel, R., et al. (2012) Integrated modeling of climate change impacts on agriculture and groundwater resources. Wat. Res. Man., 26,7, 1929-1951

Hw10S2.03

Hw10S2 - Adaptative water resources management – system design and operation

Oral

Hydrological sciences and the adaptive management cycle

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Managers of water resource systems have to contend with uncertainties about predicting future climates and water use demands as well as limitations in these predictions due to uncertainties in hydrological and climate data and models. Managing complex systems characterised by uncertainty requires an adaptive, learning-by-doing approach. The adaptive management cycle contains several stages, these can include: defining the context and status of the system under examination; visioning; planning; defining inputs; developing management processes; producing outputs and achieving outcomes. Monitoring and evaluation provides positive and negative feedbacks through the various stages of the management cycle allowing the system to be dynamic and adaptive. At each of the stages the stakeholders that should be involved in the design and operation of the adaptive management cycle differ, as do the roles they play. This presentation focuses on those stages of the adaptive management cycle where scientists and managers interact and specifically examines the contribution that water scientists (hydrogeologists and hydrologists) can make to the adaptive management cycle. Understanding the requirements of policy makers and resource managers is imperative for the provision of purpose driven models, and understanding the limitations of data and modelling provided by hydrologists in terms of the precision of estimates and projections for policy and management goals is equally important. This dialogue between policy makers and resource managers and hydrologists needs to take cognisance of the adaptive nature of the cycle such that the uptake of learning from that dialogue feeds timeously into the adaptive management cycle. This poses a great challenge both conceptually and operationally to all those involved.

Hw10S2.04

Hw10S2 - Adaptative water resources management – system design and operation

Oral

Value of distributed precipitation information for flood early warning: a case study for a pre-alpine catchment in Switzerland

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Flood Early Warning Systems (FEWS) are implemented in numerous catchments around the world where floods present a threat to life and/or infrastructures. However, the implementation of such systems may in some cases be turned down due to economic reasons. In other cases large hydrological uncertainties or complexities in the warning-response interactions may produce sub-optimal performance of certain FEWS. Under these circumstances, quantifying the ratio between the benefit of implementing and/or optimizing a FEWS and the cost of potential flood damages might help decision-makers take the most pertinent choices for each situation. The Value of Information (VOI) concept is particularly suitable for this task since it enables decision-makers to quantify the suitability of hydrometeorological networks and/or single sensors to minimize Type I and Type II errors in flood forecasting, while taking into account the consequences of committing such errors. Of the different hydrometeorological processes, precipitation is responsible for most flooding events and it is also one of the most difficult to monitor accurately. Hence, in this study the VOI methodology is applied to study the influence of distributed precipitation information to the reliability of flood forecasts and optimization strategies for diminishing forecasting failures. The method is tested in the small, partially urbanized, pre-alpine Minster catchment (Switzerland), which has been affected by several flooding events in recent years. The available high-resolution precipitation-data series are used for synthetizing a number of hypothetical sensor-network configurations. Forecasts driven by the different sensor networks are evaluated through cost/benefit analyses for the recorded flooding events and recommendations are made based on the VOI indexes of the different configurations.

Hw10S2.05

Hw10S2 - Adaptative water resources management – system design and operation

Oral

Reservoir's management on the Seine River using a centralized real-time controller and ensemble weather forecasting

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Our purpose is to investigate a possible adaptation strategy for multi-objective reservoirs management on the Seine river basin, upstream of Paris, by using a centralized Tree-Based Model Predictive Control (TB-MPC). This method uses all the information available in real-time, including ensemble weather forecasting, to obtain an adaptive control. In TB-MPC, a tree is generated from an ensemble of weather forecasts. The tree structure summarizes the information contained in the ensemble, specifying the time, along the optimization horizon, when forecast trajectories diverge and thus uncertainty is expected to be resolved. This information is then used in the model predictive control framework, to optimize an objective function over a finite receding horizon, using a model to predict the evolution of the system in response to the forecasted inputs. The TB-MPC controller is implemented in combination with the integrated model of the Seine river basin, including a semi-distributed hydrologic model of the watershed, a simplified hydraulic model of the river network, and the four reservoir models. The controller optimizes a global cost function that takes into account the costs associated to high and low flows, based on critical thresholds at some key downstream stations, and a penalty cost based on the final reservoir storages, to guarantee a sustainable management in the long term. The reservoir's management is tested under the evolution of hydro-climatic conditions due to climate change, using statistically downscaled and bias corrected climate simulations produced by seven Global Circulation Models (GCMs). For the present conditions, time series of ensemble weather forecasts are available and will be used to statistically generate time series of ensemble forecasts for the future. The performances of the TB-MPC controller will be simulated and compared to the actual decentralized management performances over present and future scenarios.

Hw10S2.06

Hw10S2 - Adaptative water resources management – system design and operation

Oral

Optimal use of streamflow data to improve river model calibration

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Modelling of regulated river systems requires a combination of hydrological components, e.g. rainfall-runoff models, and components dealing with diversion and storage of water. The resulting models often include a large number of calibrated parameters and multiple prediction points. To reduce the dimension of the calibration problem, the modelling domain can be split into river reaches delimited by inflow and outflow gauging stations. When the model is used in predictive mode, e.g. climate change studies, uncertainty generated within the upstream reaches will propagate to downstream reaches and compromises the predictions on the lower parts of the model. This study investigates the use of streamflow data to better constrain the calibration of river models. The study is based on the calibration of a river model for a set of 10 Australian catchments. This work is carried out as part of the Australian Water Resources Assessment (AWRA) framework designed jointly by CSIRO and the Bureau of Meteorology. The river model was calibrated sequentially from upstream to downstream reaches using three different scenarios. In the baseline scenario, the reaches were calibrated independently using gauged data as inflows to the reach. This option isolates the reaches and minimizes the propagation of uncertainty. However, it leads to sub-optimal parameters when the model is used in predictive mode with no flow data available. In the second scenario, the reach inflows were set to the simulations from upstream reaches. In a third scenario, the inflows were set to a weighted average between gauged inflow and upstream simulations. The performance of the model was finally assessed in predictive mode. The main results from this study suggest that medium flows are not sensitive to the calibration scenario. However, low flow and high flow simulations can benefit from the optimal use of streamflow data during the calibration process.

Hw10S2.07

Hw10S2 - Adaptative water resources management – system design and operation

Oral

Water distribution network leakage in Bordj Bou Arreridj City

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Water leakage is a costly problem, both because of wasting a precious natural resource and in economic terms. The importance of lowering leakage to improve the reduction of damage to the pipe network itself and to the foundations of roads and buildings is well understood. What is less appreciated is the impact that a high leakage level has on the water service price. The major contributor to non revenue water of Bordj Bou Arreridj Algerian Water Company is pipeline leakages. In this paper, using the Bordj Bou Arreridj Algerian Water Company databases, we inspect the impact of increasing leakages in ten recent years on the «fair price» of water. We also try to diagnosis the water network and compare between the costs of replacing the pipe and the ongoing cost of repairing leaks. Keywords leakage; Water distribution network; fair price; Bordj Bou Arreridj.

Hw11S1.01

Hw11S1 - Environmental information systems for hydrology and water resources

Oral

Designing hydrometeorological information systems for multipurpose schemes on the Rhone River (France)

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In 1933, the Compagnie Nationale du Rhône (CNR) was created to build and operate hydropower development schemes on the French part of the Rhone River with three missions: inland navigation, electricity production and irrigation.
To carry out its missions, CNR monitors a hydrometeorological network with about 250 automatic stations installed along the Rhone River and its tributaries. To manage this network, CNR has developed in partnership with IRD (Institut de Recherche pour le Développement) the HYDROMET software with a secured database to collect, store, consult, criticize and export data from its own automatic stations or from partners'.
To optimise the operation and dissemination of this big volume of heterogeneous data, two information systems have been developed, each being dedicated to a specific audience.
The Hydrometeorological Information System (SIH) is designed to disseminate hydrological and meteorological information within CNR mainly for:
- Network supervisors who monitor and control the whole network, especially stations whose data are crucial for the discharge forecasting process.
- The Energy Management Department forecasters who refer in real time to the state of the Rhone River's catchment (e.g. spatio-temporal rainfall distribution) to expertise the forecasted discharges automatically generated by rainfall-runoff and hydraulics models.
- The Remote Control Centre operators and power plant managers who control the conformity with the operating rules, optimize the management of hydraulic safety (especially during floods) and anticipate special operations (e.g. valve closure).
To improve its services related to the navigation, CNR has also implemented a website (www.inforhone.fr), providing key data mainly to the users of the waterway: conditions of navigation (navigation restriction during floods, traffic at locks, mooring levels and bridge clearances), observed discharges and meteorological information.

Hw11S1.02

Hw11S1 - Environmental information systems for hydrology and water resources

Oral

Creation of a water observatory, region of Tarapaca, North of Chile: An information management and transfer tool

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The region of Tarapacá, located in the extreme north of Chili, is one of the most arid areas of the world and the scene of a competitive use for scarce water resources between mining, domestic and agricultural sectors. In this context, water information and data is generated erratically by the different stakeholders, independently and according to their specific needs. With a difficult access to water information and uncertainty about the level of existing knowledge, sustainable development in a fast-growing region is at stake. The Water Observatory was created by CIDERH as a result of the evaluation and systematization of the water resources information of the region of Tarapacá done during 2012. It is a public web tool for the management and transfer of the water resources information of the region addressed to all stakeholders (communities, academic, private and public entities). The tool aims to answer the questions about availability, property, accessibility and principal characteristics of the existing information, not focusing on the data itself but on the traceability of the information, its origin, localization and way of access. It aims to facilitate research and management processes often lost in the strenuous search for scattered information, improving the access to the water resources information through a dynamic and easy to use tool, and thus facilitating decision-making. The work has been developed in four steps: exhaustive compilation of information, focusing on the hydrology, hydrogeology, water quality, geology and geomorphology; Revision and systematization of the compiled information; Elaboration of a Geographic Information System (GIS) with ArcGIS 10 and a documentation center of the regional water resources information; Creation of the web tool through the exportation of the SIG to the platform ArcGIS online and the elaboration of the on-line catalogue of the Documentation center with ASP VBScript program, both available on CIDERH's website.

Hw11S1.03

Hw11S1 - Environmental information systems for hydrology and water resources

Oral

Dropedia – sharing water resources knowledge with a semantic wiki

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A uniform tenor across disciplines emphasizes the need to improve communication and understanding between actors in the Integrated Water Resources Management (IWRM) domain, in order to ensure best-possible responses to upcoming water resources challenges. In this respect, this study presents an approach to collaboratively manage planning and decision making knowledge on the basis of semantic web technologies.

An initial working hypothesis stated that ontologies and semantic structures allow for flexible support of semi-automated IWRM analysis, for example according to established DPSIR (Driver, Pressure, State, Impact, Response) models. However, limitations and problems of a generic formal knowledge representation in the IWRM domain within common frameworks were uncovered and investigated. Eventually, a conceptual structure and a requirement catalogue were developed and formalized in an ontology prototype for IWRM planning and decision support knowledge sharing. The prototype was implemented as semantic wiki application (DROPEDIA) and opened to the research and stakeholder community of the SMART research project in the Lower Jordan Valley. The platform demonstrates potential to provide solutions for various critical knowledge management needs. For example to help water sector experts to easily document and formalize their work in a semantic structure, invite colleagues and stakeholders to review and comment, consistently connect their work to previously undertaken studies, and share their insights and work processes with a wider audience over the internet. It was furthermore demonstrated how the system is able to store, display and edit information in many types of rich content, and how structured queries could be realized for internal as well as external information from remote data repositories. It is expected that future IWRM initiatives could benefit from comparable approaches, and valuable insights on the subject can be achieved from the presented pilot study.

Hw11S1.04

Hw11S1 - Environmental information systems for hydrology and water resources

Oral

Public-private research on water information systems

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In the Netherlands water is everywhere. Management of the resulting problems and opportunities started with small scale projects and even today a considerable part of the operational management is done on a local level by organizations linked closely to a particular area. Currently a consortium of public and private parties is working on a way to streamline the information processing side without compromising the inherent strengths of decentralized management and private sector initiative. We report on the preparation and the initial implementation phase.

Hw11S1.05

Hw11S1 - Environmental information systems for hydrology and water resources

Oral

Modelling landslide susceptibility in a third order river basin, south Eastern,Nigeria using GIS-DEMs

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This paper addresses the need for an efficient GIS –based methodology for landslide predictions in Ungauged basin (PUB) underlain by the loose/ weakly cemented Coastal Plains Sands in Uyo area of Southeastern Nigeria. Widespread gully erosion, landslides, slumping etc. are ubiquitous features and result from infrequent occurrence of high intensity and prolonged rainstorms during the peak of wet season between June and September. In this area landslide occur mostly as earth movement, mud flow, and debris flows on slopes previously weakened by flood water. Geographic Information System [GIS] was employed as a system with advanced geo-modeling capabilities[DEM] combined with field observation were used in Iba Oku Basin, a third order basin to map potential areas of landslides in Uyo area of Akwa Ibom State in Southeastern Nigeria. The study generated landslide zonation map highlighting areas of different degrees of susceptibility elevation in meters. Slope surface in degrees was also generated and reclassified into three slope classes (uniform, gentle and steep) using the same reclassification algorithm. The result indicates that 89,583m2 representing 10.59% of the total catchment of 845,918m2 is highly susceptible to landslide. Keywords : DEM, Iba Oku Basin, landslide, GIS, Uyo, slope, slumping

Hw11S1.06

Hw11S1 - Environmental information systems for hydrology and water resources

Oral

The impact of activites industiral and human on the wadi Cheliff

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With water resources very limited and difficult to operate, our regions are at risk of pollution increasingly important, often compromising the use of this resource in many localities.

Pollution that most often affects the quality of surface waters, especially at release and wadis pollutants term groundwater. It should be noted that most of our waterways currently play a receptacle and transport of various effluents or municipal, industrial or agricultural.

Their self-purifying capacity, not long enough to reduce pollution loads and begin to experience dramatic changes, reaching alarming levels of pollution to become open sewers.

The importance of the pollution of our wadis should be emphasized and reiterated. The example is instructive for the largest wadi Chélif several provinces through which it must develop and implement a national policy on the matter.

Hw11S2.01

Hw11S2 - Environmental information systems for hydrology and water resources

Oral

A simple HIS to monitor the Mekong river

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In the last 5 years, a near real time monitoring system was implemented in the Mekong basin by the Mekong River Commission under the supervision of the WMO (Mekong-HYCOS project). 49 stations have been implemented with automatic transmission every 15 minutes. Data are sent to an FTP site where they can be retrieved for integration in the database.

Prior this integration a Quality Assurance and Quality Control process is done at 3 levels in order to produce Metadata (ISO 19115/139), Master catalogue (Geo Network), and to supply the HIS. An online Trigger is also applied to correct minors errors or to fill gaps.

Data can be seen at http://monitoring.mrcmekong.org

Hw11S2.02

Hw11S2 - Environmental information systems for hydrology and water resources

Oral

The SO KARST observatory network (France)

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- The SO KARST initiative consists in gathering researchers around major scientific issues and locks, based on the data monitoring and analysis of each network teams' sites. The aim is to organize research at the national scale to bring out issues and scientific advances specifically in terms of links between physical and hydrodynamics of karst aquifers, by the way of statistical and spectral analysis of hydrological recordings and modeling. The SO KARST thus aims to ensure international visibility of scientific products while ensuring the sustainability of long-term measurements and archiving by the creation of a common database. Particular attention is paid to the link between data and models in order to better understand the physical behavior of karst environments and to enrich the physic of the models aiming to simulate this behavior.

  The issues and challenges of major concerns for the SO KARST are:

  - transfer mechanisms and transport in karst environment
  - links between geological structure and flow
  - karst water resources facing global change

  The common observation strategy of the different sites is characterized by an integrative approach at the watershed scale and based on long term time series (flow, piezometric, chemistry). This approach helps to understand the evolution of water resources in karst area in response to short, medium and long waves forcing, in various physiographic, geological and climatic settings.

  Database.

  All information is analyzed, processed, validated and centralized in a database accessible from a portal. The portal follows the construction standards of cataloging and metadata description, including the ISO 11915 standard recommended by the INSPIRE Directive. This database is accessible via a website (www.sokarst.org) incorporating the functions of secure access downloading information. This website also includes a protected password part for supplying and updating the contents of the database and set permissions.

Hw11S2.03

Hw11S2 - Environmental information systems for hydrology and water resources

Oral

Using automatic object detection in rainwater harvesting assessment for a small size urban area

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Water resources are essential for economic development, agricultural productivity, industrial growth and above all human well-being in every community. The availability of a clean, safe and secure water resource has always been a major concern for human populations. Rainwater harvesting (RWH) is defined as the methods for collecting and storing rainwater in reservoirs such tanks, ponds or dams. RWH also reduces urban flooding and prevents runoff from going into sewer systems. Therefore, these techniques reduce loads of treatment plants. RWH from rooftops, roads, and parking can increase the water supply for various applications and help to compensate the chronic water shortage in many parts of the world. The applicability of RWH as a possible and inexpensive alternative to more traditional water resources has been discussed in many research works, in the past few years. Nowadays, LiDAR systems have been recognized as an efficient technology for the generation of high resolution digital surface models of any study area. This research evaluates the potential of using rainwater for potable and non-potable water savings in a specific case study and provides recommendations for increasing the efficient water usage by minimizing water waste and deflates water bills. This paper utilizes a new processing approach to classify the LiDAR data into which belong to ground and non-ground surfaces. The non-ground points are then categorized into planer surfaces such as building rooftops to exclude the non-planer objects such as trees using a parameter-domain segmentation approach. The ground points have been classified into planar surfaces mostly represent roads and parking, and non-planar surfaces represent the bare earth. It is assumed that building rooftops, roads, and parking lots are the main rainwater reservoirs in urban areas. Therefore, the area of these objects' surfaces are calculated using the derived planes' parameters from the segmentation process of the LiDAR data.

Hw11S2.04

Hw11S2 - Environmental information systems for hydrology and water resources

Oral

Management of ground water potential areas using remote sensing data

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Fast urbanization and industrialization leads to water scarcity in study area. Remote sensing or satellite data is extremely useful in assessment of ground water potential areas through estimation of lineament density. SPOT and IRS-1A data was used to assess ground water potential areas which falls between latitudes 28o 29' to 28o 35' E and longitudes 77o 3' to 77o 16'N. Lineament densities were estimated using satellite data to identify ground water potential areas. Development and exploration of ground water require sustainable use and recharge approach. Based on drainage pattern and slope of the study area, remote sensing data is helpful in estimation of lineament density which provide suitable site for exploration of ground water and selection of check dam sites for ground water recharge/ conservation. Lineament density is directly proportional to ground water availability in an area. Study area is highly variable in terms of lineament densities at different locations and areas indicating high lineament densities are highly potential (good aquifers) to possess ground water availability. Total 14 check dam sites were identified using satellite (remote sensing) data in the study area. Mean reflectance values at suggested check dam sites were 1.06 % to 4.53 %. Ground water modeling requires limited land use / land cover classification, which can be done with the help of remote sensing data using unsupervised classification which is then refined on the basis of ground truth .The integrated use of GIS and remote sensing techniques can be successfully used to develop conceptual ground water model. The water demand vis-a-vis water resources availability is evaluated based on hydro-geological set up, field investigation and interpretation of satellite (remote sensing) data.

Hw11S2.05

Hw11S2 - Environmental information systems for hydrology and water resources

Oral

Hydrological predictions for sustainable urban planning (SUDPLAN)

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New tools for assessing water-related changes due to climate change are now available from the EU FP7 SUDPLAN project. The tools offer web based climate scenario information on the European scale together with urban downscaling for intense rainfall, river flooding and air quality together with improved simulation results if the user includes local data. The hydrological service in SUDPLAN provides information on river discharge, local runoff, relative soil moisture, relative groundwater level, temperature and precipitation. The predictions use the European setup of the HYPE model. To improve the results locally, the user can select their basin of interest from the pan-European model and add locally observed time-series of water discharge. This data can be used for producing improved hydrological model results (as compared to the pre-calculated E-HYPE results) by optimizing the model calibration to the available local river discharge stations by an automatic calibration routine. The calibrated model can be run with climate scenarios which have been dynamically downscaled and bias corrected for the hydrological modelling. For intensive rainfall, which is of major interest for urban planning, RCM precipitation is downscaled using observations in a specific point with 30 min temporal resolution. By extreme value analysis, the RCM data are used to estimate future changes in short-term precipitation extremes and in particular the IDF curve which is widely used in urban hydrological design. Moreover, continuous rainfall time series with particular relevance for e.g. treatment plant loads and sewer overflow can be calculated. By analyses of continuous RCM precipitation time series, future changes in the frequency distribution of short-term intensities as well as precipitation occurrence can be estimated. The services have been developed in close cooperation to end users and are evaluated for the cities of Wuppertal, Linz, Stockholm and Central Bohemia.

Hw11S2.06

Hw11S2 - Environmental information systems for hydrology and water resources

Oral

Lokoja urban water supply as a basic service programme: A critical appraisal of seasonal fluctuation from 1916-2011

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This study investigates the various sources of water available in the Lokoja Township, its distribution and their related problems when there is a shortfall in supply. It was found that the water supply and distribution in this area is inadequate even with the abundance of river Niger and Benue which seem underutilized. Water supply in the Lokoja Township apparently looks like a matter of preferential treatments in terms of abundance and quality of water availability to some areas to the detriment of others. It was however confirmed from this study that the water supply is a subject of environmental determinism as the terrain determines what kind (quality) and quantity of water an area gets. The study finally proffered attendant solutions to the inadequate water supply and distribution situation in Lokoja Township.

Hw12PS.01

Hw12PS - The Third Pole Environment – Remote sensing and modelling of hydrometeorological processes in high elevation areas

Poster

Application of remote sensing with alsat-1 data in survey of forest fires and it's impact in forest ecosystem in the north of Algeria

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The Forest in the steppe present an ecological diversity, and seen the climatic unfavourable conditions in the zone and the impact of the forest fires; we notes a deterioration of the physical environment particularly the deterioration of the natural forest. This deterioration of the forests provokes an unbalance of the environment who has some serious and serious aftermaths and provokes a process of deterioration advanced in the ultimate stadium is the desertification. By elsewhere, in a middle where the climatic conditions are favourable, the fire is an ecological and acted agent like integral part of evolution of the ecosystems, the specific regeneration of plants are influenced greatly by the regime of fire (season of fire, intensity, interval), who leads to the recuperation of the vegetation of meadow- fire. In this survey we used the pictures ALSAT-1 of the year 2003 for the detection of the zones has risk of forest fire and their impact on the naturals forests of the region loud arid semi of the wilaya of Tlemcen. A thematic detailed analysis some forests well attended ecosystems some processing on the picture ALSAT-1, we allowed to identify and of classifying the forests in there opinion components flowers. we identified the ampleness of the fire on this zone also. Some parameters as the slope, the proximity to the road and the forests formations were studied in the goal of determining the zones to risk of forest fire. A crossing of diaper of information in a SIG according to a very determined logic allowed to classify the zones in degree of risk of fire in a middle arid in a forest zone not encouraging the regeneration on the other hand permitting the installation of cash of steppe which encourages the desertification.

Hw12PS.02

Hw12PS - The Third Pole Environment – Remote sensing and modelling of hydrometeorological processes in high elevation areas

Poster

Estimation of snow water equivalent based on remote sensing data

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Water produced by snowmelt is an important part of the annual water cycle in the Eastern Kazakhstan, in some cases contributing high fractions of the annual runoff in a watershed. An attempt is made to study the snowmelt runoff in Ulba and Uba rivers by estimating of the snow water equivalent. However, remote sensing techniques are innovative way in deriving the snow water equivalent. A novel snow depth and water equivalent (SWE) data estimated from passive microwave brightness temperature is proposed based on remote sensing data and temperature of the layered snowpack. The microwave emission model of layered snowpacks (MEMLS) was used to simulate the brightness temperature at different frequencies based on the snow characteristics including depth and snow layering.

Hw12PS.03

Hw12PS - The Third Pole Environment – Remote sensing and modelling of hydrometeorological processes in high elevation areas

Poster

Complex and highly nonlinear streamflow responses to low- and high-frequency climatic variations in glaciated mountain regions of Canada and Norway

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We analyzed streamflow and climate data from the southern Canadian Rocky Mountains and arctic coastal Norway for teleconnections and long-term trends. Relative to standard methods of applied statistical hydroclimatology, our approach was novel in some respects. Historical data were organized into an approximate paired-catchment format. Each such group contained a glacial river, a comparable non-glacial river, and representative temperature and precipitation data. Annual regime shifts were assessed at daily resolution. A standard nonparametric statistical method, and an information theory-based polynomial selection technique, were employed in parallel. The latter permits estimating the probability of a relationship, as distinct from conventional p-values, and accommodates highly nonlinear relationships. Outcomes were generally consistent with prior work, but several notable features were discovered: 1. Glacial rivers show highly nonlinear, temperature-associated teleconnectivity in late-summer flow to El Niño-Southern Oscillation (ENSO) in Canada and the Arctic Oscillation (AO) in Norway. The effect is absent in non-glacial rivers; 2. Glaciers influence long-term trends in late-summer flow, with more pronounced declines in glacier-fed rivers in both Canada and Norway relative to non-glacial rivers; 3. Norwegian winter-spring flows (glacial and non-glacial) show strong, nonlinear responses to near-linear temperature and nonlinear precipitation anomalies associated with AO; 4. Probabilities of long-term increases in Norwegian winter flows (glacial and non-glacial) were consistently >90%, associated with positive temperature and precipitation trends; 5. Probabilities of long-term increases in Canadian early-freshet flows (glacial and non-glacial) were locally >90%, associated with increasing spring temperature. Effects 1 and 2 constitute glacier-modulated hydroclimatic dynamics, whereas 3, 4, and 5 appear to be general mountain hydrology responses in these regions.

Hw12PS.04

Hw12PS - The Third Pole Environment – Remote sensing and modelling of hydrometeorological processes in high elevation areas

Poster

Development of snow cover depletion curves through heat units approach for Northern Pakistan

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Snow cover of Northern Pakistan serves as lifeline for down slope inhabitants, as it keeps on replenishing the river network of the country throughout the summers, therefore, estimation of snow cover and its depletion with respect to variable meteorological conditions in the summers is of utmost importance. Snow cover quantification is already performed through MODIS satellite sensor and Normalized Difference Snow Index (NDSI) techniques, hence, this effort is aimed to develop projected depletion curve of snow cover percentage with respect to heat units. In this regard, linear depletion of snow cover percentage with respect to time and heat units is brought in empirical relationship, which proved it highly reliable. Moreover, results retrieved are optimistic and depletion curves drawn can serve as input for different modelling techniques for snowmelt runoff estimation.

Hw12PS.05

Hw12PS - The Third Pole Environment – Remote sensing and modelling of hydrometeorological processes in high elevation areas

Poster

Analysis of snow cover in the Himalayan region using remotely sensed data

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Satellite remote sensing is an effective tool for monitoring snow covered area. However, complex terrain and heterogeneous land cover and the presence of clouds, impose challenges to snow cover mapping. This research analyzes snow cover and glaciers with a perspective of climate change in Himalayan Regions using remote sensing techniques. The remote sensing snow cover data from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite from 2000 to 2010 have been used to analyze some climate change indicators. In particular, the variability in the maximum snow extent with elevations, its temporal variability (8-day, monthly, seasonal and annual), its variation trend and its relation with temperature have been analyzed. The snow products used in this study are the maximum snow extent and fractional snow covers, which come in 8-day temporal and 500m and 0.05 degree spatial resolutions respectively. The results showed a tremendous potential of the MODIS snow product for studying the spatial and temporal variability of snow as well as the study of climate change impact in large and inaccessible regions like the Himalayas. The snow area extent (SAE) (%) time series exhibits similar patterns during seven hydrological years, even though there are some deviations in the accumulation and melt periods. The analysis showed relatively well inverse relation between the daily mean temperature and SAE during the melting period. Some important trends of snow fall are also observed. In particular, the decreasing trend in January and increasing trend in late winter and early spring may be interpreted as a signal of a possible seasonal shift. However, it requires more years of data to verify this conclusion. Significant coverage of lake ice was found in lower elevation zone which is due to flat terrain in this zone.

Key Words: Climate change, Himalayas, MODIS, remote sensing, snow, lake ice.

Hw12PS.06

Hw12PS - The Third Pole Environment – Remote sensing and modelling of hydrometeorological processes in high elevation areas

Poster

Evaluation of distributed hydrologic modeling frameworks for energy market forecasting

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The ENKI framework is a result of a research project started in 2002 as a cooperation between various research and energy companies in Norway. ENKI is an implementation- and test platform for distributed hydrology models. The platform is coded in C++ and has a «plug in» architecture where modules/routines can be loaded from compiled Dynamic Link Libraries (DLLs). These libraries can easily be added, replaced, or modified to test different hydrologic response functions and routing routines.

A project has been initiated to evaluate the framework in an operational setting for hydrologic analysis for energy market forecasting. The results of this evaluation demonstrate the challenges of working with distributed data and highlight the needs for improved 'watershed scale' characterization and development of driving inputs and forcing data.

Hw12S1.02

Hw12S1 - The Third Pole Environment – Remote sensing and modelling of hydrometeorological processes in high elevation areas

Oral

Assessment of runoff components in the Everest basin: Using a hydrological model calibrated with satellite snow products

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The Dudh Koshi River basin (3 720 km^2, Eastern Nepal) is located in the southern part of the Mount Everest Range. The high elevations of this basin lead to an important cryospheric cover, including snow (from 200 to 2 500 km^2, depending on the season) and glaciers (517 km^2). Moreover, the basin is under the predominant influence of the South Asian Monsoon. Knowledge of the various components of runoff (rainfall, snowmelt, icemelt) to the Dudh Koshi River is poor although the impacts of climate change on cryosphere melting and thus on the water resources are consequent. This paper assesses the components of runoff by applying a daily distributed conceptual degree-day model (Hydrological Distributed Snow Model, HDSM). The model requires as following inputs data: (i) geomorphological information, (ii) prescribed ice cover and (iii) climate forcing in order to simulate river discharge, snow cover extent and dynamics of snow water equivalent. A spatial resolution of 1 arcmin (approx. 2 km) has been chosen to accurately represent the topography and the climate variables. The novel aspect of HDSM is requiring snow cover remote sensing data (MODIS) for calibrating the snow parameters. The other hydrological parameters are calibrated using discharge time-series provided by the Department of Hydrology and Meteorology of the Nepalese Government. The use of remote sensing products in HDSM leads to quantify the spatial and temporal distribution of snow water equivalent, thus improving (1) the knowledge of snow processes in this region and (2) the estimation of snowmelt components of the Dudh Koshi River discharge. Despite these advantages, the under-estimation of precipitation in this high mountain environment induces an over-assessment of the glacier-melt volumes, which are used by the model to equilibrate the water balance.

Hw12S1.03

Hw12S1 - The Third Pole Environment – Remote sensing and modelling of hydrometeorological processes in high elevation areas

Oral

Assessment of a rapid sugarcane expansion upon the water balance of the Rio Grande basin, BR

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Since mid 70's, the Brazilian production of ethanol from sugarcane has increased as response to the ProÁlcool (national alcohol program). This increase meant an expansion of sugarcane growing areas in many regions within Brazil. In this work, impacts of sugarcane expansion on hydrological processes occurred at a regional scale were investigated. Daily values of evapotranspiration, infiltration, and surface runoff were estimated by using a distributed hydrological model. For doing so, remote sensing techniques were used for mapping sugarcane plantations from satellite images captured in 1993, 2000 and 2007. Moreover, another land use scenario was evaluated based on predictions made by Embrapa (Brazilian Agricultural Research Corporation).

Four runs were carried out for a 20-year period using all land use scenarios where the run performed with the 1993 land use scenario was adopted as the control run. Evapotranspiration, infiltration, and surface runoff rates were compared to the control run. Comparisons indicated that sugarcane plantations mostly replaced pasture lands. Evapotranspiration rates did not present significant changes once daily values of evapotranspiration increased only by 3%. In addition, sugarcane expansion implied a reduction of daily values of surface runoff and, hence, an increase of daily values of infiltration. For surface runoff, this reduction achieved up to 10% whereas infiltration rates increased by 8%.

Hw12S1.04

Hw12S1 - The Third Pole Environment – Remote sensing and modelling of hydrometeorological processes in high elevation areas

Oral

First comparison and validation of climatological calibration algorithm in TMPA real-time system over high and low latitude basins with independent rain gauge networks

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As the current i°besti ± estimate of quasi-global precipitation derived from satellite remote sensing for TRMM, the TRMM Multi-satellite Precipitation Analysis (TMPA) system underwent a crucial upgrade in early 2009 to include a Climatological Calibration Algorithm (CCA) to its real-time product 3B42RT and will continue to be applied in the future GPM-era constellation precipitation products. In this study, efforts are focused on the comparison and validation of the 3B42RT estimates before and after the climatological calibration with independent rain gauge networks located within the high-latitude Laohahe basin and the low-latitude Mishui basin, both in China. The analyses indicate the CCA can effectively reduce the systematic errors over the low-latitude Mishui basin, but misrepresent the intensity distribution pattern of medium-high rain rates. This behavior could adversely affect TMPAi¯s hydrological applications, especially for extreme events (e.g., floods and landslides) closely related to the higher rain-rates distribution. Results also show that the CCA tends to perform slightly worse, in particular during winter, over the high-latitude Laohahe basin, possibly due to the simplified scheme in the CCA that directly applies the climatological calibrators developed within 40iã latitude to the latitude belts of 40iã¨C50iã¨ N. Last, this study highlights that accurate detection and estimation of precipitation during the cold season, especially for snowing events at higher latitudes, is still a challenging task for the future development of satellite precipitation retrievals.

Hw13PS.01

Hw13PS - How can models help to solve water quality problems?

Poster

Numerical modeling of Ecoli in Rio de la Plata estuary, Buenos Aires, Argentina

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Buenos Aires is the capital and the largest city of Argentina with population of around 3 million people. It is situated on the western shore of the estuary Rio de La Plata, the main source of drinking water for the inhabitants of the city. There are number of rivers that drain into Rio de La Plata; these rivers together form Matanza-Riachuelo (MR) watershed and is one of the most contaminated river basin in Argentina. Several initiatives have been launched by the government of Argentina to tackle the most visible water pollution problem. One of the major components of the wide ranging initiative is the construction of two water treatment plants and the associated outfalls that will discharge into Rio de La Plata. This research examines the impact of coastal tributaries from the MR watershed along with the effluent discharge from the proposed outfalls of the water treatment plants on the water quality condition of Rio de La Plata with the help of numerical models. The focus of the research is to examine the water quality condition near the existing water intake structures in Rio de La Plata. To circumvent the problem of the pollution due to the coastal tributaries there are plans to move the water intake structures further away from the shore into the estuary. The water quality state variable simulated is Ecoli and is one of the major sources of concern. Delft3D suite of models is used for the hydrodynamic and water quality modeling of Rio de La Plata. Result from the hydrodynamic simulation is validated with the help of six ADCP (Acoustic Doppler Current Profiler) sites situated at different locations in the modeled domain. The result from the hydrodynamic model is then used for the water quality simulation and the variation in Ecoli is examined near the water intake structures.

Hw13PS.02

Hw13PS - How can models help to solve water quality problems?

Poster

Modeling approach as a tool for analyzing the measures and scenarios for sustainable nitrates management in barlad river basin

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The paper present the LIFE09 ENV/RO/000612 - CLEANWATER project, which foresees the development of an integrated approach for the management of nitrogen pollution, using GIS environment, with emphasis on modeling tools for delimiting the nutrients vulnerable zones within the river catchments, as well as for analyzing the proper measures from the environmental and economical point of view. The mathematical models are applied for Barlad River basin (surface: 7220 km2, mean altitude: 211 m, length: 207 km) situated in the south-east of Romania country. The surface water model used in the project takes into account the whole drainage network according to the concept of stream order and calculates the seasonal variations of the main water variables, taking into consideration the constrains related to the point and non point pollutions. The groundwater model allows computing the transfer of nutrients by taking into account processes such as advection, dispersion, and chemical reactions of dissolved constituents. By choosing a modeling approach combined with current monitoring, the GIS system proposed in the framework of the project could be able to answer different environmental questions such as: the impact of existed pollution sources especially on the phreatic aquifers that assure the drinking water supply, the synergy between man-induced changes and climatic changes and hydrological related, the contributions of different sources to the N input to the waters quality, making the deference between agricultural source and others sources. In the framework of the CLEANWATER project the measures decreasing the nitrates pollution will be classified based on the pressure categories of point sources and diffuse sources, the polluter categories, most relevant to the pressure situations, and pressure type. Six systems of measures will be analyzed using modeling approach.

Hw13PS.03

Hw13PS - How can models help to solve water quality problems?

Poster

Challenges in water quality modeling of hilly streams – a case study of Hathli stream in lower Himalayas, India

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Hathli stream is a sub-tributary of river Beas in outer Himalayas of India, polluted by the discharge of wastewater of Hamirpur town. A surface water quality model Stream-I was calibrated and verified for DO and BOD for two different sets of data. A stretch of Hathli Stream, a sub-tributary of river Beas was selected between the intake for water supply to Hamirpur town on upstream and to a point 1.2 kilometer downstream of the confluence of this stream with Kunah stream, a tributary of Beas River. Monitoring of water quality was carried out at nine stations along the selected stretch.

Hathli stream has a steep and variable slope resulting in large spatial variations in velocity. The stream comprises small waterfalls and tiny pools and the bed consists of small stones and cobbles. The re-aeration rate is very high due to presence of small waterfalls, steep slopes, and attached algae on the streambed making the modeling exercise highly challenging. The calibration of Stream-1 model with the observed data yielded very high and variable values of K1 (deoxygenation constant) and K2 (reaeration constant). The very high values of K2 were comparable to those obtained using Owens-Gibbs's empirical formula. O'Connors-Dobbins formula and Churchil's formula were not applicable to this stream. To explain high diurnal as well as seasonal variation in DO levels but no floating algae due to swift and shallow nature of the stream, it was assumed that a thin monomolecular layer of attached algae grows at the bed of the stream. The results indicated great promise. QUAL-2E Model takes into account the effect of floating algae in rivers but the effect of attached algae has not been considered in any of the known water quality models. Oxygen transfer due to small waterfalls in the stream was evaluated using Butts & Evans formula yielding good results. The model thus developed can help in water quality management of such streams.

Hw13PS.04

Hw13PS - How can models help to solve water quality problems?

Poster

How an ecohydrological model can help to solve water quality problems: experience from a regional study in Germany

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The eco-hydrological Soil and Water Integrated Model (SWIM) was used to simulate water quality in two catchments in Germany, the Rhin (1716 km²) and the Saale (24130 km²). The aims were: to find measures for improving the ecological status of the rivers, and to assess possible impacts of future climate and land use changes on water quality. The first study was done in collaboration with the Environmental Agency of Brandenburg (LUA) to answer basin specific questions supporting the implementation of the Water Framework Directive (WFD). The percental changes of discharge, nutrient loads and concentrations by possible modifications in land and water management as well as those caused by changing climate were evaluated. The second study additionally included in-stream nutrient processes (considering phytoplankton biomass and dissolved oxygen concentrations) in the modelling. The model experiments to assess the influences of possible future changes in climate conditions or point or diffuse source pollution as well as changes in river morphology on nutrient, chlorophyll a and oxygen concentrations were done. Both studies revealed sensitivity of nitrogen pollution mainly against diffuse sources, and phosphorus pollution against changes in point source emissions, but also the importance of physical boundary conditions and climate on water quality. All these findings should be kept in mind during implementation of control measures in order to increase the adaptive capacity of the basins. However, not all what is requested by stakeholders and politicians can be fulfilled by the modellers (due to limitations in data availability or process description in the model) and not all what can be easily modelled can be finally realized in the basins (due to limitations in finances and techniques and interests of the stakeholders), but models can be a useful tool for the impact assessment on water quality to find those measures with the best cost-benefit ratio.

Hw13PS.05

Hw13PS - How can models help to solve water quality problems?

Poster

Sediment transport model for potential use in water quality studies

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Water quality factors are dependent on sediment concentration which is related to the flow. This makes water quality a flow related problem. Therefore, development of a sediment transport model becomes as important as development of a water quality model due to the fact that pollutants and nutrients are attached to the sediment particles and transported with water over the watershed and through the streamflow network. Pollutant or nutrient yield can simply be calculated by multiplying the sediment yield with a potency factor, which is pollutant content of sediment. Sediment transport models are extensions of hydrological models where sediment transport equations are coupled to existing hydrological algorithm to which outputs of the hydrological model are given as inputs. In the same sense, an erosion and sediment transport model can be extended to a nutrient or pollutant transport (water quality) model due to the fact that nutrients an pollutants are mainly transported by sediment particles.

In this study, a process-based rainfall-runoff-sediment transport model considering the rilling structure over hillslope in hydrological watersheds is developed. Process-based models have physically unavailable parameters to be calibrated by using data obtained through field or laboratory experiments. For the calibration of the developed sediment transport model, a laboratory-scale rainfall simulator was constructed under which an erosion flume, 136 cm wide, 650 cm long and 17 cm deep, was built. 80 experiments considering a variety set of topographical slope, rainfall intensity and sediment size were performed. The sediment transport model was calibrated and validated by using these data. The model is capable to calculate the amount of sediment eroded from the erosion flume provided that the model parameters and physical variables (rainfall intensity, slope, sediment granulometry, size of the erosion plot, etc.) of hillslope are known.

Hw13PS.06

Hw13PS - How can models help to solve water quality problems?

Poster

Geochemical modeling to assess the safe infiltration capacity from a proposed uranium tailings pond

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Groundwater chemistry is largely a function of the mineral composition of the subsurface environment through which it flows. Rock-water interaction is responsible for the geochemistry of groundwater. It will vary spatially and temporally, depending on the geology and chemical characteristics of the aquifer. The impact on groundwater environment due to a proposed uranium tailings pond was studied using geochemical modelling in a small catchment of watershed in Nalgonda district, Andhra Pradesh, southern India. Six groundwater samples were collected and analysed for the concentration of major ions and uranium in order to understand the present groundwater quality in the study area. The groundwater quality was predicted for a period of 100 years including the expected operation life of the uranium mine which is for 16 years. Variation in parameters such as porosity, hydraulic gradient, hydraulic conductivity and concentration of uranium in the tailings waste were considered in the model. Based on several model runs, the infiltration rate of the liners to be used in order to prevent contamination of the groundwater was ascertained. The simulated results show that the transport of higher concentration of solutes beyond the background concentration in groundwater occurs until 500 m until the operation of milling plant i.e. 16 years. After this, due to dilution by rainfall the transport of higher concentration of solutes beyond the background concentration in groundwater occurs until 100 m. Geochemical modeling helped to identify the infiltration rate of the liners to be used for the tailings pond that will not adversely affect the groundwater quality of this region.

Hw13S1.01

Hw13S1 - How can models help to solve water quality problems?

Oral

How can models help solve water quality problems? A case study of the River Thames catchment, UK

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This talk will review the use of empirical and mechanistic water quality models in the Thames river-system to aid the implementation of the Water Framework Directive and other national and international policies. The River Thames is a major UK river system providing water resources for approximately 20 million people. Water quality models have been used to aid the management of the Thames water resource, mainly to attribute nutrient loading to different sources and to estimate the reduction in diffuse and point sources required to meet ecological targets. In particular, the Export Co-efficient Model has been used to identify key source areas and also quantify nutrient transport to estuaries and coasts. More recently, under the European Union FP7 project - REFRESH, modelled outcomes from the mechanistic model, INCA have been integrated with socio-economic assessments to help determine the most cost-effective methods for mitigating nutrient pollution. This has been done within the context of projected changes in land cover, climate, water resource development and atmospheric deposition over the next fifty years and the consideration of ecological indicators. Those water quality models adopted readily by government departments to inform decision making have, to date, been simpler, empirical models, for example Export Co-efficient Modelling. This paper will review why these applications have been successful and why the adoption of mechanistic models for water quality simulations in the UK is now becoming more widespread, in part due to opportunities from cloud computing.

Hw13S1.02

Hw13S1 - How can models help to solve water quality problems?

Oral

Increasing organic C and N fluxes from a northern Finnish river basin - monitoring and modeling suggest climate- related controls

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The fifty years of monitoring data from the Simojoki River basin (3160 km^2) in northern Finland are a unique resource for understanding biogeochemical processes in boreal ecosystems. The Simojoki river basin experiences low, declining sulphate deposition and limited other human impacts. Forest harvest and ditch maintenance are the main land management activities. Lepistö et al (2008) showed that concentrations of DOC and DON have increased, particularly during high flows. DOC concentrations are slowly but continuously increasing, fluctuating between droughts and wet periods. Trends in concentrations of DOC in Simojoki were not linked to declines in sulphate deposition or forestry activities but were related to trends in climate and hydrology.
Typically, DOC concentrations in Finnish rivers and lakes are high - in the Simojoki River DOC >15 mg/l are not unusual. Here, we report fluxes of DOC, possible drivers of change and the results of a modeling study using INCA-C. The analysis of seasonal patterns is important as the autumn may be particularly sensitive to climate change impacts. INCA-C is a conceptual, process-based landscape-scale model of the controls on surface water DOC (Futter et al., 2007). Our empirical and modeling results suggest that climate change driven patterns in runoff, soil moisture and temperature were more important than temporal patterns of sulphate deposition and land management in controlling surface water DOC concentrations.

Futter, M.N., Butterfield, D., Cosby, B.J., Dillon, P.J., Wade, A.J. & Whitehead, P.G. 2007. Modeling the mechanisms that control in-stream dissolved organic carbon dynamics in upland and forested catchments. Water Resour Res 43(2). doi:10.1029/2006WR004960

Lepistö. A., Kortelainen, P. & Mattsson, T. 2008. Increased organic C and N leaching in a northern boreal river basin in Finland. Global Biogeochemical Cycles, 22, GB3029, doi:10.1029/2007GB003175.

Hw13S1.03

Hw13S1 - How can models help to solve water quality problems?

Oral

Use of the MESAW model in Estonia

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The nutrient concentrations exceed permitted level in many Estonian rivers. In order to effectively manage nutrient pollution reductions, it is important to estimate the influence of different nutrient sources on water quality in rivers. The impact of point sources may be calculated by balance method. The situation is more complex with diffuse pollution. Sophisticated models need much detailed information on watershed, which is not available. According to the WFD guidance, the evaluation of diffuse sources may be done with the help of the export coefficients (EC) of nutrients. Large differences between values of EC available from published studies prevent direct use of them. EC must be estimated for each region on the basis of measurements. The presentation describes use of the MESAW model for estimation of the EC in Estonia. This model uses nonlinear regression for the simultaneous estimation of export coefficients for different land-use or soil categories and retention coefficients for pollutants in a watershed. Application of the model enabled to estimate present state of the great number of water bodies (150). Results obtained by the MESAW used to estimate effectiveness of different measures directed towards the decrease of the nutrient concentrations. On our opinion, the very significant result of analysis of the MESAW results was also possibility to find water bodies that cannot be modelled using known sources of nitrogen and to investigate why. For example, The MESAW results helped to find quite large source of nitrogen in Estonia – drained peat soils. Unfortunately application of the more sophisticated models often encounters a number of obstacles. The first one is incompetence or insufficient experience of modellers. The calibration of a model is a very complex task, which requires understanding of the modelled processes and the way of their representation in the model. The second obstacle is a lack of necessary information for the successful modelling.

Hw13S1.04

Hw13S1 - How can models help to solve water quality problems?

Oral

Adapting empirical and theoretical evidences through water quality modeling using nested catchment experiments in Brazil

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This paper contributes from current praxis and theoretical evidences on how pollution loads across nested catchment experiments (NCE) outline advances on adapting uncertainty with water quality modeling under land use changes (LUC). Most Brazilian river basins under changing conditions depict dynamical behaviors, with new challenges to water quality models at NCEs dependent on both biome and human drivers. Our working hypotheses acknowledge missing link examples classified in "Praxis", "Empiricism" and "Theory" (PET) using real-case factors of continuity, diversity, dynamics, resilience and vulnerability in rivers. Pollution loads per drainage area and reference flows derive new questions at NCE: (1) How can we model mixed water quality signals of hydrologic alteration at NCEs under progressive LUC, i.e. urban, rural or mixed ones?, (2) How to derive a novel understanding to address water quality model uncertainty and the impacts on water biodiversity at systems with a complex mosaic of LUC affecting pollution yield across NCEs?, (3) In what manner can we manage model uncertainty of pollution loads linking headwaters to downslopes, relative to the river's resilience to assimilate time-progressive pollution due to LUC? We critically analyze a database at 40 river sections at subtropical and Cerrado biomes at medium-size scales, i.e. from 0.93 km^2 to 128 km^2 area with former LUC of urban, agricultural and forestry uses. Missed linked examples and variables studied with the PET-perspective are discussed, in terms of ecohydrology regarding Total Sediment (TS), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), grey Water Footprint (gWF) and Payment for Environmental Services (PES). Seasonal effects and steady-to-unsteady constraints of NCEs are evaluated through mass pollution balances. Results address on how model uncertainty of is case-sensitive among scales and introduces equi-probable outputs to solve water quality at changing biomes and long-term scenarios.

Hw13S2.01

Hw13S2 - How can models help to solve water quality problems?

Oral

Over-parameterization: destiny or choice for physically-based water quality models?

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There seems to be an implicit view among modelers that 'physically-based' water quality models require many parameters due to their nature. Here we exemplify how over-parameterization can be avoided without much compromise on the representation of physical processes when modeling stream water quality in a boreal forest catchment. Our approach is based on the realization that stream water quality is not simply the sum of the contributions from different landscape elements and takes hydrological connectivity into account. When accounting for hydrological connectivity in boreal areas with forested till soils, wetlands and riparian zones emerge as hot spots that almost completely buffer the chemical signal from any more distant hydrological unit. Our choice to exclude less important processes from hydrologically disconnected locations lead to the development of the parameter-parsimonious but physically-based Riparian flow-concentration Integration Model (RIM). Applying RIM at the catchment scale allowed spatio-temporal simulations of variable stream water quality. More importantly, however, RIM could be used for hypothesis testing, which is often hardly feasible when using water quality models with many parameters and degrees of freedom.

Hw13S2.02

Hw13S2 - How can models help to solve water quality problems?

Oral

Linking a water quality model to an existing water resources system yield model

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Integrated Water Resource Management should be based on reliable information about natural water availability, existing uses of water and projected future uses and necessarily includes water quantity and quality. South Africa has a long history of using hydrological and water resources system yield models in practical water management, but water quality models are not well integrated with existing water quantity models, do not adequately cover the range of water quality variables or are difficult to apply. This paper outlines the development of a Water Quality Systems Assessment Model (WQSAM) that uses water quantity outputs (natural flows, abstractions, return flows and storages) from an existing monthly time-step yield model and is based on relatively simple water quality algorithms to represent the mass balance and fate of salts and nutrients. The quality parameters are designed to be compatible with information typically available in most parts of the country and, while calibration using historical water quality data is possible, guidelines for parameter estimation in ungauged areas are also being developed. The model algorithms are based on assigning water quality signatures to different flow components, simple first-order reactions are used to simulate instream nutrient fate. The model includes algorithms to simulate the dynamics of non-conservative quality variables within reservoirs. Assuming that a monthly time-step for water quality would be too coarse, the model disaggregates the monthly flow data into daily data. Water resources managers are typically concerned with risks associated with decisions, and the model output emphasises durations of quality variables exceeding certain thresholds. WQSAM has been applied to the Buffalo River in the Eastern Cape, South Africa. The results are assessed against observed water quality data and the sensitivity of the model is examined with respect to changes in the water quantity inputs and the quality parameters.

Hw13S2.03

Hw13S2 - How can models help to solve water quality problems?

Oral

Experiences of success and constraints from using S-HYPE for WFD in Sweden

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Eutrophication is a serious environmental problem in Sweden, and it affects a relatively large proportion of water bodies reported within the WFD. With over 20,000 water bodies to report, Swedish authorities have developed strategies to include both monitoring data and models within the WFD. S-HYPE is a national version of the Open Source HYPE model which has been developed to support the characterization of water bodies in Sweden. S-HYPE input data and results are freely available on the web at vattenwebb.smhi.se. Nevertheless, successful use of modelled data to resolve environmental problems depends on how well the user understands the capabilities and limitations of the model. The most important question for users tends to be: How well does the model fit measurements? To answer this question, users can compare modelled and measured data using an interactive application in Vattenwebb. Publishing this information, however, leads to a more intriguing question: Can a model still be useful if it deviates from measured data? We argue that model results can be very useful despite moderate deviations at single stations. Models provide valuable information on spatial variability in unmonitored areas as well as nutrient source apportionment. In addition, models provide an opportunity to simulate the effects of alternative input or forcing data, e.g., calculate background nutrient loads and effects from climate scenarios. Since Vattenwebb was launched in 2010, S-HYPE model results have been used extensively by national, regional and local authorities across the country to support work with national environmental quality objectives and WFD. As models continue to improve and offer a cost-effective supplement to field measurements, it is likely that models will become even more important in the coming years.

Hw13S2.04

Hw13S2 - How can models help to solve water quality problems?

Oral

Estimations of longitudinal dispersion coefficients in rivers by means of product-unit and multi-layer perceptron neural network

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A number of techniques allowing the prediction of pollutant transport in rivers have involved a great deal of attention among scientists. However, even in the case of the advection-dispersion, the identification of its parameters is usually based on designed experiment. In practice, an unexpected spillage of pollutant may occur in a river in which no tracer tests had been performed. Managers who have just a modelling tool at their disposal and the basic information about the stream, are supposed to derive some conclusions about the admixture pattern in the stream after its release. This study concerns the problem of pollution transport in rivers in situations when no results from tracer tests are available. In such case approaches pertaining to numerous empirical formulae allowing estimation of the longitudinal dispersion coefficient based on hydraulic characteristics are used. Great effort has been performed to develop empirical methods allowing practitioners to estimate longitudinal dispersion at particular river reach without performing tracer tests. Initially, mostly the regression equations were considered as a predictive tool and recently neural networks have been given much attention for this task. In this study to estimate longitudinal dispersion coefficients in rivers two types of neural networks are applied, namely product-unit and multi-layer perceptron neural networks. Both neural network types are applied with performing an uncertainty analysis, discussion on the proper optimization criteria and verification of the optimization algorithms used to find the proper weights of the network. The final results seem to be optimistic. The properly trained neural networks may significantly outperform the well known regression equations. We restrict our considerations to river reaches when most important river characteristics, including water velocity, shear velocity, bed slope, depth, width and sinuosity can be assessed for each river reach of interest.

Hw13S2.05

Hw13S2 - How can models help to solve water quality problems?

Oral

Effect of increased bioenergy crop production on hydrological response and nutrient emission in central Germany

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Several indications showed that changes in land use/cover can influence the hydrological regimes and in consequence river water quality. Hydrological water quality modelling has proven to be an efficient tool to predict how the changes in land cover can affect the discharge of river catchment and its water quality (such as nitrogen and phosphorus) using different land use scenarios. The aim of this study was to investigate the effect of increased bienergy crop production on the hydrological water quality using a scenario-based appraoch. The HYPE model (HYdrological Predictions for the Environment) was setup in two mesoscale catchments in central Germany. The selected catchments are Selke (463 km2) and Weida (99.5 km2), which are two small tributaries of Elbe river basin and are located in Saxony-Anhalt and Thuringian states, respectively. The predominant land use classes of the Selke catchment are arable land (≍ 50%) located mainly in the lowland area and forest (35%), which is situated in low montain area. Howover, the dominating land use classes of the Weida catchment are agricultural land (40%), forest (29%) and grassland (26%), which are all located in low-montain range (elevation between 357-552m). First, The HYPE model was setup for the Selke catchment. Second, the model was used to predict the measured discharge and nutrient concentration of the Weida catchment using the same corresponding optimized paramter values obtained from calibration in the Selke catchment. Therefore, the feasability of HYPE model-parameter transferability between catchments with different physiographic characteristics and new regionalization schemes were investigated. The HYPE model was then used to predict the impact of different bionergy scanarios on the river discharge and nutrient emission. The preliminary results of this study will be presented and discussed.

Hw13S2.06

Hw13S2 - How can models help to solve water quality problems?

Oral

Using modelling in monitoring of agri-environmental policy aspects in Finland

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An agri-environmental subsidy program that states water protection as one of its main objectives has been in place in Finland since 1995. It is the main tool within Water Framework Directive to control nutrient loads from agricultural areas. The annual agri-environmental support totals some 300 M euro and forms a significant part of environmental policy expenses. Policy can attempt to influence agricultural practices such as crop choice, set aside, fertilizer application rates, tillage system, and the adoption of water protection measures. Recently, Prime Minister Matti Vanhanen set a national target for nutrient re-cycling in Finland (Baltic Sea Action Summit 2010) recognizing the problem that energy and nutrients are resources not to be wasted. Monitoring of the effects on water quality on national level is based on long-term monitoring data of large river basins discharging to the Baltic Sea. On local level monitoring of the impacts of agricultural changes in water quality is concentrated on a few selected catchments, which represent the main agricultural production areas in Finland. Since 1995 also the farmers are interviewed about their annual cultivation practices. This data gives sound basis for semi-distributed process-based catchment scale modeling (INCA) of nutrient leaching. By modeling we can explain what the reasons are behind observed changes in water quality, and in some cases what are the reasons behind not to observe any changes in water quality and present a synthesis. Further, we can include effects of climate change or make scenario studies. But still one open question remains: What are the changes actually driven by policy, and what are the changes driven by e.g. economy? Thus, for successful modeling we need 1) long enough water quality data and statistical analyses of them 2) knowledge of actual measures implemented 3) process-based model but also knowledge of processes, and 4) good cooperation with economists and stake holders.

Hw13S2.07

Hw13S2 - How can models help to solve water quality problems?

Oral

Identifying strategic options to meet the requirements of the Water Framework Directive and the Urban Wastewater Treatment Directive: Water quality of the River Almond (Scotland, UK)

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Atkins was commissioned by Scottish Water to produce a dynamic water quality model of the River Almond, using MIKE-11 Ecolab (DHI). The overarching aim of this work, which is subject to regulatory sign-off from the Scottish Environmental Protection Agency (SEPA), is to assess the impact of Scottish Water assets on the water quality of the river. Extensive water quality monitoring across the catchment was carried out over the summer of 2011; covering 26 locations and including automatic monitoring and spot sampling for a range of water quality parameters. The monitoring data set served as the basis for the development of a water quality model, which also included inputs from sewer network modelling, carried out by another consultant. Based on our understanding of the catchment issues, the parameters simulated were: dissolved oxygen, temperature, ammonia, biochemical oxygen demand, ortho-phosphate and particulate phosphorus. In order to fit the requirements of this project, some modifications to the standard Ecolab template were made. The results were assessed against the requirements of the Water Framework Directive and the Urban Wastewater Treatment Directive. This analysis has been used to identify water quality parameters and specific locations of concern in the River Almond system, providing Scottish Water with a detailed assessment of catchment needs. The work continues with identification of strategic options to meet legislative requirements and improve the water quality in the River Almond.

Hw13S3.01

Hw13S3 - How can models help to solve water quality problems?

Oral

What are the conditions and obstacles for successful application of water quality models in river basins

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There is no doubt that water quality modelling is much more complex and challenging than purely hydrological modelling. This is mainly due to the multi-factor context. The water-quality related variables in a model should reflect real processes: linkages between various components during their transformations in the soil, on the pathway to surface water and within waterbodies. In addition, water quality constituents depend on hydrological processes, which should be adequately represented. There are a number of serious requirements and constraints related to adequacy of input data, level of model complexity adjusted to the task at hand, experience of the modellers, and interpretation of results. Changing climate poses an additional complication in the modelling, and there is a danger that models may not include important mechanisms and control parameters that could become important under changed driving forces. There is always uncertainty involved in the water quality modelling, so that the modelling results should never be interpreted as exact values, but within ranges defined by the parameter and data uncertainty, as indicators of possible trends, as qualitative differences, etc. The results of water quality models have to be critically interpreted, and communication with local experts is important. Considering these requirements and constraints, models have the power to provide insights in water quality processes and to support water management. Despite all the uncertainties involved in water quality modelling with limited input data, the models are important tools to support water managers in implementing IWRM. It would be impossible to evaluate the impact of land management, changes in land use and climate on water quality without using the modelling tools. However, models need to be thoroughly validated before making projections for future. The conditions and obstacles for successful application of water quality models will be discussed in the presentation.

Hw14PS.01

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Predictions of change trend of water resources based on matter analysis

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Matter analysis is an emerging branch of mathematics that has the capacity to address many practical problems and has recently had a wide application in a number of different disciplines. Based on the examination of physical causal information, it is assumed that the annual runoff (mother series) of Mou Station on the Qiantang River, China is related to 7 factors (son series). In order to select physical factors with close relationships to wetness-dryness change trends, the use of grey relational analysis has been applied to this research. In this article, we used physical factors as prior predictors and thus enabled the matter analysis to have a predictive function, which represents a novel application. There were 18 years (at Mou Station where 20 years' measurement took place during 1988-2007) in which the calculated and actual grades matched. Calculated and actual grades in 1999 and 2003 were discrepancy with one grade, indicating that the results were sound.

This method involves some unique attributes: (1) By using grey correlation analysis, we can choose physical factors with close relationships to water resources; (2) In the calculation, we can determine the maximum historical fitting rate of the mother serial calculation grade to the actual grade by gradually adding or deducting predictive factors and adjusting division values, to obtain optimal predictive results. The results presented here indicate that this technique is a new method of predicting change trends in annual runoff in drainage basins. This paper, which focused on predicting change trends of water resources, has set up a preliminary calculation system based on matter analysis. We have developed applied functional software along with the research. This is a new attempt to assess trend predictions of water resources. It is expected that this system application will become more sensitive and will further increase the performance of trend predictions of water resources using matter analysis.

Hw14PS.02

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Approche de modélisation de l'index d'érosivité des pluies en zone urbaine subhumide en Algérie septentrionale

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Dans ce travail, nous présentons une approche de modélisation de l'index d'érosivité des eaux de pluies en zones urbaines et périurbaines, sous climat subhumide. En effet, ces régions connaissent, après chaque averse torrentielle, des inondations, chargées en sédiments, obstruant le réseau d'évacuation des eaux pluviales. En absence de jaugeages, il reste difficile d'estimer les pertes en sols, dues à l'agressivité des eaux de pluie, arrachées au bassin versant et déposées sur les voies de communication. Dans un objectif de pouvoir estimer la quantité de sédiments pouvant être déposée sur un tronçon de route, limitrophe de la zone d'étude, l'index d'érosivité est déterminé à partir d'un dépouillement de 744 averses enregistrées, sur une période de 19 ans. L'équation Universelle des pertes en sols (USLE) de Wischmeier et Smith est appliquée. Du point de vue hydrologique, cet index a un poids conséquent dans l'équation. Il repose sur les intensités de la pluie déclenchant le processus d'érosion en nappe. Une région du Nord-Ouest algérien, en plein cœur de la Mitidja, vulnérable aux inondations, avec une érosion en nappe visible, est choisie comme zone d'étude. Des relations fonctionnelles sont recherchées entre ce facteur et les variables explicatives (cumul annuel des précipitations et intensités maximale). Un modèle régressif, type puissance, s'est dégagé entre l'index d'érosivité et le cumul des précipitations. Ce modèle, très prometteur, permet d'apporter une aide à la décision en absences de mesures, en climat subhumide, dans les zones à dominance «érosion en nappe «.

Hw14PS.03

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Will we have more floods in future and what can we do about it

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Flooding has been major natural hazard to all the nations around the world, especially in Wales due to the long wet winters and certain summers due to its geographical location and topography. Flooding has caused major economical and human losses over the years notably the recent floods in Islamabad, Pakistan, which took the lives of over 400 people and dented the national economy by millions of pounds. Wales has not been affected by flooding of that stature, however, it has been subjected regular flash floods that created great human as well as economic losses. Taking into consideration of the current economic climate and the value of human life, it is paramount important that the nation safeguards itself from floods. Aim of this project is to identify the possible trend of flooding in the past for the study area and give a projection of future climate; it aims to reveal the trend of future floods. With the newly identified trend and prediction, investigation on the measures that should be taken by the government to safeguard the country in an event of flooding will be carried out, should flooding be predicted. Daily day River flow data for the past forty years from six gauge stations will be collected. Two were situated in the north, two in south and two in centre. Using several Computer programmes including MS Excel and MATLAB, the data will be analyzed to form graphs that will show the trend if there are any. From the graphs that were formed, there were not any strong trends that can be used to clearly predict the future floods. Most areas seem to have fluctuating climates over the years. However, the recent past has shown a very strong case for increased flooding in future. 2012 eclipsed 2011 as the wettest summer since the records began. To reduce any more loss due to flooding, the government should tighten its stand on construction on floodplain and increase urban plantation.

Hw14PS.04

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Hydrological data and mathematical parameters for catchment regionalization: A case study of osun drainage basin, South Western

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A protocol is proposed for the regionalization and subdivision of catchments based on hydrometric parameters. Such catchment regionalization may assist the development of appropriate catchment management strategies and policies. As a case study, the trends of variations in daily stage and discharge of seven gauging stations located in the 9,900 km2 Osun Drainage Basin (South West Nigeria) were investigated. Linear regression models for all stations show the expected strong positive association of stage and discharge. The estimated daily changes explain only 1.44% of variations in stage, 0.25% variation in discharge and 99.5% in stage-discharge for station 5, 5.5% variation in stage, 0.7% variation in discharge and 99.7% in stage-discharge at station 25, and 10% variation in stage, 8.9% variation in discharge and 100% in stage-discharge at station 27. For the other studied stations, R2 estimated from daily stage and daily discharge give widely varying patterns. R2 estimated from daily stage and daily discharge is non-significant, but is significant for the daily stage-discharge relationship. The exponents of the stage-discharge equation can also be used for spatial classification. Zone A exponent is in the range of 1.3-1.7, Zone B exponent is in the range 2.2-2.3 and Zone C exponent is in the range 4.0-4.7. These can be combined to produce three hydrometric regions. It is proposed this regionalization protocol could be used as an initial step in dividing complex catchment systems into more homogeneous subunits, to assist subsequent catchment management and planning. The hydrometric regionalization protocol is now being evaluated on the Osun and other drainage basins in Nigeria.

Hw14PS.05

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Prediction models for hydrometric analysis: A case study of the Osun Drainage Basin, southwestern Nigeria

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The correlation matrix for maximum stage and maximum discharge revealed that there are eighteen regression equations with correlation coefficients of over 50% from maximum stage while only ten can be obtained from the maximum discharge matrix for the seven stations. Analysis of variance (ANOVA) was used to evaluate whether there are differences between the average value, and mean, across several population groups. The appropriate equations were derived for the maximum stage (H) and maximum discharge (Q), with the coefficient of correlation (r) of the ranging between 50% and 99% and coefficient of determination (r2) ranging between 25% - 99%. It was observed that four equations out of the eighteen derived for the maximum stage (H) have negative slopes while three out of ten equations derived for maximum discharge (Q) have negative slopes. All the equations with negative slope are from the stations upstream of the basin. It was also observed that station 35 was highly correlated to stations 52 and 64 for both the maximum stage and maximum discharge and the four equations derived with station 35 as dependent variable are all having negative slope. It could be concluded that the derived equations for the maximum stage (H) and maximum discharge (Q) can be adopted for mitigation of natural disasters and could be used for warnings for short-term events like flash floods to seasonal outlooks of the potential water supply for irrigation and even design of small hydraulic structures such as culverts.

Hw14PS.06

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Future rainfall and flooding in Sweden: an integrative project to support climate-adaptation actions

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Temperatures, rainfall amounts and the number of days with extremely heavy precipitation are expected to increase in Sweden in the future. It is becoming increasingly important for societies to develop tools to adapt to climate-related risks. Higher rainfall is likely to increase river runoff, which may increase the risks of erosion, flooding, and landslides. During the recent 20 years, Sweden has experienced a series of heavy and/or persistent rainfall events and floods. An integrated project involving climatologists, hydrologist, geographers and meteorologist was setup to deal with future precipitation, temperatures and hydrological changes and their associated flood risks, potential damage and possible protective measures in Sweden.

The primary objective of the project is to develop an integrated framework of data, methods and tools to support municipalities and counties in Sweden in their climate adaptation actions regarding future precipitation and temperature changes and their impacts on flooding. This includes: obtaining local climate change information; hydrological modelling to assess future runoff; hydraulic modelling to estimate flood risk; and analysing the results in a GIS-based system to map potential damage. The project is still ongoing and we intent to report on some of the results obtained so far.

Hw14PS.07

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

A non-parametric method of incorporating uncertainty in estimating areal rainfall from point rainfall

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Rainfall is the main driver of catchment hydrological processes and a major input of catchment models. In many regions, radar rainfall measurements are either unavailable or cover much shorter spans of time and rain gauge measurements remain the main source of rainfall data for practical hydrological analysis including areal rainfall determination. The variation of rainfall between the gauges is usually inadequately captured as the rain gauges are sparsely located and the resulting areal rainfall estimates are therefore considerably uncertain. A method of quantifying these uncertainties and incorporating them into ensembles of areal rainfall is formulated and tested. The uncertainties are imposed as linear perturbations based on the differences in areal rainfall that result when half of the rain gauges are alternately omitted. In addition a procedure for estimating the proportion of rainfalls that fall on areas where no gauges are located is formulated. The zero areal rainfalls obtained for these periods are replaced with plausible non-zero rainfalls is included. The model only requires the specification of the number of rain gauges that would be considered sufficient to cover all significant rainfall events in the catchment. The model is tested using daily rainfall from two South African catchments and is found to obtain realistic uncertainty bands of areal rainfall.

Hw14PS.08

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Study of hydrological simulation on the basis of underlying surface characteristics of the basin

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Drainage networks for the Three Gorges inter-basin area in China was derived by use of ARC/ INFO and RiverTools based on the digital elevation models (DEMs) of different scales. Comparative analysis shows that the reliability of the drainage networks is high for the river basin with the rugged terrain, and there are the differences between the drainage networks derived with different methods, especially in the river basin with the un-rugged terrain. Some topographic indexes derived according to the drainage networks, such as the mean length of flow concentration routes and the mean gradient of hill slope, vary with the grid size of the DEM, so they can only be used as relative indexes. The undulation of topography and the grid size of the DEMs should be taken into account when the forementioned indexes are applied in hydrological modeling.

The parameters of the Xinanjiang hydrological model were calibrated in the six sub-basins of the Three Gorges inter-basin. The underlying surface characteristics of the river basin including vegetation, soil and geomorphy, etc are extracted. The relationship between these characteristics and the hydrological parameters such as capacity of free water (SM), coefficient of surface runoff (KI) and groundwater runoff (KG), as well as the flow concentration parameter of Muskingum Method (X) are established by means of correlation analysis or the physical meaning. These deduced parameters were verified by using reverse calculation method according to the model simulated matching with the measured discharge process, and have been applied in real-time flood forecasting for the Three Gorges Project.

Hw14PS.09

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Courbes Intensité-Durée-Fréquence avec insuffisance de données: Comparaison de méthodes dans trois contextes bioclimatiques

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Résumé: La maîtrise des inondations en milieu urbain nécessite de connaître les précipitations, ce qui pose probléme lorsque les données sont insuffisantes et/ou éparses. La construction des courbes « Intensité-Durée-Fréquence «, à travers une étude approfondie des averses, permet une approche synthétique des précipitations et la prédétermination des évènements de récurrence donnée. Pour leur construction, plusieurs méthodes sont proposées dans la littérature, l'objectif étant in fine de voir celles qui s'adaptent le mieux aux conditions algériennes. La méthode classique, le modèle global de Koutsoyiannis et la méthode marginale sont retenus. Les deux premières méthodes sont appliquées aux séries des maximums annuels (SMA) et aux séries des durées partielles (SDP), la troisième sur la totalité de l'enregistrement. Les SDP sont construites en fixant un seuil choisi à l'avance. Différentes durées d'agrégation (de 15 minutes à 24 heures), sont retenues, pour trois contextes bioclimatiques: subhumide, semi-aride à hiver tempéré et semi-aride à hiver frais. Pour chaque site, les quantiles sont estimés pour des périodes de retour de 2, 5, 10, 20, 50 et 100 ans. Pour les méthodes appliquées aux SMA et SDP, les quantiles sont comparés à la racine carrée de l'erreur quadratique moyenne (RMSE). Les SMA et SDP s'ajustent à une loi Log-normale. La méthode marginale n'a pas été retenue, l'erreur sur les quantiles étant trop importante. La construction des courbes IDF a permis d'identifier l'exposant climatique de chacune des zones étudiées. Mots clés : IDF, averse, méthode marginale, maximums annuels, modèle de Koutsoyiannis, séries des durées partielles.

Hw14PS.10

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Distributed hydrological modelling for flood hazard mapping under climate change scenario: The case of Yang River basin, Thailand

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This study presents an application of BTOPMC, physically based distributed hydrological model and a hydraulic model, HEC-RAS for flood hazard mapping under climate change scenarios in Yang River basin of Thailand. The climate change scenarios of A2 and B2 emission scenarios (2020s, 2050s and 2080s and baseline data of 1976-2005) are constructed based on the bias-corrected output of PRECIS, a regional climate model (RCM) driven by the ECHAM4. The dimensionless hydrograph was developed from the heavy runoff pattern in 2007. The hydrograph was applied to derive synthetic inflow hydrographs for 25-, 50- and 100-year return periods to obtained flood hazard maps. The results from simulated flood return periods of 25, 50 and 100 years were used to generate flood hazard map by dividing into three water depths which are 0.6, 1.0 and 3.5 m. In the baseline period, area inundated by 25, 50 and 100 years return period flood is 205, 224 and 240 km2 respectively. This amount of inundated area may occur with corresponding to 16-year flood in the lookahead period of 2020s under A2 scenario. In medium future (2050s) under A2 scenario, the probable flood event with 25-year return period may have the most relative change (30.90 %) in total inundated areas compared to baseline with the same return period. For B2 scenario, the most relative change in total inundated areas compared to baseline is approximately 30.97% during the furthest future (2080s). These scenario simulations suggest that future climate changes will have an influence on the discharge regime and may increase the flood hazard in large parts of the Yang River basin.

Hw14PS.11

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Runoff modeling under conditions of climate change and human activities in the Hutuo River basin, China

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Climate change and human activities impact assessment on runoff play an important role for regional water resources planning and management. Statistical methods are considered as the ordinary tools for quantitative assessment of impacts on water resources modeling. The objective of this paper is to find out the change point of runoff series and modeling the runoff process using lagged climate indices in a statistical way in the HaiHe river basin. The sequential clustering method is selected for testing the consistency and finding out the change point of precipitation and runoff series. The multivariate linear regression and artificial neural networks are chose for modeling the runoff processes before and after the change point using lagged climate indices. The optimal climate indices are well selected from the 74 circulation parameters. The results show that the variation of precipitation series is slightly compared with the runoff series. Hence, the variation of runoff is mainly caused by human activities rather than climate change. In addition, we have constructed statistical models for the runoff processes before and after the change point with the above-mentioned methods. The simulated results of the above two methods are compared and the artificial neural networks model is of high precision. Based on this study, it can provide the guidance for the water resources development and management and the society, economy and environment sustainable development in the Hutuo River basin.

Hw14PS.12

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Multi-station rainfall-runoff modelling using ANN approach

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Climate change as an influential factor in hydrologic cycle may cause changes in rainfall–runoff patterns and this may result in discharge amount and land surface changes. To this end, multi-station modelling of rainfall-runoff provides spatial prediction for discharge. This paper investigates the ability of artificial neural network (ANN) to predict daily runoff at multiple gauging stations for the Peace River basin in Florida with three proposed scenarios. The first scenario was a general model with an integrated ANN model trained by the discharge data of multiple gauging stations and uniformly distributed rainfall data over the watershed. For the second scenario, all the sub basins were modeled individually. Finally in the third scenario, ANN models for downstream stations were trained by upstream discharge records as input in addition to discharge and precipitation records of desired station. The obtained results revealed the appropriateness of third scenario due to better performance at multiple stations within the watershed.

Hw14PS.13

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Uncertainty of input data on VICMODEL

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A variety of hydrological models have been widely used in hydrological simulation and hydrological prediction. Linking model parameters to physical catchment attributes is a popular approach that enables the application of a conceptual model to an ungauged site. The effective running of a hydrological model not only relies on the functional relationship derived either from the calibrated model parameters or by calibrating the functional function but the representative data. However, it is so impossible to make the data corresponding to realistic condition that the hydrological models can not show the reality perfectly, that is, uncertainty always exists in the data. The uncertainty arises from incomplete process representation, uncertainty in initial conditions, input, output and parameter error. Thus, an explicit estimate of the associated uncertainty should be made to give the probability that a hydrological model makes an unreasonable simulation or prediction. In this paper, the uncertainty of input data for VICMODEL hydrological model is studied. The uncertainty is explicitly accounted for by the application of the GLUE (Generalized Likelihood Uncertainty Estimation).

Hw14PS.14

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Assessing the impact of meteorological data uncertainty on SWAT model

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Hydrological model is a useful tool to predict runoff. Since meteorological data is commonly important input data in hydrological models. Due to the limitations of technical measurement, model performance will be negatively impacted by data uncertainty. To investigate the influence of meteorological data uncertainty on predictive uncertainty, the integrated river basin model SWAT was chosen to simulate streamflow of the Heihe basin in northwest China. In this paper, the observed meteorological data which input in the SWAT is precipitation, daily maximum, minimum temperature, average wind speed, relative humidity. Solar radiation was generated by weather generator(WXGEN). To quantify the uncertainty, add random data which was calculated by Monte Carlo method on original data. The results of study indicate that meteorological data has a great influence on streamflow predictions, and compared with the observed runoff data, the simulation results that have considered data uncertainty are much better than the simulation results of original data. Among all meteorological data, precipitation uncertainty has the most significant impact, while others have much less influence. This study shows that the impact of meteorological data uncertainty on SWAT model is mainly from precipitation data. Improve the accuracy of precipitation can efficiently improve the model performance.

Hw14PS.15

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Uncertainty of input data on TOPMODEL and sensitivity of parameter for hydrological model

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Radar estimates of rainfall are being increasingly applied to flood forecasting applications. Parameter sensitivity is important to hydrological models. In this paper, the uncertainty of input data (radar precipitation data) and sensitivity of parameter for TOPMODEL hydrology model are studied. Hydrological model parameter sensitivity is explicitly accounted for by use of the GLUE (Generalized Likelihood Uncertainty Estimation). The radar precipitation data is used as the input data from Shiguan River Basin in eastern China. The errors sources are adjusted by applying a radar rainfall estimation algorithm. Radar rainfall estimates adjusted and not, are used as an input to TOPMODEL for flood simulation. Statistics are proposed to evaluate both the wideness of the uncertainty limits and uncertainty bounds. Results show the critical importance of proper adjustment of radar estimates and the use of radar estimates as close to ground as possible. Uncertainties affecting runoff predictions from adjusted radar data are close to those obtained by using a dense raingauge network.

Hw14PS.16

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Regional drought event identification and characteristics analyzing in China

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China has been experiencing frequent severe droughts since the second half of 20th century, causing at least $36.5 billion damages annually. A regional drought event identification scheme was proposed based on the soil moisture anomaly percentage index (SMAPI) and China's regional drought events over a 60-year period (1951-2010) was identified. The SMAPI was calculated based on the soil moisture generated by the VIC-3L (Variable Infiltration Capacity Model-3 Layers) with a 30km resolution forced by gridded precipitation and temperature. The drought characteristics like frequency, duration, magnitude, intensity and areal extent were quantified by analyzing the identified regional drought events. The results show that for drought area greater than 30% and duration longer than two months, a total of 333 droughts over China's nine study regions were identified. The identified regional drought events agreed quite well with the recorded historical drought events. Up to 48% of the whole county experienced prolonged droughts every two year, both South and North suffered the most severe and frequent droughts with more than 54% of the regional areas suffering droughts almost once a year, while Xinjiang incurred the least severe and the shortest droughts, averaging once a decade. Short-term droughts within 6 months were prominent over South, Southwest, East and Xinjiang, whereas long-term droughts above 6 months were remarkable over Northwest, Tibet and North. Extensive droughts with average drought area above 60% were widespread over South, while droughts with average drought area less than 60% were pervasive over Northwest, Tibet and Xinjiang. Droughts in China seemed to alleviate during the period 1950s to 1970s, while exacerbate afterwards, indicating an increasing susceptibility to agricultural drought in the recent 30 years. Droughts in North, Inner Mongolia and Northeast had significant uptrends during the recent 60 years, whereas Xinjiang had significant downtrends.

Hw14PS.17

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Regional analysis of rainfall and flood discharges in Guinea

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The Regional Analysis is a set of statistical methods that try to combine the local information with information known at some key points within a given homogeneous region. Regionalization approach can be seen as a kind of spatial interpolation methods. Many variants of this approach are used in hydrology. Regionalization relies upon two main principles: (1) identification of homogeneous regions; (2) identification of regional equations. In this paper, the regionalization was performed for rainfall intensity, mean annual discharge and for flood discharges in Guinea.

For Rainfall three main regions have been identified. The Intensity-Duration-Frequency curves were derived using a regionalization of the parameters of the Montana's relation. The parameters of the Montana law were estimated using frequency analysis and regressions on the Annual maximum 24, 48 and 72 hours rainfalls series. To extrapolate the daily Depth-Duration-Frequency to short Depth-Duration-Frequency the scaling method was adopted.

For river discharges, the regional analysis of the Mean Annual Discharge (MAD) was based on the use of the catchment area as a key variable. Analysis showed that the studied Guinean watersheds can be classified into two main almost homogeneous regions: the region of the coastal and central basins of Guinea and the upper region of the Niger Basin.

The regional analysis of flood discharges was performed using the GEV distributions. The GEV distribution family includes Gumbel, Weibull and Frechet distributions as special cases. The Regional GEV is a GEV distribution whose parameters were estimated by regression methods using results from individual GEV distribution fitted at key locations (gauged rivers).

Hw14PS.18

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Hydrological modelling through regionalisation of parameters: A case of Mazowe Dam Catchment

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Understanding catchment hydrology is a pre-requisite for sustainable water resource management and hence, hydro-meteorological data forms the basis for carrying out water resources assessments. This data is either obtained through direct measurements at hydro-meteorological stations or can be derived from remote sensing. However, inhibiting factors such as rugged terrain, inaccessibility of areas, lack of measuring infrastructure and lack of remote sensing information at appropriate temporal and spatial resolution can hinder the collection and availability of this information. In hydrology, regionalisation then comes into play to assign basic data to ungauged catchments. Regionalisation is best achieved through modelling. The HBV model -a rainfall-runoff model - was used to model two gauged sub-catchments of Mazowe Dam Catchment and parameters were transferred to the remaining two ungauged sub-catchments using the spatial proximity regionalisation method. The regionalisation parameters were tested on the gauged catchments and they showed high regression coefficients (R^2) between the simulated and observed runoff with R^2 of 0.90 and 0.89 for Dassura and Mazowe sub-basins respectively. Therefore, the regionalisation parameters can be successfully applied to the two ungauged sub-basins of this catchment for water resources assessment with limited bias as errors cannot be totally ruled out with modelling

Hw14PS.19

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Flow modeling of the Rositza river

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Catchment modeling of the Rositza river basin, located in North Bulgaria will be presented. The Rositza river is tributary of Yantra river that discharges to Danube river. Both rivers are located in North Bulgaria and they are part of Danube hydrological zone in the country. Rositza river has length of 164 km, catchemnt area of about 2 265 km2. Along the main river body the reservoir Stamboliiski is located.

The multi-annual river discharge simulation is performed. Two models from US Army corps of Engineering – HEC-GeoHMS and HEC-HMS have been selected and executed. HEC-GeoHMS is a geospatial hydrology tool kit for engineers and hydrologists. The program allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, delineate subbasins and streams, construct inputs to hydrologic models. HEC-HMS is designed to simulate precipitation-runoff process in dendritic watershed system. The model includes a large set of methods to simulate river basin, channel and water control structures. In our study the reservoir Stamboliiski is taken into account during model performance.

The model HEC-HMS is run on daily time step. Daily hydrological and meteorological data for 1985-2005 period are utilized. In the river catchment three hydrological gage stations are available on the main river body and four stations are located on its tributaries. For the mentioned above study period four rain gage stations and two temperature gage stations are used. The HEC-HMS accounts for snow accumulation and melt processes. The simulations and model verification are made for the hydrological year with beginning November 1. Long term runoff simulation is performed and discussed.

The two models were successfully applied for geographic, climatic and hydrologic conditions in North Bulgaria. The obtained results will be presented and discussed.

Hw14PS.20

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Investigating major hydrological characteristics of Gin catchment, Sri Lanka using distributed hydrologic simulation approach

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Major hydrological characteristics in Gin catchment are simulated in the study by applying the distributed hydrological model, YHyM/BTOPMC (University of Yamanashi Distributed Hydrological Model with Block-wise use of TOPMODEL and Muskingum-Cunge method) utilizing the global data sets readily available in public domain along with the local available rainfall and discharge data. Gin river having a catchment area of about 932 km2 is one of the main sources of water supply to the southern region of Sri Lanka. Hence, it is vital to comprehend the hydrology of the catchment in order to gain knowledge on current and future hydrological conditions.

In the study, YHyM/BTOPMC model performance was evaluated by the Nash-Sutcliffe Efficiency (E) and the volume ratio of simulated discharge to observed discharge (Vr). Daily discharge data from 1997 to 2001 and from 2002 to 2006 were used for calibrating and validating the model, respectively. Model calibration and validation results at the down-stream gauging station included Nash-Sutcliffe efficiency of 68% and 63%, respectively. The observed and simulated discharge hydrographs during both calibration and validation showed a good agreement except for few extreme events. In particular, the low flows were simulated very well. In response to the rainfall, base flow showed rather direct action due to the sandy textured soils present in substantial area of the catchment. Summary of the simulated water balance for Gin catchment demonstrated that the simulated average annual values of actual evapotranspiration, interception evaporation, ground water recharge and discharge are 865 mm, 81 mm, 1336 mm and 1290 mm, respectively. The simulated average annual discharge volume varies from the observed average annual discharge volume by +4.25%. Overall simulation results well represented the major hydrological characteristics of Gin catchment including runoff volume, evapotranspiration, base flow and soil moisture states of the catchment.

Hw14PS.21

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Application of multivariate analysis for locating groundwater potential zones in dry zone of Sri Lanka

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Wet, intermediate and dry zone are the main climatic zones in Sri Lanka. Most of the shallow dug wells in the dry zone of Sri Lanka go dry during dry periods. Therefore, majority of the people live in this region depend on tube well for their day to day water requirements. As a result of this, construction of tube wells has been increasing in dry zone. However, few occasions it was found that these tube wells were not constructed at the most suitable groundwater potential areas. Thus, preparation of groundwater potential maps help to locate tube wells in the most suitable places. Arial photographs, Geographical Information Systems (GIS) data and satellite images have proven their importance as additional tools in groundwater prospecting by outline geology, structure, landforms, surface anomalies and drainage characters to locate recharge or discharge sites. Remote sensing provides synoptic view and better hydrographic, geologic, geomorphic and structural information to study groundwater hydrology of an area. Geology, landform structure and climatic conditions control the groundwater storage, occurrence and movement. In this study essential hydrological and hydrogeological data such as depths to groundwater level, draw down, discharge, sand percentage, etc were used and factor analysis multivariate statistical approach has been carried out to demarcate groundwater potential zones in dry zone of Sri Lanka. Finally, using GIS techniques such as reclassification and spatial modeling, groundwater potential map was prepared for the study area.

Hw14PS.22

Hw14PS - Regional modelling in hydrology using statistical tools

Poster

Regional flood frequency modelling for Benin-Owena River Basin

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The increasingly failure of many hydrological and structural design of control structures and reports of over designing of this structures most especially in developing countries call for detailed investigation on catchment system response and the processes involved. This is necessary in the wave of climate variability /change and increasingly capita water demand and modification of this river catchment through human development activities. One of the consequences of this modification is the increasingly extreme hydrological events which demand a thorough investigational approach towards the provision of an optimum lead time. Hence, it is very important to adequately carry-out detailed investigation of the flood intensity and frequency at catchment regional level, if appropriate water resources management plan is to be achieved within a river catchment Thus, due to paucity of hydrological data for a long-term hydrological investigation a statistical investigational approach has being adopted to analyses flood tools designed for the storage and flood analysis based on observed annual maximum peak flows at gauging stations, and information on the physical and climatic characteristics of Benin-Owena River Basin. The analysis functions include the fitting of regional flood frequency distributions of the grouped data using Extreme Value Type 1 distribution (EV1), Log-Pearson Type III distribution (LP3) and Wakeby distribution (WAK) frequency distributions were adopted to develop regional flood frequency curves for the Catchment. The usefulness of the design regional flood frequency curve for ungauged stations within the catchment was also stressed. In addition, as part of the regional flood frequency estimation method the mean annual flood (MAF) was developed using multiple regression techniques. This was combined with the regional flood frequency curve for complete flood estimation within the region.

Hw14S1.01

Hw14S1 - Regional modelling in hydrology using statistical tools

Oral

The implications of hydrologic similarity definitions for model regionalisation

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Daily streamflow information is critical for solving any number of hydrologic problems. Because most of the world's stream reaches are ungauged, this data is commonly needed for rivers that have no readily available measurements of streamflow. One approach for estimating daily streamflow time series at ungauged catchments is to transfer a set of model parameters resulting from the calibration of a rainfall-runoff model at a gauged catchment (or set of gauged catchments) to an ungauged site of interest. Central to this approach is the selection of a gauged donor catchment that is considered hydrologically similar to the ungauged catchment. A number of published studies compare various methods of defining hydrologic similarity, typically using distance between the catchments or similarity in catchment characteristics; however, no single metric of hydrologic similarity has been demonstrated to consistently select a suitable donor catchment. For 82 unregulated catchments located across the United States, this study explores the use of various similarity metrics from which to select a donor catchment. Similarity metrics were based on the distance between the watersheds as well as their physical and climatic characteristics. We evaluate effectiveness of model parameter transfer between a pair of catchments in two ways – transferring a single best performing set, and, evaluating the difference between the empirical cumulative distribution functions of the top performing parameter sets from a common set of random model parameters. Finally, we use the map-correlation method to combine the information on effectiveness of model parameter transfer with the similarity metrics. Using this new approach, we attempt to explain the confounding results of previous hydrologic similarity studies.

Hw14S1.02

Hw14S1 - Regional modelling in hydrology using statistical tools

Oral

A hydrologically-oriented classification of catchments

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In this study, we propose an original methodology to cluster catchments from a hydrological perspective. The clustering algorithm is based on the k-medoids and the similarity metric is based on the efficiency of the transfer of model parameters from one catchment to the other. The obtained classification is then analyzed with respect to the catchment behavior signatures and physiographic attributes of the catchments. This allows discussing the relative relevance of physiographic attributes in explaining catchment behavior. This methodology was applied on 708 catchments located in France using the simulations of the GR4J model to derive the hydrological similarity metric.

Hw14S1.03

Hw14S1 - Regional modelling in hydrology using statistical tools

Oral

Regional estimation of parameters of a rainfall-runoff model using a one-stage procedure

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Management of water resources problems usually needs implementation of methods for the estimation of river flows. This is usually achieved either by analyzing the available measured river flows statistically or through the use of a rainfall-runoff model. In principle, both approaches rely on availability of enough observed flow data. Such a requirement, however, may not always be met in practice. Regionalization techniques, which are aimed at establishing a relationship between either certain flow characteristics or parameters of a rainfall-runoff model with measurable catchment physiographic and climate attributes, have been in use to circumvent this problem. In this work, an approach for the regionalization of parameters of a rainfall-runoff model is presented. Model parameter regionalization is classically done using a two-stage procedure, which involves estimation of parameters by independently calibrating the model for a number of gauged catchments followed by establishing a regression relationship between the estimated parameters and catchment properties. Due to the known problem of equifanality, model calibration does not lead to a unique set of parameters and, therefore, the established regression relationship will also not be unique and may not even be strong. The approach presented in this work combines the two steps into one. Model calibration in the selected gauged catchments is performed with a dual objective of maximizing the goodness of fit measures related to both the model performance and the relationship between the model parameters and catchment attributes. Applicability of both regression and a kriging based relationship in a space defined by catchment attributes is considered to establish the relationship between model parameters and catchment attributes. The approach was implemented and validated in the German part of the Rhine catchment.

Hw14S1.04

Hw14S1 - Regional modelling in hydrology using statistical tools

Oral

Robust parameters and assessment of structural uncertainty in hydrological models using a depth function

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Hydrological model-parameter values often need to be calibrated to produce adequate simulations. Reducing the complexity of the natural system to a set of functional relations involves simplifications and is made difficult by several factors including data uncertainty, incomplete knowledge, and computational limitations. It is therefore desirable to use parameter values that are robust, rather than optimal ones. The geometric structure of the set of behavioral (well-performing) parameter-value vectors can be explored using depth functions. The deepest parameters within this set are often found to be robust. In the present study, the applications of depth functions to the exploration of the behavioral set was expanded on two fronts. Firstly, since a plethora of depth functions exist, and considering the heavy computational costs related to most of them, a computationally simple one, the convex hull peeling depth (CHPD), was tested as a tool to explore how hydrological robustness, in terms of temporal transferability, varied with depth. The second experiment consisted in evaluating the CHPD as a tool for the visualization and characterization of the multivariate distribution of behavioral set. Methods based on the CHPD were tested to detect differences in the distribution of behavioral parameter values for four different models and two objective functions: the Nash-Sutcliffe efficiency and one based on flow-duration curves. The four models had increasing complexity and were tested with data from the Paso la Ceiba basin in Honduras. It was shown that robustness generally increased with depth also for the CHPD. It was also possible to give an idea of the shape of the multivariate distributions and detect differences between them, both between models and objective functions. In order to be able to compare the different models, it was necessary to project along a common dimension, the volume of the behavioral set, potentially introducing bias.

Hw14S1.05

Hw14S1 - Regional modelling in hydrology using statistical tools

Oral

Catchment classification based on apparent similarity and functional similarity

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Prediction in ungauged basins is one of the common problems in hydrology. In order to predict in ungauged catchments regionalization approaches were developed. They are usually based on the assumption that model parameters can be linked to catchment properties. Unfortunately these procedures are very diverse. The objective of this study is to describe catchment similarity which is identified on the basis of catchment descriptors that can be derived for ungauged basins. Our study considered 279 catchments located in the eastern United State, for which several catchment descriptors, geomorphoclimatic characteristics and response behaviors are available. Firstly, a reference classification which was identified by using model parameters was set up. The conceptual rainfall-runoff model HYMOD was applied for parameter estimation. Instead of the usual catchment by catchment calibration a simultaneous calibration of the model for a number of catchments was performed. All the catchments were classified into homogeneous groups that have the similar hydrologic behavior. Then this reference classification will be compared with two alternative classifications that are identified on the basis of catchment properties. One alternative classification adopts the catchment properties as input to fuzzy rules assessment model by using simulated annealing algorithm. The other alternative classification is identified by using data depth function to the sets of available catchment properties. Preliminary results from this study indicate that the hydrologic behavior could be significantly represented by the combination of specified catchment properties. The classification of this study will be used to improve our knowledge about the overlap between apparent catchment descriptors and hydrologic response, enhance the ability of spatial and temporal transfer of hydrologic information.

Hw14S1.06

Hw14S1 - Regional modelling in hydrology using statistical tools

Oral

On updating flow statistics based on predicted climatic changes

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Estimates of flow quantiles are needed for a variety of engineering applications. Estimates are first required at gaging stations, after which regionalization procedures may be applied to extrapolate to ungaged areas. Here, we will stop at the gaged catchment level, put us in a climate change perspective, and ask the following question: **could a simple approach be proposed to update the statistics obtained at streamflow gaging stations?**

An approximate method seems feasible for reasonably small changes, and such a method could be validated based on catchments which have had in the past a sufficient climatic variability. Here, we test a simple method on a set of 527 unregulated French catchments, which all have long-term records: we start from regionalization formulas obtained for low-flows and mean flows, and propose a method to account for climate evolution. Then, we validate the method on present climatic variability, by confronting observed changes to estimated changes.

Hw14S1.07

Hw14S1 - Regional modelling in hydrology using statistical tools

Oral

Methods for regional water resource assessments in the sub-Saharan Africa region

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There are many areas of sub-Saharan Africa that are poorly gauged and where the information available to characterize hydrological responses is very limited. It is also a region where informed water resources management is critical for economic development and social upliftment. This paper will initially review some of the approaches that have been previously used to establish hydrological models for generating both water resources availability (natural hydrology) and the extent to which existing resources are already utilised. These methods include statistical relationships between model parameters and basin physical properties, direct parameter estimation from physical basin properties, transfer of parameters from gauged (after calibration) to ungauged sub-basins based on assumptions about sub-basin similarity and the use of regional signatures of basin hydrological behavior to constrain uncertainty ensembles. The paper will also discuss the various ways in which uncertainty analyses can be included as part of the various methods. A number of examples of previous work will be presented in an attempt to make some conclusions about what are the most appropriate methods. 'Appropriateness' is assumed to refer to the ability of the different methods to generate reliable and robust results as well as whether or not the methods are practical to apply. Several of the several problems with many of the approaches based on initially calibrating models on gauged catchments include poorly quantified upstream development effects (what is the model being calibrated against?), uncertainties in the climate inputs due to inadequate meteorological observation networks and inherent equifinality within the structure of some models. The paper will also present some results of applying a monthly time-step hydrological model to simulate the natural and present day hydrology of the Caledon River basin (15 266 km2), a poorly gauged tributary of the Orange River in South Africa.

Hw14S1.08

Hw14S1 - Regional modelling in hydrology using statistical tools

Oral

Non-parametric catchment classification using data depth function

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It is important to classify catchments for many reasons. For example, for prediction in ungauged basins, model parameterization and watershed development. There have been many studies on catchment classification, but no silver bullet exists for choosing the most relevant measure of catchment similarity. The aim of this study is to explore a new measure of similarity among catchments, using data depth function. We compare this new measure with existing catchment classification matrices, i.e. flow and flow indexes. A cluster analysis was performed on catchment characteristics and also on catchment response behaviour using Affinity propagation (AP) clustering algorithm. Catchments classification based on both the method was compared and also catchment similarity defined based on catchment response behaviour was compared with similarity defined based on catchment characteristics. We evaluate whether the similarity based on data depth-depth plots does provides a better basis for transferring parameter sets of a hydrological model between catchments. In this study, we focused on 42 catchments located in Bay of Plenty region in the North Island of New Zealand. The catchments have a wide range of topographic properties, response behaviours and geological features. Results shows clustering based on our proposed depth-depth measure, catchment characteristics, flow, and flow indices are different. TopNet model was then set up for all the catchments and transferability of model parameters among the similar catchments was tested by transferring the parameters from within the cluster group and outside the group. The preliminary results based on Nash-Sutcliffe coefficient are promising. The catchment classification of this study will be used to improve regional flood forecasting capabilities.

Hw14S2.01

Hw14S2 - Regional modelling in hydrology using statistical tools

Oral

A hydrological model of New Zealand

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We report recent progress on a long-term hydrological modelling project whose goal is to make reliable estimates of all water fluxes and storages of New Zealand, and reliable estimates of potential changes in those water resources. This is an ambitious scientific project, with many practical implications for water use and water planning.

The model assumes a single model structure (TopNet, see Clark et al 2008), and uses a priori parameter estimation, based on national datasets, without calibration. The model uses an hourly timestep and was run for 40 years. New Zealand's 260,000 sq km area is subdivided into 35,000 subcatchments of about 7 sq km each.

We will show results for selected regions and river basins, and assess the model performance against measured soil moisture and snow storage, as well as measured streamflow. As well as being useful as regional and national models, the results provide a sound start for model calibration, if needed.

Comparisons of the reliability of these streamflow predictions against other methods reveal that, not surprisingly, jacknifed results from calibrated statistical methods outperform the uncalibrated TopNet in predicting flow indices. We show the results of applying a statistical correction to the TopNet flow hydrographs, making use of the more accurate predictions from a Random Forest model of flow duration curves in ungauged catchments.

There are opportunities to improve on these results through improved mapping of recession characteristics, improved use of recording raingauge data, and selection of model structure to match the spatial variations in hydrological processes which are not captured by a fixed model structure. This model underpins new regional and national forecasts and climate change assessments which are now in development.

Hw14S2.02

Hw14S2 - Regional modelling in hydrology using statistical tools

Oral

Parameter regionalization using Self-Organizing Maps considering non-stationary climate conditions

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Currently many hydrological studies are focusing on changing climate and landuse conditions. Often statements are requested in un- or poorly gauged catchments, so that hydrographs for the calibration of conceptual hydrological models are not sufficiently available. Therefore techniques to regionalize model parameters (MP) are required. State of the art is the transfer of stationary MPs, which might be not sufficient under changing conditions.

In this study we present a novel regionalization method based on Self-Organizing Maps (SOM) and its application to 41 catchments of the Aller-Leine River Basin in Northern Germany. In a first step the SOM measures the physical similarity of catchments. Therefore sets of catchment descriptors (CD) are needed as input data. These CDs can consist of, from the view of hydrologists, stationary information like topography, geology, etc. but also of non-stationary information like climate and land use. After the similarity of the catchments is known, the model parameters (MP) get calibrated. The sets of MPs of the single catchments are related to each other using techniques based on SOM as well. This allows the connection of sets of MPs to sets of CDs and therefore the transfer of MPs to ungauged catchments. After introducing and validating the novel method, we train the relationships between MPs and CDs with two different sets of CDs for all 41 catchments. The first set uses only stationary CDs for the measurement of the similarity of the catchments, while the second one also includes climate indices. For three catchments the time series are divided in dry and wet periods and MPs are estimated and validated on the opposing periods, respectively using the two different sets of CDs for comparisons.

Results indicate that the transfer of whole parameter sets to ungauged catchments is working under stationary conditions. Furthermore we will show first results of regionalized MPs under non-stationary conditions.

Hw14S2.03

Hw14S2 - Regional modelling in hydrology using statistical tools

Oral

Effects of inter-annual and seasonal variability in regionalization of hydrologic response in the Great Lakes basin

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Methods for predicting streamflow in areas with limited or nonexistent measurements typically invoke the concept of regionalization, whereby knowledge pertaining to gauged catchments is transferred to ungauged ones. Hydrologic response indices have frequently been employed in contemporary regionalization research related to predictions in ungauged basins. In this study, we developed a suite of regionalization models using multiple linear regression and regression tree analysis to derive relationships between hydrologic response and catchment physical characteristics for 163 catchments in the Great Lakes basin. Relevant data were extracted from Version II of the Geospatial Attributes of Gauges for Evaluating Streamflow dataset for the water year 1981-2010. Runoff ratios at different temporal scales were used as the dependent variables in the regression analyses. Our study resulted in a means for predicting runoff in ungauged basins at a monthly time step. Our results show that accounting for inter-annual and seasonal variability of hydrologic response can result in substantially different model-predicted runoff compared to using long-term averages. These results indicate that predictions based on long-term characterizations of hydrologic response can produce misleading conclusions when applied at shorter time steps.

Hw14S2.04

Hw14S2 - Regional modelling in hydrology using statistical tools

Oral

Hydrogeological classification as a tool to support regional scale groundwater modelling

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Groundwater flow and transport models rely primarily on local data which is usually not available at any location of a large river basin. A new approach is proposed to statistically derive relevant information for unobserved areas, making use of existing information from observed locations. The proposed concept is based on the hypothesis that similar groundwater systems respond similarly to similar impacts. At its core is the classification of (i) static hydrogeological characteristics (such as aquifer geometry and hydraulic properties), (ii) dynamic changes of the boundary conditions (such as recharge, water levels in surface waters), and (iii) dynamic groundwater system responses (groundwater head and chemical parameters). Dependencies of system responses on explanatory variables will be used to map knowledge from observed locations to areas without measurements. Classification of static and dynamic system features combined with information about known system properties and their dependencies provide insight into system behavior that cannot be directly derived through the analysis of unclassified data. The foreseen approach will combine existing regionalization methods with classical methods of multivariate analysis and novel methods (e.g., Copula). Hydrogeological a priori and regional expert knowledge are an essential element to support this approach. Classification and dependency analysis could finally lead to a new framework for groundwater system assessment on the regional scale as a replacement or supplement to numerical groundwater models and catchment scale hydrological models. This contribution presents the main ideas underlying the approach, discusses the state of the art, and presents preliminary results. We see this as an important contribution to strengthen the link between groundwater and surface water hydrology and come to more holistic regional scaled system descriptions and understanding.

Hw14S2.05

Hw14S2 - Regional modelling in hydrology using statistical tools

Oral

Climate change impact on intensity-duration-frequency curves

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It is widely acknowledged that climate change will alter precipitation patterns across the globe, but there are considerable differences between climate models in their projections of change amplitude for individual locations. Most climate change studies focus on changes in mean precipitation, yet in many hydrological applications extreme precipitation is the main interest. In this study, we examine and evaluate different methods for estimating changes in future intensity-duration-frequency relationships, using output from regional climate models. Climate models have significant biases in extreme precipitation statistics which tend to be relatively more important for shorter-duration rainfall. We propose to deal with this issue by exploiting the fact that extreme rainfall events obey certain temporal scaling laws that we assume will remain largely unaltered in future climates, even if the frequency of these events change. This hypothesis is used to develop IDF curves for several locations in Manitoba, Canada. We demonstrate that annual maximum precipitation at most stations in the province are well modelled by simple scaling laws, which allows distributions of sub-daily extreme precipitation to be derived from daily extreme precipitation. Output from the Canadian Regional Climate Model (CRCM) is then used to investigate how IDF curves may change in the future. To investigate uncertainties in model predictions, we also employ model output from the North American Regional Climate Change Assessment Program. The overall conclusion is that there is evidence of more extreme precipitation in future climates and these changes are relatively more important at shorter durations. However, the exact amount of change is subject to large uncertainties.

Hw14S2.06

Hw14S2 - Regional modelling in hydrology using statistical tools

Oral

Optimal hydrological regional frequency analysis

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Classical methods of regional frequency analysis (RFA) of hydrological variables face two drawbacks: (1) the restriction to a particular region which can correspond to a loss of some information and (2) the definition of a region that generates a border effect. To reduce the impact of these drawbacks on regional modeling performance, an iterative method is proposed. The proposed method is based on the statistical notion of the depth function and a weight function φ. This depth-based RFA (DB-RFA) approach is shown to be superior to traditional approaches in terms of flexibility, generality and performance. In order to avoid subjective choice and naïve selection procedures of ϕ, an algorithm-based procedure is introduced to optimize the DB-RFA and automate the choice of ϕ. This procedure is applied to estimate flood quantiles in three different regions in North America and compared to traditional approaches. The DB-RFA approach leads to better performances both in terms of relative bias and mean square error.

Hw14S2.07

Hw14S2 - Regional modelling in hydrology using statistical tools

Oral

Regionalization of IDF curves using the property of scale invariance

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Networks of daily rainfall raingauges are often much dense than tippet bucket raingages networks. Consequently, it would be of high interest to make use of daily rainfall information assessing IDF curves for unobserved locations. The present work proposes achieving this goal by using the assumption of simple scale invariance. The simple scaling property is identified using the fitting of regression of log transforms of rainfall statistical moments of order q versus log transforms of rainfall durations (scale). In case where the relation of slopes versus moment orders is linear, “simple scaling invariance” is assumed (Gupta et Waymire, 1990). Yu et al. (2004), Bara et al. (2009) as well as Ceresetti et al., (2010) adopted the assumptions of simple scaling to maximum annual rainfall for durations in the interval 30 mn to 24 h. Thus, using 24h-rainfall totals, they suggested estimating quantiles of rainfall intensities of short durations using quantiles of 24 h rainfall. In the present work, series constituted by the N most important maximum annual intensities observed during N years in 15 stations are studied. Observed intensities for various time resolutions extending from 5 minutes to 24 h are available. The period of observation is 1950 to 2001. Two simple scale invariance behaviors are identified namely a scale regime in the interval [5 minutes - 30 minutes] and another in the interval [30 minutes - 24 hours] for all stations. The study focuses on durations in the interval [30 minutes - 24 hours]. The resulting scale exponents vary from k=0.55 to k=0.89 for the resolutions [30 minutes - 24 hours] and vary from k=0.40 to k=0.65 for [5 minutes - 30 minutes] resolutions. Furthermore, for regionalization purposes, a power low regression is fitted and cross-validated between the estimated scale exponents and 90th percentile of sample maximum annual daily rainfall.

Hw15PS.01

Hw15PS - Testing simulation and forecasting models in non-stationary conditions

Poster

Applicability of a kinematic wave flow based distributed hydrologic model for various climate and land use conditions

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A distributed hydrologic model based on a kinematic wave flow approximation considering surface and subsurface flow components is tested at various catchments with different climate and land use conditions. The distributed model, 1K-DHM, has been applied to many Japanese mountainous catchments in the temperate climate with wet conditions. The distributed hydrologic model is linked with a two-dimensional inundation model in a lower flood plane to assess a change of inundation by a change of flood discharge caused by climate and land use change. The distributed hydrologic model estimates time and space distributions of discharge at the upper part of a study basin by a one-dimensional kinematic wave model including surface and subsurface flow processes using a function of discharge-soil storage relationship. 1k-DHM uses 1km spatial resolution topography data provided by HydroSHED and a two-dimensional inundation model uses 90m one, which is easily developed for different catchments in all over the world. The model shows high applicability in Japanese catchments, however, the applicability is not assured in various catchments with different climate, land use, topography, soil type, catchment scale, and so on. Our target is to analyze the applicability of the distributed hydrologic model on different climate and land use conditions and to examine a proper hydrologic process to be included in a distributed hydrologic model depending on various hydrologic conditions.

Hw15PS.02

Hw15PS - Testing simulation and forecasting models in non-stationary conditions

Poster

Hydrological modelling in presence of non-stationarity induced by urbanisation: an assessment of the value of information

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The proposed protocol of the workshop is followed, which regards the investigation of the effect of non-stationarity due to urbanisation on the performance of a hydrological model. In particular, the rainfall-runoff component of HYDROGEIOS modelling framework (Efstratiadis et al., 2008) is used. This is a parsimonious model of the conceptual type, based on the idea of Hydrological Response Unit (HRU). It is parameterised per HRU with seven parameters in each. Both a lumped and a semi-distributed version are employed. In the latter, two HRUs are assumed, representing the urban and rural areas of the basin. The Evolutionary Annealing Simplex method is used to obtain the best parameter set along with a large number of other retained parameter sets. Levels 1 and 2 of the proposed protocol provide the necessary information for analysis of Level 3, where a stochastic framework is considered inspired by the ideas proposed by Montanari & Koutsoyiannis (2012). This takes into account external information on urbanised fraction of the studied basin. A relationship is established between data on fraction of urbanised area and one of more parameters of the lumped model, while the semi-distributed one takes into account the fraction of urbanised area explicitly. Comparison of prediction intervals with and without exploiting such relationship allows the assessment of the value of information regarding the factor that induces non-stationarity. The methodology as a whole is applied to one of the two drainage basins that show growing urbanisation (Ferson Creek at St. Charles, USA).

Efstratiadis, A., I. Nalbantis, A. Koukouvinos, E. Rozos, & D. Koutsoyiannis, HYDROGEIOS: A semi-distributed GIS-based hydrological model for modified river basins, Hydrol. Earth Sys. Sci., 12, 989-1006, 2008.

Montanari, A., & D. Koutsoyiannis, A blueprint for process-based modeling of uncertain hydrological systems, Wat. Resour. Res., 48, W09555, doi:10.1029/2011WR011412, 2012.

Hw15PS.03

Hw15PS - Testing simulation and forecasting models in non-stationary conditions

Poster

Understanding impacts of future climate conditions upon flooding in the Lez catchment using the ALADIN Med-CORDEX simulations

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The behaviour of conceptual hydrological models under the influence of climate change is difficult to predict. These models are heavily dependent on the atmospheric conditions and calibration periods selected. Hydrological variables (rainfall, surface runoff) issued from global (~200 km) and regional circulation (10-50 km) models (GCMs and RCMs) are generally not appropriate for calibrating or forcing local impact models (<1-10 km). This study proposes a method for correcting the bias in atmospheric variables produced by the ALADIN RCM Med-CORDEX simulations (12 km) in order to conduct an impact study on the Lez catchment in Southern France. This catchment, due to its karstic nature and small size (114 km2), presents a challenge for modellers as the catchment is less that the size of a single grid cell for the highest resolution RCMs currently available (~144 km2). Furthermore, the catchment is best adapted to a conceptual modelling approach, since the role of the karst in increasing or attenuating discharge remains poorly understood. The hydrological model selected is a derived version of the SCS equations. A delta approach applied by quantiles, called futurisation, is used to create an estimate of future rainfall from the observed rainfall (four stations per 114 km2) and ALADIN simulations (144 km2) between 2006 and 2100. The application of this method is tested under two conditions: the application of a daily correction to hourly data divided equally among all time steps and the application of a daily correction to hourly data weighted by the historical rainfall intensity. The impact of the future soil wetness state upon discharge simulations is then explored with sensitivity tests. While the impact of climate change cannot be determined using a single climate model, this study shows that simple and rapid statistical methods can be used to overcome the challenges presented by the need to study impacts at local scales.

Hw15PS.04

Hw15PS - Testing simulation and forecasting models in non-stationary conditions

Poster

Modelling 1000-year catastrophic flood scenario of the Danube between Bratislava and Nagymaros

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1 Institute of Hydrology SAS, Slovakia; 2 Comenius University, Dept. of Applied Mathematics and Statistics, Slovakia

The goal of this paper is simulation of the catastrophic 1000-year Danube flood wave transformation between Bratislava and Nagymaros under recent river reach conditions by means of the nonlinear reservoir river model NLN-Danube. In the first part we created the scenario waves based on observed historical waves at Bratislava. Besides the analysis of floods from the «discharge observation period» we tried also to reconstruct the hydrograph of the probably most destructive Danube flood of the last millennium which occurred in August 1501. Marks of peak levels of this flood exist along the Austrian section of Danube, which are highest ever recorded there, in some river sections exceeding those reached in 1954 by almost two meters. Its peak discharge is estimated close to 14000 cumecs at Vienna. Analysis of the 1954 flood formation indicates a similar meteosynoptical situation with the exception that the cyclonal disturbance over Austria in 1954 did not penetrate that far to the east. As a result of the above considerations, we decided to take for further analysis as a catastrophic flood scenario a hydrograph at Bratislava with peak flow 14000 cumecs and shape similar to that of the 1954 flood. The scenario floods with recurrence period T = 1000, 100, and 50, years were derived. In the second part we modeled transformation of the 1000-year (100-year, 50-year) scenario flood wave in the river reach Bratislava – Nagymaros. The estimation of the hypothetical transformation of historical waves under present conditions is possible only by model simulations. For this purpose the simple river model NLN-Danube was developed and calibrated for present channel conditions. The NLN-Danube model system is based upon the concept of a series of equal nonlinear reservoirs, thus, it belongs to the category of hydrological conceptual nonlinear models. Acknowledgement. This work was supported by the Slovak Research and Development Agency under the contract No. APVV-0015-10.

Hw15PS.05

Hw15PS - Testing simulation and forecasting models in non-stationary conditions

Poster

Improvement of a rainfall-runoff model with multiresolution analysis

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Transfer function-based models are widely used in rainfall-runoff modeling. These models simulate discharges, using the convolution between rainfall rates and a transfer function. Most often, rainfall-runoff models are linear and suffer from lack of physical meaning.

The rainfall-runoff model introduced here is versatile. It has up to four parallel branches. Each branch consists of an input convoluted by up to three transfer functions. The output is the sum of the convolution products. The number and the type of transfer functions are chosen for every simulation.

Four probability density transfer functions are available: Gamma distribution, normal distribution, Beta distribution and power-law distribution. Each one represents a physical phenomenon. For example, the Gamma distribution also known as the Nash model represents a cascade of n linear reservoirs.

This model is non-linear because of its architecture with several branches. It has up to twenty-eight parameters: one per branch and two per transfer function. They are calibrated with a particle swarm optimization algorithm.

To deal with non-stationarity issues, a multiresolution cross-analysis is performed. The input signal is decomposed in different scales, using a discrete wavelet transformation. Then, a cross-correlation is calculated between these sub-signals and the output. The aim is to identify which scales of the rainfall rates are correlated with the discharge, and which are not.

Once uncorrelated scales are identified, they are removed from the input signal. This filtered input is used to calibrate the model during calibration periods. This method should improve the model efficiency during validation periods.

Hw15PS.06

Hw15PS - Testing simulation and forecasting models in non-stationary conditions

Poster

Testing five one-parameter solutions to try to account for forest cover changes in the GR4J model

Andréassian, V. 1; Thirel, G. 1; Coron, L. 1; Furusho, C. 1; Perrin, C. 1; Oudin, L. 2

1 Irstea, France; 2 Université Pierre et Marie Curie, UMR Sisyphe, France

Testing five one-parameter solutions to try to account for forest cover changes in the GR4J model

Three catchments proposed for the workshop have seen a noticeable change of their forest cover, due either to harvesting (Fernow), wild fire (Rimbaud), or devastating storm (Mörrumsån River). Here, we test whether a single free parameter could account for the observed changes. GR4J has four free parameters, and we will add a fifth possibility, through a parameterization of the actual evapotranspiration-potential evapotranspiration relationship. We will compare the five solutions, to test whether a single parameter can account for the observed changes (i.e. keeping all parameter but one constant over the entire period and allowing a single one to carry all the weight).

Hw15PS.07

Hw15PS - Testing simulation and forecasting models in non-stationary conditions

Poster

Parsimonious runoff simulation and non-stationarity detection in mountain basins

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1 Politecnico di Torino, DIATI , Italy

Runoff prediction in high elevation basins is required for water resources management and for studies related to the hydrological sensitivity of mountain basins to climate change. The estimation of the daily runoff in ungauged high-elevation basins represents a challenging topic, due to a number of factors: i) the dynamics of snow accumulation and melting largely affects the timing and the volumes of runoff; ii) the topographic heterogeneity requires detailed spatial characterization of the hydrologic variables; iii) the high spatial variability of precipitation is poorly described, in general, by meteorological network measurements.

Detailed representation of the accumulation and melting of snow at the basin scale is then prevented by the lack of observations in mountainous environments. This suggests that parsimonious models can be helpful in the assessment of dominant parameters in the snow-controlled precipitation-runoff mechanisms.

In this study a conceptual water balance model is proposed, aimed at the investigation and discrimination of the fundamental mechanisms that influence runoff in mountainous regions. The model adopts a temperature threshold to partition precipitation into rainfall and snow and to estimate evapotranspiration-sublimation volumes. A 1-parameter snowmelt module is proposed describing snowmelt as a non-linear function of temperature, that depends on the distribution of basin altimetry.

Due to its simple and easily falsifying characteristics, the model is suitable for application as a diagnostic tool to detect non-stationarities and as a tool to predict effects of changes in the runoff of mountain basins.

Hw15S1.01

Hw15S1 - Testing simulation and forecasting models in non-stationary conditions

Oral

Introduction and synthesis of the experiments made by the workshop participants

Thirel, G. 1; Andréassian, V. 1

1 Irstea, France

During this introduction talk, we will present an overview of the results we collected from the participants which worked on the catchment dataset we provided. The diverse methods, that the participants implemented in order to address the non-stationarities issues, will be discussed.

Hw15S1.02

Hw15S1 - Testing simulation and forecasting models in non-stationary conditions

Oral

Modelling experiments with conceptual rainfall-runoff models under non-stationary conditions

Vaze, J. 1; Chiew, F.H.S. 1; Potter, N. 1; Post, D.A. 1; Petheram, C. 1; Lerat, J. 1; Teng, J. 1; Wang, B. 1

1 Water for a Helathy Country Flagship, CSIRO Land and Water, Australia

Rainfall and runoff can vary from year to year and from decade to decade. The relationship between climate and runoff can also be different in different time periods. Modelling the variability over different time scales and the different dominant characteristics under dry conditions and under wet conditions can be challenging. Given the changing climate-runoff relationship over time, equally challenging is how best to parameterise and calibrate hydrological models to reliably predict the future.

We will present modelling results for the modelling experiments designed for this workshop. We will attempt to complete the level one (model calibration against entire data period) and level two experiments (various model calibrations against data from one period with the optimised model parameters used to simulate runoff in a different period) for most of the 10+ catchments chosen for the workshop experiments. We will also discuss, based on the learnings from the level one and level two experiments, model improvements or modelling considerations that can improve hydrologic prediction under the different types of non-stationary conditions (level three).

We will conduct the modelling experiments using several lumped conceptual daily rainfall-runoff models that we are familiar with (from SIMHYD, GR4J, Sacramento, SMARG, IHACRES). We hope that similar models will also be used by some of the other modelling groups, allowing us to explore whether different hydrologists can produce the same modelling results and more importantly to learn how to better consider changing climate-runoff relationship to improve hydrologic prediction.

Hw15S1.03

Hw15S1 - Testing simulation and forecasting models in non-stationary conditions

Oral

Dynamic averaging of rainfall-runoff model simulations within non stationary climate conditions

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1 Universite Pierre et Marie Curie, UMR Sisyphe, France

To cope with the instability of model parameters calibrated on catchments in a non-stationary climate, we apply a method that dynamically averages model simulations from complementary parameterization. Two objective functions are used to infer two sets of parameters, one set being optimal for low flow situations and the other being optimal for high flow situations. Then a time-varying weighting function is implemented to average out the two simulations. Since this weighting function depends on the hydric state of the catchment simulated by the model, the weight attributed to the two 'expert' simulations are not stationary. The methodology is tested on the catchments of the workshop dataset that had experienced non stationary climate conditions, and the model used is the GR5J model.

Hw15S1.04

Hw15S1 - Testing simulation and forecasting models in non-stationary conditions

Oral

How far can we go with non-stationarity studies in poorly gauged catchments? A case study in a semi arid catchment in Australia

Lerat, J. 1; Kim, S. 1; Petheram, C. 1; Shao, Q. 1; Andreassian, V. 2; Perrin, C. 2

1 CSIRO, Land and Water, Australia; 2 IRSTEA, France

Non-stationarity studies are based on the analysis of trends in observed and simulated hydrological time series. When the uncertainty in model and data is low, the trends can be clearly detected. However, this approach is often challenged in semi-arid catchments where flashy response and intermittent flow regimes remain difficult to capture by both models and measurement networks. This study explores the sensitivity of non-stationarity metrics derived from model results to the uncertainty in seamflow data used to calibrate the model. The case study is the Flinders catchment, located in Northern Australia. The catchment expericenced a humid period between 1970 and 1980, followed by prolonged dry period until 2000, which allowed to calibrate the GR4J and Sacramento rainfall-runoff models on two contrasted periods. First, the calibration was performed using original streamflow data. Second, the process was repeated 50 times using replicates of streamflow data obtained from an uncertainty analysis flow gaugings. Quantiles of simulated flows were finally computed for all calibrated models. The non-stationarity analysis was based on the difference between the quantiles from a wet and dry calibration, large differences suggesting a change in flow regime that is not captured by the model. To assess if the difference was significant, non-stationarity metrics were computed as the ratio between the original difference (models calibrated against original flow data) and the standard deviation of replicate difference (models calibrated against replicates. The metrics were finally compared between the two rainfall-runoff models and across the range of flow quantiles. Resuts indicate that the difference between simulated quantiles remains significant for both models in medium and high flow regime, which suggests that non-stationrity issues are present, but not for low flows where large uncertainty dominates the simulation.

Hw15S1.05

Hw15S1 - Testing simulation and forecasting models in non-stationary conditions

Oral

Optimization of specialised hydrological models committees adapting to changing regimes

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1 UNESCO-IHE Institute for Water Education, Netherlands; 2 Russian State Hydrometeorological University, Russian Federation

In hydrological modelling and forecasting typically a single model accounting for all possible hydrological regimes is used. However often a model cannot capture all facets of a complex process, especially in non-stationary conditions, and hence more adaptive modelling architectures can be employed. One possibility here is building several specialized models and making them responsible for various sub-processes, and to calculate output as a combination of individual models' outputs. We term such a combined model a committee of models. Outputs of individual models are combined using a dynamic weighting scheme using, for example, an idea and algorithm of a fuzzy committee developed in our earlier studies. Such a committee is subject to optimization to ensure best possible way of combining outputs depending on the objectives of modelling or forecasting.

In the presentation we consider various regimes for which individual models are built (based on multi-objective calibration employing a combination of different objective functions), and various ways of combining their outputs.

Applications of the presented approach to the proposed case study are presented.

Hw15S2.01

Hw15S2 - Testing simulation and forecasting models in non-stationary conditions

Oral

The role of water balance adjustment during calibration on robustness issues for conceptual hydrological models

Coron, L. 1; Andréassian, V. 2; Bourqui, M. 3; Hendrickx, F. 3; Perrin, C. 2; Lerat, J. 4; Vaze, J. 4

1 Irstea-EDF, France; 2 Irstea, France; 3 EDF, France; 4 CSIRO, Australia

Conceptual models require a calibration phase where parameters are adjusted to maximize the fit between simulations and measured. Using a model on a period different from the calibration one rely on the assumption of parameters “temporal transferability”, i.e. the possibility to use the model’s parameters under conditions different from the model’s construction ones. This research work aims at improving knowledge concerning the robustness of conceptual hydrological models in the context of a changing climate. We study temporal variations of model performances in relation to parameters transfer conditions (e.g. errors in flow volumes or dynamic related to changes in mean rainfall or temperature during transfer). We try to carry out an exhaustive diagnostic of this issue, numerous catchments (almost 600) and several hydrological models being included in this procedure.

The results show the existence of correlations between robustness issues during parameters transfer and changes in climatic conditions between the periods involved in the transfer. At the same time, a high heterogeneity in the behaviours is observed across the catchment set, with no obvious explanation. The question of water balance adjustment within each catchment appears to be a core aspect for understanding temporal robustness issues for hydrological models. Calibrating a model on a sub-period necessarily reduces bias on that period but our work shows that this bias adjustment is not transferable to others periods whose climatic conditions differ. Similar behaviours are obtained for the different models tested. This result guides our reflexions towards two directions for further work: (a) the errors in measurement or estimation of the three components of the mid-term water balance (precipitations, evapotranspiration and runoff); (b) the difficulty for models to reproduce slow-dynamics processes, which influence the balance between these components.

Hw15S2.02

Hw15S2 - Testing simulation and forecasting models in non-stationary conditions

Oral

Evaluating and comparing the ability of Three Lumped Conceptual Models in non-stationary conditions

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Hydrological models, which provide a framework to investigate relations between climate and hydrology response, are widely used tools to provide information on global, regional and catchment scales under current and future climate. The models, accuracy of which more depends on the existing climatic condition for which the model is initially developed and calibrated, may not function well in climate change impact study. The main purpose of this research is to evaluate the ability of well-structured conceptual models in handling the non-stationary conditions and provide insights for the further climate change study. Three lumped conceptual hydrological models, the Hydrologiska Byråns Vattenbalansavdelning (HBV), Water And Snow Balance Modeling System (WASMOD) and XinAnJiang (XAJ) were tested in the Wimmera River catchment with a basin area of 2000 km^2, at Glenorchy Concrete Weir Tail Australia. These three models and/or their concepts are highly valued in many regions of the world both for practical and scientific research purposes. This comparative study would improve our understanding of the uncertainties associated with impact studies of climate change due to model structures and the selection criteria of hydrological models.

Hw15S2.03

Hw15S2 - Testing simulation and forecasting models in non-stationary conditions

Oral

Exploring non-stationarity in catchment response

Croke, B.F.W. 1; Guillaume, J.H.A. 1; Shin, M.J. 1

1 Australian National University, National Centre for Groundwater Research and Training, Australia

This paper will explore all the datasets provided for the workshop using a combination of analysis tools and the IHACRES rainfall-streamflow model (within the Hydromad software package). Each dataset will be tested for non-stationarity in the unit hydrograph, as well as in the mass balance portion of the IHACRES model. The analysis techniques used will include direct estimation of the UH, cross correlation, Fourier deconvolution and constrained deconvolution using an inverse filtering method. This will produce not only the variation in the unit hydrograph, but an optimal time series of effective rainfall which will be compared to the modelled time series so that non-stationarity can be explored on a range of time scales. Finally, the model structure will be explored to examine how this can be adapted to accommodate the observed non-stationarity.

Hw15S2.04

Hw15S2 - Testing simulation and forecasting models in non-stationary conditions

Oral

Benefits and drawbacks of using data assimilation for hydrological modelling in karstic regions: recent work on the Lez basin

Coustau, M. 1; Harader, E. 2; Borrell Estupina, V. 3; Ricci, S. 2; Bouvier, C. 4; Thual, O. 5; Piacentini, A. 2

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The present study focuses on the 114 km^2 Lez catchment near the Montpellier agglomeration in Southern France. This region is subject to violent rainfall that may lead to devastating flash floods. An event-based, distributed, parsimonious rainfall-runoff model is used to simulate discharges at the catchment outlet. Model efficiency is limited by uncertainties in the rainfall spatial variability and the initial catchment wetness state. Rainfall measured by weather radar are used to force the model in order to better represent spatial variability. Because of seasonal variations in the quality of radar data, radar rainfall were only used during the fall, when spatial variations in rainfall are the greatest. In winter, radar rainfall are of poor quality due to the weak vertical extension of the clouds and the low altitude of the 0°C isotherm; during this period, the model is forced by rain gauge measurements. By using different rainfall products based on the season considered, we are able to adapt the hydrological model to temporal variations in data quality. Bias in radar rainfall and uncertainties in the assessment of the catchment initial wetness state are also reduced using a data assimilation technique: the Best Linear Unbiased Estimator (BLUE) algorithm. This algorithm was used to assimilate discharges observed at the catchment outlet to correct either radar rainfall or errors in the initial condition of the model. In most cases, correcting either radar rainfall or the model initial condition leads to an improvement in peak discharge simulations. Nevertheless, in some cases, the assimilation method is limited by the capacity of the model to correctly reproduce the rising limb of the hydrograph. To draw more general conclusions, the hydrological model and the data assimilation technique have been transferred to the French national service for flood forecasting (SCHAPI) in order to be tested on a larger number of sample catchments.

Hw15S2.05

Hw15S2 - Testing simulation and forecasting models in non-stationary conditions

Oral

A comparative assessment of AWBM and SimHyd for forested watersheds

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AWBM and SimHyd are relatively simple conceptual models widely used for simulating daily flows in Australia. To evaluate their ability to model non-stationary daily flows, and to quantify the effect of land disturbance, and to assess their performance in catchments outside Australia, these two hydrologic models were applied to the 2 small catchments, Fernow in West Virginia, the USA, and Real Collobrier, Rimbaud, in the Alps, France. Both catchments are experiencing abrupt changes through clearing and fire, respectively. The two models were run for each of the 2 catchments to gauge the baseline model performance. The whole period for each catchment was then sub-divided into two meaningful sub-periods to align with documented land disturbance in these catchments. The 2 hydrologic models were then calibrated for each sub-period and applied to the other sub-period to evaluate the potential to quantify the effect of land disturbance in terms of simulated flows as well as model parameter values. In addition to testing these models using these non-stationary hydrologic time series to highlight the challenges in using conceptual models, the paper argues for the benefit of using these models to quantify the magnitude of non-stationarity for the purpose of assessing the effect of land use changes.

Hw15S2.06

Hw15S2 - Testing simulation and forecasting models in non-stationary conditions

Oral

Application of several hydrological models to the complete dataset of the workshop

Thirel, G. 1; Coron, L. 1; Andréassian, V. 1; Perrin, C. 1

1 Irstea, France

Addressing the issues of non-stationarity and transposing models parameters over time period under changing climate conditions is one of the research topics of the HYDRO team at Irstea (Antony). For example, Coron et al. (2012) generalized the split-sample test on 10-year sliding windows, using several hydrological models.

The GR4J model will be applied to all the study cases prepared for this workshop, and the evaluation protocol described on the non-stationarities.irstea.fr website will be followed (levels 1 and 2). Other hydrological models will be tested (inspired from MORDOR, HBV and TOPMODEL models). We will try to understand the behaviours of the models based on the evaluation protocol.

Trying to obtain a constant bias over time instead of a bias changing according to the period can for example be considered as an indicator of reliability of the model for future conditions. Our main results will be presented.

Ref.: Coron, L., V. Andr ássian, C. Perrin, J. Lerat, J. Vaze, M. Bourqui, and F. Hendrickx (2012), Crash testing hydrological models in contrasted climate conditions: An experiment on 216 Australian catchments, Water Resour. Res., 48, W05552, doi:10.1029/2011WR011721.

Hw15S3.01

Hw15S3 - Testing simulation and forecasting models in non-stationary conditions

Oral

Simultaneous calibration of hydrological models to capture non-stationary conditions

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Hydrological models should capture the effect of changing signals under non-stationary conditions. For single catchments and models observation periods are often too short and the corresponding signals are too weak to quantify the dependence of model parameters under changing conditions. Considering a larger number of catchments simultaneously one can have catchments with strongly varying climate and land use conditions. A simultaneous calibration of the hydrological model under the assumption is the parameters corresponding to the runoff dynamics are shared and explicitly dependent on land use. This allows a reasonable quantification of the parameter alterations for land use change signals. Further the consideration of catchments under different climatic conditions enables to identify model parameters which can be used under changing climate. The suggested methodology is demonstrated using two different simple rainfall runoff models HYMOD and HBV. More than 200 mezoscale catchments in the US are used to demonstrate the methodology. Different cross validation strategies are used to demonstrate the applicability of the concept.

Hw15S3.02

Hw15S3 - Testing simulation and forecasting models in non-stationary conditions

Oral

Observed hydrologic non-stationarity in south-eastern Australia and implications for future modelling predictions

Chiew, F.H.S. 1; Potter, N.J. 1; Vaze, J. 1; Petheram, C. 1; Zhang, L. 1; Teng, J. 1; Post, D.A. 1

1 CSIRO Land and Water, Australia

This paper will complement the modelling by our group for the experiments set out for the workshop. Three of the 10+ catchments used for the workshop experiments come south-eastern Australia. The far south-eastern Australian region is interesting because the recent prolonged 1997–2009 “Millennium” drought exposed different types of hydroclimate and hydrologic non-stationarity.

The hydroclimate data in this region show very different rainfall-runoff relationship during the Millennium drought at the annual and other time scales. Annual models developed using pre-1997 data significantly overestimates the post-1997 runoff. Rainfall-runoff models calibrated against pre-1997 data also simulates very poorly the post-1997 runoff at all time scales.

The long drought also exposed hydrologic processes that become more dominant in long dry spells. In particular, the reduced connectivity between surface and subsurface water and farm dams intercepting proportionally more water during dry periods accentuate the runoff decline from lower rainfall. Nevertheless, because the Millennium drought has highlighted the importance of these hydrologic processes and we have now seen the changes in the climate-runoff relationship, we can adapt hydrological models and use smarter modelling considerations to better simulate these. Consistent with the focus of this workshop, we will present some of the modelling methods, and show that these models will then be able to predict near-term changes to runoff resulting from changes in the climate inputs.

However, predicting changes to runoff further into the future will remain difficult. This is because future runoff will be impacted by higher temperature and atmospheric CO_2 concentrations not seen in past records, as well as the complex interactions and feedbacks between various variables and processes (many of which are not yet known) in a warmer and higher CO_2 environment.

Hw15S3.03

Hw15S3 - Testing simulation and forecasting models in non-stationary conditions

Oral

Testing a physically based distributed model under changing climate conditions

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An ability of a physically based distributed model to simulate river runoff response to change of climate conditions has been studied using the Ecological Model for Applied Geophysics (ECOMAG). The model utilizes daily meteorological variables (precipitation, air temperature and air humidity deficit) as the inputs to simulate processes of snow accumulation and melt, water infiltration into unfrozen and frozen soil, soil freezing and thawing, thermal and water regime of soil, overland, subsurface and channel flow. A river basin is schematized onto the landscape elements taking into account peculiarities of topography, soil and vegetation types, land-use, etc. Parameters of the model are physically meaningful and can be related to measurable characteristics of river basins. Combined with and resulting from the physical background of the model, this feature provides opportunity for obtaining reasonable results in the case of environmental changes, particularly, to assess hydrological consequences of the projected climate change. To test the ECOMAG under changing climatic conditions the Differential Split Sample Test procedure detailed by Klemes (1986) has been applied. The idea is to calibrate and validate the model on streamflow records for the periods with dissimilar climatic characteristics (e.g. wet-warm calibration period and dry-cold validation period), i.e. to mimic the desired situation of climate change and to evaluate temporal transposability of the model. The procedure has been applied for two river basins characterizing by visible changes of annual air temperature and streamflow discharge for the period of observations.

Hw15S3.04

Hw15S3 - Testing simulation and forecasting models in non-stationary conditions

Oral

Evaluating snow data assimilation methods for use in distributed modelling

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In Switzerland, snow melt dominates the runoff in many watersheds and the total snow storage contributing to discharge can vary largely from year to year. Accurately quantifying snow storage and subsequent runoff is important for regulating lake levels throughout the country. Additionally, melting snow can contribute to floods imposing large damages on infrastructure. The objective of this study is to compare the performance of a distributed snow model when different methods for assimilating snow depth point observations are used. Accurate measurements of daily snow depth are much easier and quicker to perform than measuring snow water equivalent. Due to this, snow depth readings are more frequently available, which allows for more data to be integrated into the distributed snow model. However, point measurements of snow depth suffer under the representativeness problem; they are not always representative for the grid cells of a distributed model. Therefore, we study the sensitivity of a series of simulation results from different snow depth data assimilation methods. We use a parametric snow melt model driven by input data from a weather forecasting model. We combine the model output with observations using sequential data assimilation methods, foremost the ensemble Kalman filter. Before assimilation, we convert the observed daily snow depth readings to snow water equivalents from a layered one-dimensional snowpack model forced only by snow depth. This gives us the opportunity to assimilate the estimated snow water equivalents either directly or as differences from day to day. By assimilating daily differences in snow water equivalent, the problem of time-correlated errors accumulated over time is partly avoided and simulation results are less sensitive to erroneous observations. We compare the simulation results against independent measurements of snow water equivalent and satellite images of snow covered area.

Hw15S3.05

Hw15S3 - Testing simulation and forecasting models in non-stationary conditions

Oral

Non-Recurrent vs Recurrent Neural Network Models for non stationnary modelling

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Neural networks are non-linear models widely investigated in hydrology due to their universal approximation and parsimony properties. As «black-box» models, they do not presume any a priori behavior, given that the model construction is data-driven and the parameters are devoid of physical significance. They thus can be applied to any watershed provided that a large dataset would be available. Nevertheless, the excellent capabilities that neural networks prove for training must be counterbalanced by their ability to reliably generalize to unknown dataset. This trap is well known in machine learning and was formalized as the bias-variance tradeoff. Thanks to application of regularization methods as early stopping and cross validation, rigorous variable and complexity selection can be performed providing efficient generalization. In this experimentation two models will be investigated, the feed-forward model and the recurrent one.

The feed-forward model is mathematically explained as:

$s(k)=gNN(q(k-1),...q(k–r), u(k),u(k – 1)...,u(k – m))$

where s is the estimated discharge, gNN is the non-linear function implemented by the neural network, k is the discrete time (sampled each time step of the dataset) q is the measured discharge, u is the vector of exogenous variables (rainfalls, temperature, etc), r is the order of the model, m is the width of the sliding window of rainfalls information.

Using same notations the recurrent network is expressed as:

$s(k)=gNN(s(k-1),...s(k–r), u(k),u(k – 1)...,u(k – m))$

It can be considered that the feed-forward model would be more efficient than the recurrent one on non stationary datasets, because it integrates measured information from input variables (rainfalls, temperature, etc …) and implements data assimilation.

Classical ways to compute data assimilation will be applied in order to make the recurrent model adaptive to the watershed evolutions.

Both models will thus be compared following the 3 protocols.

Hw15S4.01

Hw15S4 - Testing simulation and forecasting models in non-stationary conditions

Oral

Testing the process-based Hydrograph model under non-stationary conditions in fire-affected watersheds in France and Russia

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Fire disturbance spreads over large areas. It leads to significant changes in hydrological regimes due to collapse of the soil organic layer and consequent changes in water and heat fluxes forming non-stationary conditions. Fires in cold environment have both immediate and long-term impacts on the ecosystem due to their effects on underlying permafrost. The goal of the study is to simulate runoff formation in small Mediterranean watershed Rimbaud in France and small permafrost watershed in the basin of the Lena River (Eastern Siberia) using process-based hydrological Hydrograph model. To cope with non-stationary conditions we propose to estimate physical characteristics of landscapes (soil and vegetation) in post fire period. The model parameters are proposed to change in time in a dynamic mode reflecting the vegetation/soil succession in post fire period. The efficiency of such an approach in completely different environments of France (Mediterranean climate, maquis shrubs) and Russia (continental climate, coniferous forest) will be investigated.

Hw15S4.02

Hw15S4 - Testing simulation and forecasting models in non-stationary conditions

Oral

HYPE model simulations for non-stationary conditions in European medium sized catchments

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The HYPE (Hydrological Predictions for the Environment) model is a hydrological model developed in Sweden. The model is oriented towards large-scale applications at high spatial resolution, and makes use of information on land-use and soil type to improve parameter generalization and interpolation. Usually the model assumes stationary conditions, with only time variation in the forcing data: daily precipitation and temperature. In this study, the model was set-up for medium sized catchments in Europe identified as having experienced non-stationary conditions. Model setups for each catchment were extracted from existing set-ups of the HYPE model for all of Sweden (S-HYPE) and all of Europe (E-HYPE), but using local forcing data and calibration. Key parameters were adjusted slightly to match local data during a period before the change being studied in each catchment. Model simulations were thereafter carried out extending over the period when the change occurred. Two types of simulations were made. Firstly, the model was run without accounting for the change itself, i.e., the model was used as a reference tool in order to distinguish the effect of the change versus variations due to variations in the forcing data. Secondly, when applicable, the change itself was modeled explicitly, i.e. by perturbing model input data and/or parameter values. The results of the two types of applications were compared, to examine whether or not the two evaluations suggested similar responses to the change, with respect to direction and order of magnitude.

Hw15S4.03

Hw15S4 - Testing simulation and forecasting models in non-stationary conditions

Oral

Is bias correction of Regional Climate Model (RCM) simulations possible for non-stationary conditions?

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The direct application of Regional Climate Model (RCM) simulations in hydrological climate-change impact studies poses a risk for considerable biases. Therefore, several bias correction approaches ranging from simple scaling to more sophisticated methods have been developed to help impact modelers handling the various problems arising from biased RCM output. The main disadvantage of any of these correction procedures is that their parameterizations are derived for current climate conditions and assumed to apply also for changed future conditions. Whether or not this presupposition is actually fulfilled for future conditions cannot be evaluated given our lack of time machines. Nevertheless, systematic testing of how well bias correction procedures perform for conditions different from those used for calibration can be done by applying a differential split-sample as proposed by *Klemeš* ['Operational testing of hydrological simulation models', *Hydrolog Sci J*, vol. 31(1), pp. 13-24, 1986]. In our contribution we demonstrate how to apply different commonly-used bias correction methods using an ensemble of 11 different RCM-simulated temperature and precipitation series for five catchments in Sweden. Differential split-sample testing was performed to evaluate the performance of these correction procedures under changing climate conditions with only a limited amount of data. During the validation based on an independent data set, some of the correction methods resulted in a large spread and a clear bias. More sophisticated correction methods such as 'distribution mapping' performed relatively well, whereas the simpler and more widely used 'delta change' and 'linear scaling' approaches resulted in the largest deviations and least reliable projections for changed conditions. Therefore, we question the use of these methods in future climate-change impact studies despite the simplicity in applying them and recommend using higher-skill bias correction methods.

Hw15S4.04

Hw15S4 - Testing simulation and forecasting models in non-stationary conditions

Oral

Sensitivity of a physically-based LSM to the calibration period in the Upper Durance catchment

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The CLSM is a physically-based SVAT model (Soil-Vegetation-Atmosphere Transfer) which solves the coupled water and energy budgets at an half-hourly time step in elementary catchments. It has been applied over the Upper Durance watershed at La Clapière, which exhibits a marked nival hydrological regime. This catchment has experienced a drastic increase of temperature over the last century.

The CLSM subdivides this 2170 km^2 catchment into four sub-catchments of about 500 km^2 with an average altitude range of 2700 m. A multi-layer physically-based description of the snow processes is included in the model, including hysteresis in the snow-cover extent parameterization, recently shown to be necessary in the Upper Durance Catchment. To define a higher sub-grid variability of the snow-cover extent during snowpack ablation than during accumulation, we introduced a new parameter, Wmelt, which is presently calibrated. It is probably linked to morphological characteristics of catchments and we would like to ascertain that is is not dependent on climate.

To do so, we rely on automatic calibration of the parameter Wmelt over contrasted periods in terms of temperature and precipitation within 1958-2010. Each simulation is preceded by a 3-year spinup and performances are calculated against observed discharges. Based on preliminary results over five contrasted periods, calibration leads to better performances but the parameter Wmelt is not very sensitive to the calibration period. This suggests that the physically-based snow-parameterization is robust enough to describe climate non-stationarities. This will be explored more thoroughly using automatic multi-criterion calibration on 25 additional 2-year simulations. Eventually, we would like to examine if the responses to climate change (I.e the differences in hydrological regime between future and historical conditions) are sensitive or not to this parameter.

Hw15S4.05

Hw15S4 - Testing simulation and forecasting models in non-stationary conditions

Oral

A simple solution for dealing with non-stationarities in urbanizing catchments with GR4J

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The increase of urban areas within a catchment may affect its hydrological functioning in various ways. As expected, higher and anticipated peak flow enhanced by faster runoff from impervious surfaces and engineered drainage systems is often detected (Bhaduri et al., 2000; Burns et al., 2005). However, the decrease in base flow caused by reduced infiltration and sewer drainage was observed (Bhaduri et al., 2000; Joannis et al., 2002; Breil et al., 2010), but it was not necessarily clear in other cases (Burns et al., 2005; White and Greer, 2006). These inequalities could be partially explained by the difference in the spatial distribution of urban growth (Mejia and Moglen (2010a, b)), along with differences in storm water control devices, which may intensify or moderate the effects of increasing urban areas. The effects of increasing urban fraction being not easily predictable, modeling these changing processes remains an interesting challenge, particularly in lumped conceptual models. That is precisely what motivates this work, which consists in studying the impacts of the urban fraction on each of the four parameters of the lumped conceptual model GR4J. Two study sites for which the annual urbanized fraction values are available will be studied: the Ferson Creek at St. Charles and the Blackberry Creek at Yorkville, both in the USA. Two approaches are initially proposed: - Splitting the basin into a totally urbanized sub-catchment and a totally non-urbanized one. The rainfall is split between the two sub catchments according to the urbanized fraction, and the simulated discharges are combined by convolution. - Replacing the parameters that represent the reservoirs capacity and the unit hydrograph by functions depending on the urbanized fraction. We expect that the evaluation of these approaches may contribute to identify simple methodologies to deal with this particular aspect of non-stationary parameters that concerns urban sprawl in lumped models.

Hw15S4.06

Hw15S4 - Testing simulation and forecasting models in non-stationary conditions

Oral

Testing the Hydrograph model within highly non-linear catchment behaviour in south-eastern Australia

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Catchments respond differently to temporal variations in their precipitation inputs depending on the characteristics of the catchment. In general, catchments that are classified as water limited (with a very low aridity index) respond in a more non-linear fashion. In this presentation, we examine the application of a physics-based model, the Hydrograph model to a number of catchments in south-eastern Australia which experienced a decline in mean annual precipitation of between 10 and 20 percent during the so-called Millennium drought, lasting from 1997 to 2009. In some catchments, the same reduction in mean annual precipitation led to a much greater decline in runoff. We investigate the reasons of runoff response variations attributing them not only to differences in the rainfall input but also to the shift of dominating processes. We investigate if the Hydrograph modelis able to represent hydrologic in non-stationary conditions capturing the changes in the hydrologic functioning of catchments.

Hw15S5.01

Hw15S5 - Testing simulation and forecasting models in non-stationary conditions

Oral

In defence of stationarity

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As long as “steady flow” describes a flow, a “stationary process” describes a process. It is then a tautology to say that in a process there is change. Even a stationary process describes a system changing in time, rather than a static one which keeps a constant state all the time. However, this is often missed, which has led to misusing the term “nonstationarity” as a synonymous to “change”. A simple rule to avoid such misuse is to answer the question: can the change be predicted in deterministic terms? If the answer is positive, then it is legitimate to invoke nonstationarity. Otherwise a stationary model should be sought. In addition, we should have in mind that models are made to simulate the future rather than to describe the past, which is better to try to observe than simulate. In this respect, in studying the above question we must assess whether or not future changes are deterministically predictable. Usually they are not and thus the models should, on the one hand, be stationary and, on the other hand, describe in stochastic terms the full variability, originating from all agents of change. Even if the past evolution of the process of interest contains changes explainable in deterministic terms (e.g. urbanization), again it is better to describe the future conditions in stationary terms, after “stationarizing” the past observations, i.e. adapting them to represent the future conditions. An exception in which nonstationary models are justified is the case of planned and controllable future changes (e.g. catchment modification by construction of hydraulic infrastructures, water abstractions), which indeed allow prediction in deterministic terms.

Hw15S5.02

Hw15S5 - Testing simulation and forecasting models in non-stationary conditions

Oral

Analysis of the dependence of the optimal parameter set on climate characteristics

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Two different rainfall-runoff models were applied to test the influence of climate characteristics on the values of optimal parameters. In the first approach we applied a lumped conceptual HBV model. It is a conceptual model with a physically-based structure that takes into account soil moisture, snow-melt and dynamic runoff components. The model parameters were optimized by the one of the most successful and relatively novel algorithms, named Differential Evolution with Global and Local Neighborhood (DEGL). The second model was based on a stochastic Transfer Function (STF) approach, combined with a nonlinear transformation of variables using state Dependent Parameter (SDP) method.

Parameters of both models were calibrated according to the proposed common framework Level 2 for selected catchments from the proposed database and an additional catchment located in Poland.

In addition to correlation analysis we discuss the identifiability of hydrological model parameters using analyses of response surfaces created by objective function for a range of climatic conditions. The influence of climatic conditions on the shape of response surface, estimated using sensitivity analysis will serve as an indicator of parameter nonstationarity.

Hw15S5.03

Hw15S5 - Testing simulation and forecasting models in non-stationary conditions

Oral

Sensitivity analysis of SCHADEX extreme flood estimations to the calibration period used for the MORDOR rainfall-runoff model

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Several stochastic simulation methods have appeared in the scientific literature over the past two decades. These approaches are based on the statistical analysis of flood series simulated by rainfall-runoff models which are forced by simulated rainfall and they are typically composed of a probabilistic rainfall model coupled with a rainfall-runoff model. Usually, both of these models are calibrated over observed hydrometeorological series, which may be subject to significant variability and/or unstationnarity over time. This study aims at investigating the sensitivity of extreme flood estimations to the calibration period used for the rainfall-runoff model.

After applying the workshop calibration framework, a supplementary analysis is performed. The proposed methodology consists in a block-bootstrap experiment generating different sets of observed series sub-samples. These sub-samples are then used to calibrate the rainfall-runoff model used within the stochastic simulation method. Finally, we compare the extreme flood estimation obtained using the different rainfall-runoff model parameter sets.

The SCHADEX (Simulation Climato-Hydrologique pour l'Appréciation des Débits EXtrê;mes) extreme flood estimation method, developed and applied by Electricité De France since 2006 for the dam spillway design, is used in this study. The rainfall-runoff model classically applied in the SCHADEX method is MORDOR, which is continuous, daily, lumped and has 22 free parameters. The SCHADEX extreme flood estimation method is applied over the Kamp at Zwettl catchment, located in the northeastern part of Austria. This 622 km2 catchment is an interesting case study since it has experienced dramatical floods in August 2002. The role of these extreme floods in the rainfall-runoff model calibration process and in the resulting extreme flood estimations is investigated.

Hw15S5.04

Hw15S5 - Testing simulation and forecasting models in non-stationary conditions

Oral

Applications of IHACRES to workshop-selected catchments exhibiting precipitation–streamflow non-stationarity

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An IHACRES rainfall-streamflow model structure will be applied to datasets provided to workshop participants. Prescribed Level 1 analysis will be undertaken for two or more of the Project basins (Set A). Level 2 analysis will be performed on as many of the basins in Set A as resources permit. Level 3 analysis will be undertaken for those basins where the results from Levels 1 and 2 indicate further work might be of interest and utility, e.g. where there are well-defined temporal patterns of model parameter values, especially if they might exhibit relationships with known possible causes of precipitation–streamflow non-stationarity.

Hw15S5.05

Hw15S5 - Testing simulation and forecasting models in non-stationary conditions

Oral

Incorporating expert knowledge in a complex hydrological conceptual model: A FLEX-TOPO case study for a central European meso-scale catchment

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Catchments are open systems meaning that it is impossible to find out the exact boundary conditions of the real system spatially and temporarily. Therefore models are essential tools in capturing system behavior spatially and extrapolating it temporarily for prediction. In recent years conceptual models have been in the center of attention rather than so called physically based models which are often over-parameterized and encounter difficulties for up-scaling of small scale processes. Conceptual models however are heavily dependent on calibration as one or more of their parameters can typically not be physically measured at the catchment scale.

Parallel to the evolution of modeling attempts, our understanding of rainfall/runoff models increased due to improvements of measurement techniques. Heavily instrumented catchments have been studied, and measured system responses have been modeled for testing a priori hypothesis of system function. Although our understanding of how catchments may work has increased the lessons learned from the case specific studies remain locally valid and are not widely used in model calibration and development.

In this study we try to constrain parameters of a complex conceptual model built on landscape units classified according to their hydrological functions, based on our logical considerations and general lessons from previous studies across the globe for the Luxembourgish meso-scale Wark catchment. The classified landscapes were used to assign different model structures to the individual hydrological response units. As an example deep percolation was defined as dominant process for plateaus, while rapid subsurface flow as dominant process for hillslope, and saturation overland flow as dominant process for wetlands. The modeled runoffs from each hydrological unit were combined in a parallel set-up to proportionally contribute to the total catchment runoff. The hydrological units are, in addition, linked by a common groundwater reservoir. The parallel hydrological units, although increasing the number of parameters, have the benefit of separate calibration. By stepwise calibration different mechanisms can be calibrated at periods when these mechanisms are active in isolation. For instance, the groundwater module is calibrated during dry season recession and the wetland module during isolated summer storms when the hillslopes are below the activation threshold. Moreover, one can constrain parameters by realistic conditions. As an example, the lag time of wetlands is likely to be shorter than the lag time of water traveling to the outlet from a plateau. Moreover, due to the dominance of forest on hillslopes in this

catchment, the interception threshold should be higher on hillslopes than on plateaus, which are mainly used for agriculture. Furthermore, fluxes and processes can be compared. For example, actual evaporation and transpiration from wetland can potentially be higher than from other entities within a catchment as wetlands are close to saturation for much of the year and evaporation and transpiration is thus less supply limited than on plateaus. To include all the comparisons and criteria in calibration, an evolutionary algorithm was used. The algorithm was adapted and applied in a way that in subsequent steps more and more comparative criteria are forced to be satisfied.

Including landscape classification and our basic understanding of how a system may work into hydrological models appears to be a powerful tool to achieve higher model realism as it leads to hydrograph simulations with high Nash-Sutcliff efficiency even without being calibrated on observed hydrograph. Not only does it allow to consider and to make use of crucial feedback processes between the hydrological system and the eco-system, it also leads to more detailed information on how a catchment may work than would be the case in a lumped model.

Hw15S5.06

Hw15S5 - Testing simulation and forecasting models in non-stationary conditions

Oral

Workshop summary and perspectives for further work

Andréasian, V. 1

1 Irstea, France

Here, we will discuss options for continuing the work started during this workshop.

Hw16PS.01

Hw16PS - Hydrology education and capacity building in developing countries

Poster

Water resources, climate and environmental research in Sub-Saharan Africa: Recommendations for international collaboration

Ngounou Ngatcha, B. 1; Sebag, D. 2; Diedhiou, A. 3; Favreau, G. 2; Durand, A. 4; Servat, E. 2; Ekodeck, G.E. 5

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During November 2011, a four-day International Conference was organised at the University of Ngaoundéré in Cameroon to gather recent progress and diffuse knowledge on the advances in Water Resources, Climate and Environmental Sciences in Sub-Saharan Africa for a sustainable development in the context of global change. This event helped to (i) bring together specialists in the different disciplines related to climate, water, environment and earth sciences, (ii) identify common key-research priorities, (iii) find ways to balance scientific research and regional development needs for a joint management and a more sustainable use of natural resources and (iv) develop a roadmap for future research and for the training of young researchers. Recognizing that sustainable development and the rationalization of resource management require an understanding of global change and anticipation of its consequences, the conference participants stressed the importance of performing retrospective studies and of monitoring environmental changes from regional scale to local levels at a pluri-decennal time-scale. The interdisciplinary approaches must be encouraged to help understand the diversity of changes and human-environment interactions at regional and local scales. However, it remains a challenge to have meteorological, hydrological information and climate scenarii at appropriate scales for impact studies as well as to define quantitative indicators of environmental changes. It is recommended also to encourage regional agencies and national institutions to facilitate access to their data to local researchers. The participants recommended to organize training workshops on rapidly evolving techniques including statistical analysis, on the use of satellite data and on regional hydrological modelling. Trainings on writing proposals, funding applications and requests for grants are also welcome and are important to support regional capacity and promote academic exchanges.

Hw16PS.02

Hw16PS - Hydrology education and capacity building in developing countries

Poster

Towards the new Tunisian agro-pedo-hydrologists – renewing the curriculum

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The Tunisian academic system shows several technical universities in different fields, which had been set up on the French model, in order to teach engineers and beyond to enhance the development of the country. Agriculture being the first economic sector from ages, agronomists have played a key role across the history, with master specializations ranging from agriculture itself to many connex aspects such as food processing, economy, or water management. The master sub-curricula were traditionally copy-pasted from the organization chart of the Ministry of agriculture, the State being the main employer and each Ministerial division having its own recruitment for the head and the regional offices. This led to highly specialized civil servants, unfortunately with some perverse effects. The main one is the segmentation between the ministerial divisions (e.g. soil and water conservation, small dams, big dams, groundwater resources, hydrometry, agrometeorology, water quality, soil mapping…) which led to incoherences and inabilities to address some of the stakes of soil-land-water integrated management, scales nesting and sustainability. The second main one is an inadequacy of the profile of overspecialized graduates with the needs of the alternate recruiters which emerged over the last 10 years as the State was less and less recruiting. We present how the curriculum has been renewed in the fields of soil and water, over the last years in the frame of INAT – the Tunisian National Institute for Agronomy, towards a stronger multidisciplinarity, collective works, communication skills, training periods, scientific mobility and methodology, master-PhD coupling. This has been initiated in the mid-2000 through a European-Tunisian Tempus project and is now being fully implemented, allowing to graduate a new generation of Tunisian agro-pedo-hydrologists.

Hw16PS.03

Hw16PS - Hydrology education and capacity building in developing countries

Poster

A holistic strategy to hydrological learning

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This study explores the vast experiences of a consortium of actors involved in hydrology. The objective of the study was to enhance learning and research on water resources and experiences as an example that a regional approach can work. The study showed that preliminary findings and conclusions that the holistic strategy presented did make a contribution to the capacity needs of the consortium both in terms of management and research capacity. The study drew two generalized lessons from the consortium experience. One of the lessons related to the importance of legitimate ownership and an accountability structure for consortium effective performance and the other related to the financial and intellectual resources required to jointly developing learning programs through shared experience. Keywords: Holistic, Strategy Hydrological, Learning

Hw16S1.01

Hw16S1 - Hydrology education and capacity building in developing countries

Oral

Reflections on the hydrological training needs of the southern Africa region.

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The southern African region has many problems associated with water resources management including the assessment of the available resources in what are largely data scarce basins. One of the critical questions is whether there is a large enough hydrology and water resources science skill base within the region to address these problems. Given the number of water resources development projects that are allocated to consultants from outside the region, it can perhaps be concluded that the answer is no! An additional indicator is the relatively small research output compared to other parts of the world and the fact that many scientific papers on water resources issues in southern Africa are authored by individuals from outside the region. This paper will look at the training needs of the region and the extent to which these needs are being met with existing educational resources and what should and can be done in the future. These 'reflections' will be partly based on the author's experience and partly on opinions canvassed from other individuals and institutions involved in hydrology and water resources science education, training and research. One of the conclusions of the paper is that financial resources allocated from within the region for training and research remains one of the constraints to further development of the skill base. A further conclusion is that, while existing institutional networks certainly do exist and do contribute to addressing educational needs, there is plenty of scope for extending networks to facilitate the sharing of ideas and resources.

Hw16S2.01

Hw16S2 - Hydrology education and capacity building in developing countries

Oral

HYDRARIDE, a field school in Hydrosciences and Geosciences to study the semi-arid environments of the Lake Chad Basin

Ngounou Ngatcha, B. 1; Sebag, D. 2; Boucher, M. 3; Demarty, J. 2; de Rouw, A. 4; Deschamps, P. 5; Menot, G. 5; Mesnage, V. 6; Oszwald, J. 7; Rajot, J.L. 4

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At the summer 2012, a consortium of French and African partners coordinated the first HYDRARIDE field school in the region of Maroua (Far North of Cameroon). The field school's mandate is to train master and Ph.D students in practical fieldwork for research with French and African researchers and academics. The first objective is to train students in observation, measurement, and sampling techniques specific to Hydrology, Hydrogeology and Surficial Geosciences in the context of semi-arid environments. The field school meets specific identified needs: European students have little knowledge of the field realities in tropical environments, while their African counterparts sometimes suffer from a lack of technical expertise. The trainees, therefore, have had different practical instruction in the field about landscape analysis, description of surface features and vegetation covers, groundwater and surface water sampling, and soil sampling, etc. The students directly apply the techniques in field and laboratory, acquiring essential hands-on experience. After two days dedicated to the study of the watershed as a whole, groups of 3 to 4 students rotate through thematic workshops. The field days are followed by classroom presentations about the theoretical content of the workshops. The field school ends with the debriefing of workshops and an evaluation of the training by students. The second objective aims to develop scientific activities of a multidisciplinary team in order to contribute to a better understanding of the hydrological and sedimentary dynamics within the Tsanaga River catchment and, more generally, within the iconic Lake Chad Basin. Surveys and sample collections are used for research internships and Ph.D co-supervised by members of the teaching team. So, the HYDRARIDE field school will directly contribute to education and capacity building in African and European research institutions and to our general scientific understanding of semi-arid environments.

Hw16S2.02

Hw16S2 - Hydrology education and capacity building in developing countries

Oral

Recent advances in the Trans-African Hydro-Meteorological project: New sensors and crowdsourcing

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The Trans-African Hydro-Meteorological Observatory (TAHMO) seeks to place weather stations across Africa. The idea behind this project is to build a dense network of hydro-meteorological monitoring stations in sub-Saharan Africa; one every 30 km. This entails the productions of 20,000 such stations. By applying innovative sensors and ICT, each station should cost not more than $200. The stations would be placed at schools and integrated in the educational program. The data will be combined with models and satellite observations to obtain a very complete insight into the distribution of water and energy stocks and fluxes. Within this project, we have built a prototype of an acoustic disdrometer (rain gauge) that can be produced for much less than the cost of a commercial equivalent with the same specifications. The disdrometer was developed in The Netherlands and tested in Tanzania for a total project cost of €5000. First tests have been run at junior high schools in Ghana to incorporate hydro-meteorological measurements in the science curriculum. The latest activity concerns the organization of a crowdsourcing competition at university campuses throughout Africa to design and build new robust sensors.

Hw16S2.03

Hw16S2 - Hydrology education and capacity building in developing countries

Oral

The first lesson in Civil engineering Hydroloy course: experiences on how to start

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Giving the Hydrology course in a Civil engineering department where students are mainly interested by civil and infrastructure construction is not always an easy task. The first session is of prime importance to hold student's attention and put into evidence relationships with other courses (topography, geology, hydraulics, urban water, infrastructures and statistics). The paper aims sharing two experiences of the content provided during the first session knowing that the general objectives of the course are to quantify the water cycle at the watershed scale and to present flood risk assessment methods. In the first experiment, the point of departure is the global water cycle presenting global fluxes of precipitation, evapotranspiration and runoff. An idea is given on how to estimate such fluxes. Some elements of the water cycle are reported for Tunisia as case study. The proof of hydrological databases requirement is established outlining the water services missions. The last part presents the earth radiation balance. The second experience begins from local issues such as flood management and civil engineering works. Then, the question of how to determine the size of such infrastructures for safety and efficiency is addressed. Hydrological measurements are briefly reviewed. The need of estimating soil moisture for its crucial role in flood generation is clarified. The time variability of those natural variables (temperature, rainfall, and runoff) is addressed and elements about rainfall and hydrological variability in Tunisia are given followed by the presentation of the global water cycle. Last of all, the two approaches come nearly to the same contents and conclusions. However, from my own experience, the second method has proven that it is more attractive for students. I found that using the local problem approach, it is easier to give ideas about water regulation, services, databases, environmental issues and unresolved problems.

Hw16S2.04

Hw16S2 - Hydrology education and capacity building in developing countries

Oral

Hydrology education and capacity building in developing countries: The role of networks

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The past ten years have seen several education and training networks related to hydrology being established in the developing world. In sub-Saharan Africa these include Waternet, CAP-NET, the NEPAD Water Centres of Excellence (SANWATCE), FETWATER, and others, where hydrology forms part of the water resources foci as well as several others that deal with water indirectly, e.g. climate change, agriculture. Typically, supported by foreign donor funds, these networks have produced many graduates, usually at masters level, but increasingly PhD and are reported to fill a critical gap in the training of young scientists and practitioners in the region - yet their sustainability is uncertain.

In this paper, we summarize the current situation, assess the need for these networks, their successes and failures and consider their future need and role.

Hw16S2.05

Hw16S2 - Hydrology education and capacity building in developing countries

Oral

Courses in the hydrological sciences - an international data base

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IAHS maintains a project on education in the hydrological sciences, one component of which has the aim of making available information on national and international courses which lead to a qualification in hydrology. The courses may be at technician or professional level. The information is being compiled into a data base that will be open for use by all who interested in the subject.

The aim is two-fold. First it is to provide prospective students and those who are in a position to support their studies with information as to what courses are currently available so that they might choose that which best suits their particular needs. In addition, the data base will give those who organize and teach such courses, or are planning to do so, information as to what other courses are already in existence; thereby facilitating the exchange of experience between the experts concerned and encouraging the maximum of co-operation and minimum of duplication.

The background to the project is presented, plus an overview of the information being collected. The current state of the data base will be reported, together with details as to how information on courses can be submitted and retrieved.

Hw16S2.06

Hw16S2 - Hydrology education and capacity building in developing countries

Oral

Hydrology education and capacity building – A comparative study between parts of Africa and India

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The recent spurt in agriculture activity, industrial development and urbanization supplemented by uneven distribution of rainfall in time and space, failure of monsoon, popular policies of government and financial institutions has mounted unprecedented stress on ground water regime in many developing nations. There has been a significant increase in the sources and extent of contamination of water resources in recent times. Augmenting additional water resources to cope up with the growing developmental activities is mostly executed through adoption of ad-hoc measures with very little scientific backing on availability and dynamic behaviour of various components of water resources viz., atmospheric, surface and sub-surface and more so their interrelationship and behaviour in time and space. Lack of trained manpower, institutional support for sustained training in hydrological education, proper assessment and management of water resources, lack of infrastructure and critical data on evaluation and assessment of hydrological components are the main constraints. The problems can be partially addressed by providing suitable comprehensive hydrological education, capacity building in terms of short-term training for professionals and infrastructure and analytical facilities at local and regional levels. Awareness and public participation can strategically improve the situation of water resource management in rural areas of developing nations. The paper provides critical information on the content and the structure of hydrological education with a comparison between the sub-Saharan African region and the Indian continent, the constraints in the academic and government sector and lack of involvement and awareness among the public, professionals and policy makers. It also indicates possible solution that can address various issues at local level. The scope and benefit of support from international community in capacity building and education is also discussed.

Hw16S2.07

Hw16S2 - Hydrology education and capacity building in developing countries

Oral

Hydrological education and training needs in developing countries: opportunities and constraints

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This paper analyses the opportunities and constraints on hydrological education and training needs in Zimbabwe. It discusses the requirements in the country, some recent developments, initiatives and constraints that exist. Country requirements include development of academic research capacity at a variety of levels. Constraints include a lack of adequate funding, follow-up after short training courses, institutional support to continue training, and competition from outside organizations. It is vital to sustain both educational and practical expertise in hydrology in the country by building networks.

Hw16S2.08

Hw16S2 - Hydrology education and capacity building in developing countries

Oral

Hydrological education as the essential component of enhancing capacity building in the water sector: Ukrainian experience

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A development of capacity building in the water sector is a primary task for sustainable water management in Ukraine. A practice is revealing that the awareness level of managers of water sector organizations in the area of hydrology, methods of water quantity and quality assessment is insufficient. Such situation is reducing an efficiency of measures on management of surface waters.

In order to solve this problem, the Ukrainian Research Hydrometeorological Institute has developed the education program of skills upgrading for managers working in the local branches of the Ministry of Environment Protection and the State Agency of Water Resources. The program consists of two modules.

Module with a basic program. It is developed for persons with tertiary education, but having no special qualification in the hydrology, meteorology, hydrochemistry, ecology.

The module's program consists of the following subjects: basic knowledge of meteorology and hydrology; basic factors of forming of water quantity and quality; impact of extreme weather events, climate change and human activity on waters; water quality and quantity monitoring programs and equipments.

Module with an advanced program. It is developed for persons with tertiary education and some qualification in the field of meteorology, hydrology, hydrochemistry, ecology. The more attention is paid to study to: forecasting of severe weather phenomena using remote sensing and GIS- technologies; floods and droughts risks assessment; using the hydrometeorological information for development of urban environment, European water quality monitoring legislation.

Two variants of training are supposed:

- traditional variant. The two week courses (lectures and practicum) will be organized in the eight regional centres of the Hydrometeorological Service;
- variant based on using of internet resources. Practicum will be organized in the nearest organizations of the Hydrometeorological Service.

IAHS.01

IAHS plenary

Plenary

Delta Decadal Initiative: A framework of actionable research towards delta sustainability

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Deltas are economic and environmental hotspots, food basket for many nations, home to a large part of the world population, and hosts of exceptional biodiversity and rich ecosystems. Deltas, being at the land-water interface, are international, regional, and local transport hubs, thus providing the basis for intense economic activities. Yet, deltas are disappearing and deteriorating at an alarming rate as victims of human actions (e.g., water and sediment reduction due to upstream basin development), climatic impacts (e.g., sea level rise and flooding from rivers and intense tropical storms), and local exploration (e.g., sand or aggregates, groundwater and hydrocarbon extraction). The international scientific and stakeholder communities are called to action now to develop and deliver the knowledge base for understanding and protecting these vulnerable coastal systems. This talk will describe an international effort to spearhead this call-to-action by coordinating, integrating, and enhancing national, regional and local efforts on deltas around the world towards developing an integrated framework for delta sustainability.

IASPEI.01

IASPEI Opening plenary and Keynotes

Plenary

GEM - the Global Earthquake Model initiative

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The Global Earthquake Model initiative is completing its first five-year phase in 2013. Initiated by the OECD in 2009, GEM is transforming the way seismic hazard and risk are assessed and providing new avenues to mitigate seismic risk mitigation around the world. GEM is implemented as a public-private initiative, with the participation and support of governments, private companies and international associations, such as IASPEI. GEM is based on three integrated elements: (i) global components developing the new global standards in seismology and earthquake engineering, such as the new ISC-GEM Global Earthquake Catalogue and the new global database of acgive faults (GEM Faulted Earth), (ii) the establishments of regional programs for hazard and risk assessment in every region of the globe, for example the European SHARE program (Seismic Hazard Harmonization for the European region), and (iii) the development of a coherent, integrated set of methodologies and codes allowing uniform probabilistic and event-based hazard and risk assessment. IASPEI is an important driving force of GEM; our scientists and seismologists are the primary components in the hazard components of GEM, and our regional commissions are involved in the implementation of the GEM regional programs. We review the GEM history, progress and future prospects, as well as the involvement of IASPEI in the development and success of this important initiative.

IASPEI.02

IASPEI Opening plenary and Keynotes

Plenary

A history of British seismology

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The work of John Milne, the centenary of whose death is marked in 2013, has had a large impact in the development in global seismology. On his return from Japan to England in 1895, he established for the first time a global earthquake recording network, centred on his observatory at Shide, Isle of Wight. His composite bulletins, the “Shide Circulars” developed, in the 20th century, into the world earthquake bulletins of the International Seismological Summary and eventually the International Seismological Centre, which continues to publish the definitive earthquake parameters of world earthquakes on a monthly basis. In fact, seismology has a long tradition in Britain, stretching back to early investigations by members of the Royal Society after 1660. Investigations in Scotland in the early 1840s led to a number of firsts, including the first network of instruments, the first seismic bulletin, and indeed, the first use of the word “seismometer”, from which words like “seismology” are a back-formation. This paper will present a chronological survey of the development of seismology in the British Isles, from the first written observations of local earthquakes in the 7th century, and the first theoretical writing on earthquakes in the 12th century, up to the monitoring of earthquakes in Britain in the present day.

JP.01

Joint Plenary

Plenary

JFAST: Drilling to the plate boundary to study large slip of the 2011 Tohoku-Oki, Japan earthquake

Mori, J. 1; Chester, F. 2; Eguchi, N. 3; Toczko, S. 3; Brodsky, E. 4; Kodaira, S. 3; Expedition 343 Scientists, 1. 5

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The 2011 Tohoku-Oki earthquake produced the largest fault slip ever recorded for an earthquake, up to 50 meters on the shallow portion of the subduction megathrust. This region of the plate boundary was not expected to have large slip during earthquakes, so the huge co-seismic displacements and resultant devastating tsunami were a shocking surprise to the seismological community. In response to the earthquake, the Integrated Ocean Drilling Program (IODP) rapidly planned and carried out Expedition 343 (JFAST) to investigate the rupture mechanisms and physical conditions that produced the large slip. During April/May and July 2012, three boreholes located at a site close to the Japan Trench about 90 km east of earthquake epicenter, successfully reached the plate boundary fault at depths of about 820 meters below seafloor. These boreholes enabled geophysical logging, core sampling and installation of a temperature observatory in the vicinity of the fault zone.

Analyses of core samples obtained from the plate boundary decollement show a narrow zone (less than 5 meters) of highly deformed fabric in a clay layer. The pronounced localization of deformation within this material suggests coseismic weakening during past earthquakes. Estimates of the level of dynamic friction during the recent earthquake are expected from the temperature monitoring that was installed during the expedition. Also, laboratory experiments on the retrieved core samples will give estimates of the frictional properties of the fault rocks. Combining investigations of the physical, chemical, and mechanical properties of the fault zone along with determinations of the local stress state from borehole breakouts, will provide information to help explain the very large slip that occurred during the earthquake.

JP.02

Joint Plenary

Plenary

The coherence and impact of meridional heat transport anomalies in the Atlantic Ocean inferred from observations

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Observations of thermosteric sea level (TSL) from hydrographic data, equivalent water thickness (EWT) from satellite gravity data, as well as altimetric sea surface height (SSH) anomalies, are used to construct budgets of heat and mass for the Atlantic Ocean from 67N to the Southern Ocean and to infer anomalies in the meridional heat transport (MHT). The time-varying budgets are forced by surface heat and freshwater flux anomalies; discrepancies between the modeled response to surface fluxes and observed mass and heat content are used to infer lateral heat and mass convergences. The «unknown control» version of a Kalman filter is employed to extract smoothed budget terms and a smooth residual in each of eight regions, given reasonable estimates of model and data errors. Regional convergences are used to estimate meridional heat transports for 1993-2010 by two different methods: 1) summing the HTC toward the south and 2) assimilating more direct MHT estimates, constrained by the HTC estimates. Both methods show that MHT is highly coherent between 35S and 40N, the latitude of the separated Gulf Stream. The analysis shows that anomalies in MHT comparable to or larger than that recently observed at the RAPID/MOCHA line have occurred multiple times in this 18-year period. Positive anomalies in coherent MHT correspond to increased heat loss in the subtropical gyre demonstrating the influence of MHT on the atmosphere. A correlation of MHT with the Antarctic Oscillation suggests a southern source for the coherent MHT anomalies.

JP.03

Joint Plenary

Plenary

Geo-sciences for proactive disaster risk reduction

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1 ICHARM, Japan

Disasters triggered by natural hazards are increasing in frequency and intensity. This is mainly due to increasing societal vulnerability, but is accelerated by climate change and tectonic activities. Disasters are evolving, too. Recent devastating disasters such as Hurricane Katrina, the Great East Japan Earthquake and Tsunami and Chao Phraya Flood reveal new dimensions of disasters, such as concatenated, globally-extended impacts. This is due to increasing interdependence of socio-economic activities and globally-distributed irreplaceable manufacturing technologies. Disasters are no longer regionally confined matters but global issues and a threat to global sustainability.

In order to cope with such profound problems, proactive disaster risk reduction is necessary to shift emphasis from humanitarian emergency responses to reducing risk before disasters happen without postponing necessary actions. For this shift, advanced geo-scientific knowledge is indispensable. Without understanding hazards and having predictions, society cannot target appropriate preparation. Observations and analytical knowledge of hazards have been making great progress in geo-sciences. For example on storm surges, there are remarkable success stories in Bangladesh etc. in the use of predictions for early warning. But the practical use of predictions to address disasters such as flash floods, landslides, debris flows, earthquakes etc. is still limited. The lack of ground observations is a serious obstacle for efficient use of scientific models. Past experiences are the ones most relied upon and used in decision making but under global changes, many inexperienced phenomena are anticipated for which only geo-sciences can give prospective information. For the use of uncertain information in societal decision making, more scientific attention is necessary.

There are key strategies that geo-sciences have to take for proactive disaster risk reduction, that is, the integrated approach. Geo-scientists are expected to work with other players in different disciplines including politicians and media regardless of difficulties in risk communication. Geo-scientists' role is huge in hazard mapping, early warning, risk assessment and monitoring. But also important is to increase disaster literacy of the public which forms the basis of proactive disaster risk reduction. Post-2015 Sustainable Development Goals, post-Hyogo Framework for Action, Integrated Research on Disaster Risk and many others expect geo-scientists' contribution to proactive disaster risk reduction.

P01PS.01

P01PS - General topics on ocean physics and chemistry

Poster

A new sea surface roughness expression based on the concept of wind-wave saturation

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There is much uncertainty in the relation between sea surface roughness and sea states. However, a clear relationship has not been verified yet. In order to solve this problem, a new concept of saturation ratio of wind-wave spectrum is proposed. The concept is based on the 3/2-power law between non dimensional significant wave height and period, which was proposed by Toba (1972). The saturation ratio of wind wave spectrum is calculated by using spectral analysis in principle, however a new parameter derived by the 3/2-power law gives us a saturation ratio from significant wave parameters without spectral analysis.

It is found that the negative correlation between sea surface roughness and saturation ratio of wind-wave spectrum exists. A new sea surface roughness expression is proposed by using this relation. This relation can be explained as that the saturated wind-wave conditions reduce the momentum exchange from wind to wave, so the sea surface roughness reduces in proportion to the momentum exchange.

This linear relation between sea surface roughness and the saturation ratio of wind-wave spectrum, can explain sea surface roughness fluctuation better than the other expressions such as a function of wave age.

P01PS.02

P01PS - General topics on ocean physics and chemistry

Poster

Scattering phase function: parametrizing the IOP we know least about

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Inherent optical properties are the absorption and scattering. Everyone agrees about this. However in most applications one ignores the fact that scattering is not just a wavelength dependent coefficient. It is also an angular function of scattering angles distribution, namely phase function.

Phase functions for several decades were treated as not very important for the light field including water leaving radiance. Therefore an average of three single wavelength measurements of the San Diego harbor, the Petzold function, were treated as good enough for radiative transfer calculations. In a similar way, an analytical phase functions created for diffuse galactic light, the Haltrin-Greenstein function, was used in modelling. Only recently things started improving when more realistic analytical phase functions were created by Haltrin as well as by Fournier and Forand and new instruments started appearing. Basing on those improvements, Mobley and colleges proposed in 2002 a parametrization of Fournier-Forand functions using backscattering ratio as the parametrization coefficient.

We use Monte Carlo radiative transfer code to show that backscattering ratio is not the only factor ruling the phase function shape. Reflectivity values calculated using "realistic" phase functions with identical backscattering ratios can differ by up to 10%. This is the motivation for proposing a new phase function parametrization, an improved version of one we have published in 2007. This spectral parametrization is based on Baltic phase function measurements for four wavelengths. The parameter used to choose the correct Fournier-Forand function is absorption. At this moment this is only a regional parametrization but with more data it can be improved to become a universal one. We hope other researchers will try using their measured phase functions to verify and improve our method. It is high time we stopped taking phase functions for granted.

P01PS.03

P01PS - General topics on ocean physics and chemistry

Poster

Some statistical features of the Kattegat-Skagerrak surface front

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Being the entrance to the Sounds and the Baltic Proper the conditions in Kattegat are crucial for the water exchange and the ability to oxygenate the deeper parts of the Baltic Sea. Comparatively fresh water of Baltic origin is spread over large parts of the Kattegat and separated from the saltier water of Atlantic origin by a halocline in the vertical direction, and by a surface front in the northern part of Kattegat. Apart from its dynamical importance the front also acts as a regulating factor for the phytoplankton production in the area since an exchange of nutrients and organic material takes place across it. Previous studies of the Kattegat-Skagerrak front have made use of only a limited number of observations. Remote sensing, together with other observation techniques like underway measurements by research vessels, ferries and other ships, have increased the amount of data considerably. The significant improvement of the spatial and temporal data coverage has now given the prerequisites for making further progress in the understanding of the front dynamics.

The first results from a study concerning the Kattegat-Skagerrak front will here be presented. Statistics of the front position, as detected by satellite images and FerryBox observations, will be given. The position and variability of the front will also be correlated with possible driving mechanisms

P01PS.04

P01PS - General topics on ocean physics and chemistry

Poster

Possible causes series of typhoons

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An interesting phenomenon is the so-called serial typhoons, which represent a 2-4 typhoons occurring in a day or two almost at the same point of the ocean. This phenomenon is contrary to established notions about the conditions of typhoon's generation, main of which is the heating water to a temperature above 26°.

The possibility of the second and subsequent typhoons generation is not clear, as the first in a series strongly cools the ocean water along the path. There are several hypotheses to explain this contradictory picture. By V.L. Syvorotkin (2002) the serial typhoons generation sites are located in areas of deep degassing over an active geological structures, located at the bottom of the ocean. K.N. Fedorov (1972) proposed scheme of vertical circulation under the typhoon path, which explains the complex pattern of the thermal trace, when together with strong cooling below the center of the typhoon temperature rise on either side of the path is observed. Fedorov's physical model of this phenomenon (1979) was confirmed experimentally [1] and is two pairs of vertical circulation cells that provide upwelling (under the typhoon eye), that bring colder water from the depths of the first 100 meters to the surface; on the periphery of typhoon trajectory (at distances of 100 km) daunvelling takes place. So in typhoon thermal trace cellular temperature distribution, which may leave the potential conditions for the «secondary» typhoons.

The arguments for and against these hypotheses are discussed. This paper presents statistics of serial typhoons, which can serve as a basis for overcoming the contradictory ideas about the nature and conditions of typhoon's generation.

The reported study was partially supported by RFBR, Research project No. 11-08-00795 1 - Alekseev V.V., Kiseleva S.V., Lappo S.S. Laboratory models of physical processes in the atmosphere and ocean. Moscow., Nauka, 2005. 311pp.

P01PS.05

P01PS - General topics on ocean physics and chemistry

Poster

Variations of upper ocean salinity in the northwestern subtropical gyre of the North Pacific

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The upper ocean in the northwestern subtropical gyre of the North Pacific is characterized by subtropical mode water (STMW), a thick layer of vertically uniform properties in the thermocline. It forms south of the Kuroshio Extension in winter due to strong surface cooling and resultant thickening of the mixed layer, subducted into the main thermocline and spread to a wide region by the gyre circulation. A large number of studies have described variations of STMW. However, because their attention has been paid to changes of temperature and potential vorticity, it still remains questions how the salinity of STMW changes with time and what is the cause of them. The present study examined changes of salinity in the formation region of STMW. The monthly time series of temperature and salinity profiles averaged in the formation region was constructed for the period from 1960 to 2011 using observation data from World Ocean Database 2009. The salinity in the mixed layer shows a clear seasonal cycle with highest in late winter and lowest in late summer. The surface saline water extends more than 200 m depth in winter, remaining at subsurface depths as STMW in the following seasons. Comparison with atmospheric reanalysis data reveals that the seasonal change can be explained quantitatively by the difference between evaporation and precipitation, and be mostly caused by the change of evaporation. The wintertime evaporating cooling may lead to not only the deepening of the mixed layer but also the salinification. Regarding interannual and decadal variations, the salinity of STMW varies coincidentally with that of the mixed layer in late winter. The late-winter salinity shows predominant decadal variations, which are not correlated with changes in temperature of the mixed layer. Unlike the seasonal variations, the decadal variations are not related to evaporation and precipitation, but show a significant correlation with the Pacific Decadal Oscillation.

P01PS.06

P01PS - General topics on ocean physics and chemistry

Poster

LOTUS— Preparing Land and Ocean Take Up from Sentinel-3

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The objective of the new EU FP7 LOTUS project is to support the development of GMES by developing applications of Sentinel-3 to complete the space observation infrastructure that are designed for land and ocean monitoring for GMES. Sentinel-3 is the GMES space component for monitoring the oceans. The SRAL instrument onboard Sentinel-3 is a radar altimeter that will provide observations of sea-surface and land-ice topography, in continuation of altimeter missions such as ENVISAT, Jason-1 and Jason-2. Furthermore, the SRAL instrument will operate in a SAR mode and provide along-track high-resolution heights of the sea surface in the open oceans, in the coastal seas, in-land water and sea ice areas. The SAR capability is a new feature and no data products based on this SAR mode data are provided or used operationally. New methodologies and new data processing chains need to be developed to prepare the take-up of the GMES Sentinel-3 data. The LOTUS project will develop new methodologies, data processing chains, and applications of the SAR mode data for the high resolution sea surface heights, wave heights and wind speeds in the open oceans, coastal seas as well as in sea ice covered regions for operational marine services. For the operational land services, the LOTUS project will develop new methodologies, data processing chains, and applications of the SAR mode data for the in-land water levels in rivers and lakes, soil moisture, and snow water equivalents. In turn, the new products based on the SAR mode data will support operational services for emergency response and security in the events of, e.g., storm surges and flooding. The new land products will provide valuable information about the hydrological cycle and support services on monitoring hydrological parameters for climate change. This poster presents the project objectives and some preliminary results.

P01PS.07

P01PS - General topics on ocean physics and chemistry

Poster

Identification of river plumes of Ganga- Brahmaputra-Meghna (GBM) river basin in the Bay of Bengal using satellite altimetry

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Ganga-Brahmaputra-Meghna (GBM) river basin in the east coast of India is one of the major river basins in the Bay of Bengal (BoB) that directly influences the amount of fresh water discharge into the BOB. It is estimated that almost half the fresh water discharge into the BoB is due to the discharge of these three rivers. The quantity of fresh water that reaches coastal seas develop into a plume extending large distances further offshore which cannot be identified using the available in situ measurement techniques due to the rough weather conditions during the monsoon period. It is in this context, the significance of satellite altimetry finds relevance in monitoring plume development in the coastal seas as a source of information for climate scientists. The effect of freshwater discharge on the sea surface height anomalies in the BOB is thus related to the amount of rainfall over the GBM river basin. Using the daily rainfall data collected from the Indian Meteorological Department(IMD) and the Sea Level Anomalies derived from the JASON-1 altimetry data made available by AVISO, the signature of river plume due to monsoon rainfall and the sea level anomalies are identified. From this data, the years 2002 and 2004 were clearly identified as drought years and the years 2003 and 2007 were good wet years. It can be noted that the SLA plume of 2007 (active monsoon) is positive than the SLA plume of 2004 (weak monsoon). However, the SLA during August (2004) which is a weak monsoon year is higher than SLA during 2007 August (active monsoon year). The variation is mainly due to high rainfall during August(2004) compared to August(2007).

P01PS.08

P01PS - General topics on ocean physics and chemistry

Poster

Bio-physical changes along the coastal upwelling regions over the North Indian Ocean

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North India Ocean is one of the strongest coastal upwelling regions in the world during monsoon seasons. It is divided into two seas by the Indian sub-continent. The two seas shows a peculiar characteristics in coastal upwelling phenomena and also bi-physical changes. In present study I wish to investigate the short to long term changes in bi-physical process along the coastal upwelling regions in the two seas during the monsoon seasons (summer and northeast monsoon) using multi satellite (AVHRR, SeaWifs, TOPEX/POSEIDON, QuickScat and ASCAT) and also Argo data products. The results shows that the bio-physical changes are strong in the Arabian sea than the Bay of Bengal. The upwelling intensity has a good linear relationship with the alongshore wind stress in the Arabian Sea (Oman coast and southwest coast of India) during summer monsoon sea, where as in the Bay of Bengal the relationship weak and also less biological activity during the summer monsoon season. North Indian ocean's bio-physical changes are also influenced by the ocean-atmospheric teleconnections (ENSO and Indian Ocean Dipole).

P01S1.01

P01S1 - General topics on ocean physics and chemistry

Oral

The incredible saga of satellite oceanography

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The paper will review the past thirty years of incredibly successful series of satellite missions devoted to ocean observation, and describe some highlights of the most significant achievements, covering the various ocean Essential Climate Variables now accessible to space-based measurements. Beyond the historical aspects the paper will propose an analysis of some of the main reasons that explain this astounding success, which has paved the way to the operational monitoring and forecasting of the global ocean. It will provide an overview of the ocean-observing satellite missions planned for the coming decades, which hold the promise of many new discoveries and more generally, a better in-depth understanding of the role of the ocean in the Earth system.

P01S1.02

P01S1 - General topics on ocean physics and chemistry

Oral

Satellite altimetry in the coastal zone: past, present and future

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Satellite altimetry has allowed an unprecedented mapping of the ocean surface dynamics at the large- and meso-scale. With improvements in orbit models, radar processing, atmospheric and geophysical effect corrections, altimetry gives today also a very accurate estimation of the rate of sea level rise and its geographical variability. However, altimetric data in the near-land strip (0 to 50 km from the coastline) are often flagged as bad and left unused, due to 1) difficulties with the corrections; and 2) presence of land in the footprint, which makes the fitting of the altimetric echoes with a waveform model (the so-called 'retracking' of the waveforms) problematic. This has prevented the applications of altimetry to be extended to the domain where the impacts of changing climate and rising sea levels are most severely felt by society: the coastal zone.

In the last few years a vibrant international community of researchers has developed the new field of coastal altimetry, i.e. techniques to recover meaningful estimates of height, significant wave height and wind in the coastal zone, by improving the corrections and developing specialized retracking; this has led to a number of new applications, that are showcased at the annual Coastal Altimetry Workshops (http://www.coastalt.eu/community).

We will describe the main achievements of coastal altimetry so far, and show examples of the improvements in retracking and corrections. We will discuss the need for integration with models (and the question on how best to assimilate the reprocessed data) and other in situ observations, and the continuing efforts for calibration and validation of the new data. Finally, we will discuss the future of this relatively new discipline, that looks bright not only for the continuing improvements in reprocessing, but also thanks to the advent of SAR altimetry, the technology adopted for ESA's Cryosat-2 and Sentinel-3 missions, which has inherently better coastal capabilities.

P01S1.03

P01S1 - General topics on ocean physics and chemistry

Oral

Satellite monitoring of the Nord Stream gas pipeline construction and operation in the Gulf of Finland in 2010-2012

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To assess the impact of construction of the Russian section of the Nord Stream gas pipeline on the formation of fields of suspended matter in the eastern Gulf of Finland a daily satellite monitoring was organized in the period from 12 May to 31 December 2010 and from 1 April to 30 November 2011. The objectives of the monitoring included: (1) identification of the spots of turbid waters in the vicinity of the pipeline and in the surrounding waters, (2) determination of natural areas of suspended matter distribution, (3) separation of the effects of anthropogenic impact on the marine environment and natural processes responsible for an increase in the water turbidity, and (4) monitoring of the transboundary transport of turbid waters. From 1 January to 30 November 2012 satellite monitoring was focused on the detection of possible thermal effects (ice, SST, suspended matter anomalies) at the sea surface resulted from the pumping of the heated gas via two pipelines at the bottom of the sea. For this purpose, we used all cloudy free over the pipeline route satellite images, obtained with the MODIS-Terra and -Aqua, MERIS-Envisat, and Landsat-7. ASAR-Envisat was used to determine ice cover and the ice edge, as well as oil pollution in the Gulf of Finland. Over the period of satellite observations only a few cases of local patches of water with high concentration of suspended matter can be attributed to the construction of the pipeline (only in the vicinity of Portovaya Bay). This concentration was less than maximum concentration for Nord Stream project approved by Russian Environmental Authorities. All other detections of turbid waters, crossing the pipeline, were of natural origin (wind-wave mixing, river plumes, transboundary transport). No thermal effects related to the pipeline route have been detected. Our conclusions were confirmed by the turbidity and SST maps of Gulf of Finland presented at the web site of the Finnish Environment Institute.

P01S1.04

P01S1 - General topics on ocean physics and chemistry

Oral

Interannual variability of the Black and Azov Seas level and estimation of water exchange between them based on satellite Altime

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Variability of the Black and Azov Seas level is characterized by alternating periods of rise and drop according to the altimeteric measurements of TOPEX/Poseidon and Jason-1/2 satellites. For the period from January 1993 to June 1999 the Black Sea level was rising at a rate of 2,64 ±0,31 cm/yr. In the next five years (from June 1999 to April 2003) there was a slight drop in its rate (1,23 ±0,02 cm/yr). A short period of sharp rise of the sea level at a rate of 20.72 ±0,72 cm/yr was observed from April 2003 to June 2004. Then, from June 2004 to February 2008, the level dropped again at a rate of 8,59 ±0,65 cm/yr, and from February 2008 to December 2011, the Black Sea level was rising at a rate of 6,72 ±0,32 cm/yr. In 1993 1994 the Azov Sea level dropped at a rate of 13,14 ±1,71 cm/yr. In 1995 1999 it was rising at a rate of 3,12 ±0,99 cm/yr. In 1999-2002 the Azov Sea level dropped again at a rate of 3,96 ±1,07 cm/yr, then to spring of 2004 it was rising at a rate of 12,77 ±2,31 cm/yr and the next period (till winter of 2007/2008) was characteized by the sea level drop at a rate of 8,94 ±1,53 cm/yr. Further to the end of 2011 the Azov Sea level was rising at a rate of 6,78 ±1,11 cm/yr. Estimation of variability of water exchange between the Black Sea and the Sea of Azov was based on the difference in the sea level along the 42 pass of the satellites, which crosses both seas. This study was supported by a series of grants of the Russian Foundation for Basic Research (No 13-05-01125, 13-05-00728, 13-05-00256, and 13-01-00753)

P01S2.01

P01S2 - General topics on ocean physics and chemistry

Oral

Sea-level measurements from coastal GPS stations

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Monitoring and understanding global and local sea-level variations due to climate change is of great importance to coastal societies. The existing techniques for sea-level measurements, e.g., tide gauges and altimeters, have provided valuable data and results in this field. However, both of these techniques have their issues; tide gauges are affected by the motion of the land on which they are established and altimeters have problems with near-coast measurements and drifts. Therefore, further observations with additional instrumentation are necessary in order to fully understand the underlying sea-level processes.

We present a technique for local sea-level measurements using Global Positioning System (GPS) signals received by existing permanent GPS stations at the coast. A GPS antenna close enough to the ocean is affected by multipath signals from the ocean, i.e., GPS satellite signals reflected off the sea surface. The multipath signals interfere with the direct satellite signals and the composite signals are recorded by the GPS receiver. The multipath effect is especially visible in the Signal-to-Noise Ratio (SNR) data. From analysis of the SNR data it is possible to determine the distance between the sea surface and the antenna phase centre. Thus, a coastal GPS station can be used as a GPS tide gauge measuring sea-level variations.

The advantage of a GPS tide gauge is that it allows both determination of the sea level and determination of the position with respect to the International Terrestrial Reference Frame, using a single geodetic instrument. This is particularly valuable in areas with land-surface motion where the usefulness of traditional tide gauges is restricted.

We present the analysis of more than one year of data from several existing permanent GPS stations around the world. The resulting sea-level time series and ocean-tide parameters from GPS are compared with those from traditional tide-gauge measurements at the respective sites.

P01S2.02

P01S2 - General topics on ocean physics and chemistry

Oral

Regional effects on the coherence of sea-level at islands with the wider ocean

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Studies comparing tide gauge measurements (necessarily at the coast) with sea level from nearby satellite altimetry (usually some way off-shore) have shown good agreement for some islands, and poor agreement for others. Using the 1/12° OCCAM ocean model, we investigate the relationship between sea level at small, open-ocean islands, and offshore sea level. For every such island or seamount in the model, we compare the shallow-water sea level with the steric and bottom pressure variability in a neighboring ring of deep water. In order to separate topographic and distance effects, we also compare deep ocean points with their surrounding rings.

We find that at high frequencies, for which bottom pressure signals dominate, there may be high coherence between island and off-shore sea-level. At sufficiently low frequencies (periods of many months), steric signals dominate and there is high coherence. However there is an intermediate spectral region, for which coherence may be low. The frequency of this band of low coherence is latitude-dependent, being governed by the Rossby wave cut-off frequency. It appears to represent steric variability which cannot propagate in a wavelike manner.

This mode of decoupling does not arise because of island bathymetry, as the same decoupling is seen between deep ocean points and surrounding rings. It gives insights into discrepancies between satellite altimetry and tide gauge records and the time-scales over which they may be expected to agree.

P01S2.04

P01S2 - General topics on ocean physics and chemistry

Oral

Sub mesoscale eddies ('Peddies') on the south-west Australian continental shelf

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Eddies are a common feature in the oceans with diameters ranging from millimeters, to hundreds of kilometers. The smallest scale eddies, due to turbulence, may last for a few seconds, whilst the larger features may persist for several months. Those eddies which are between 50 and 500 km in diameter, and persist for periods of days to months are commonly referred to in oceanography as mesoscale eddies and are a common feature of the Leeuwin Current System. Smaller scale eddies with diameters less than ~40km are defined as sub-mesoscale eddies and persists for periods of 1-3 days and are now believed to be important features for nutrient cycling in the upper ocean. Along the south-west continental shelf, data from the WERA HF Radar system, indicate the presence of these eddy structures which are defined as peddies ('petite' eddies). In many cases satellite imagery and field measurements have shown these features to have eddy centres which had different water properties (temperature, chlorophyll) to those of the adjacent ocean. In this presentation we provide examples of selected peddies including those which were sampled during a ship voyage and with an autonomous ocean glider. Majority of the peddies occur on the shear zone between the southward Leeuwin current and the northward flowing Capes Current.

P01S2.05

P01S2 - General topics on ocean physics and chemistry

Oral

Impacts of the Wyrtki Jets on the western Arabian Sea upwelling region

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The sea surface temperature (SST) in the western Arabian Sea upwelling region is known to influence amount of precipitation associated with the Indian summer monsoon. Thus, understanding what determines the SST in this region is an important issue. Using outputs from an ocean general circulation model, we examine how a reflection of semiannual downwelling Kelvin waves, which are forced by westerly winds during monsoon breaks and accompanied by the Yoshida-Wyrtki Jet, may influence this region. It is shown that the SST in the western Arabian Sea becomes colder especially in boreal fall when a damping is introduced in the eastern equatorial Indian Ocean. Based on mixed layer heat balance calculation, we show that this SST difference is mainly due to a difference in horizontal advection.

P01S2.06

P01S2 - General topics on ocean physics and chemistry

Oral

On the hypothesis of regional scale water circulation in stable ocean crust

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Experimental evidences on occurrence of hydrothermal circulation in ocean crust is limited those occurring in the rift valley and along flanks of mid-ocean ridges. The hypothesis that deep circulation of ocean water may also occur on regional scales away from the ridge crust has been discussed in the recent literature. Observations of heat flow values lower than those predicted by the widely accepted thermal models of oceanic lithosphere (Half-space cooling and Plate models) are often cited as supporting evidences for this hypothesis. Nevertheless, such models assume that the integration limit in the solution of the heat diffusion equation for the bottom boundary can be taken to infinity, implying that the growth in the thickness of lithosphere with time elapsed is unlimited. In the presence of changes in mechanisms that control thermal interaction processes at the lithosphere – asthenosphere boundary, the assumption of unlimited growth leads to unreasonable physical conditions. We point out that such difficulties can be overcome if we introduce the assumption that the formation of lithosphere is limited to the magma-rich layer in the top part of the asthenosphere. Under this condition, the geometry for development of the lithosphere is better described as finite half-space, and not semi-infinite half-space. The new model is compatible with the current knowledge of the spatial domains of the solid lithosphere and the magma rich layers. Results of numerical simulations reveal that theoretical values derived from this model provide vastly improved fits to observational data for heat flow and bathymetry for the entire age range of the oceanic lithosphere. More importantly, the improvements in model fits have been achieved without the need to invoke the ad-hoc hypothesis of hydrothermal circulation in the stable ocean basins.

P01S3.01

P01S3 - General topics on ocean physics and chemistry

Oral

Water masses and tracers as tools to monitor climate change

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Water mass analysis can become a means of monitoring the ocean's heat storage and verifying model predictions of climate change if it is developed from a descriptive into an objective quantitative tool. Attempts to achieve this, which include the use of nutrients and tracers as parameters, are described and their current limitations discussed.

The large discrepancy in data density and data accumulation between physical and chemical parameters puts methods that include chemical parameters at a space and time disadvantage against classical temperature-salinity diagram techniques.

This presentation reviews the development of water mass analysis methods from earliest applications to the introduction of mathematical techniques based on point-wise analysis of multiple-parameter data sets. It demonstrates their exposure to meso-scale processes and presents results from recent work that minimize this exposure.

The water mass signature of climate change depends on the water mass formation process. Water masses formed through convection are characterized by a distinct set of parameter values that changes in response to changes in the formation process. Water masses formed by subduction are characterized by parameter relationships. Climate change can affect their properties in two ways. The concept of water types and water type density is used to differentiate between the two cases.

To date studies to evaluate long-term changes of water mass properties are still based on elementary temperature-salinity diagram techniques. More advanced methods are limited in their ability to identify long-term trends by the paucity of chemical data over long time spans. Great advances have been made to monitor the physical properties of the ocean (Argo floats, gliders etc.). The challenge remains to increase the collection of chemical data to a somewhat comparable level so that the potential of modern water mass analysis for monitoring the ocean can be fully exploited.

P01S3.02

P01S3 - General topics on ocean physics and chemistry

Oral

GOCE user toolbox and tutorial

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The GOCE User Toolbox GUT is a compilation of tools for the utilisation and analysis of GOCE Level 2 products. GUT support applications in Geodesy, Oceanography and Solid Earth Physics. The GUT Tutorial provides information and guidance in how to use the toolbox for a variety of applications. GUT consists of a series of advanced computer routines that carry out the required computations. It may be used on Windows PCs, UNIX/Linux Workstations, and Mac. The toolbox is supported by The GUT Algorithm Description and User Guide and The GUT Install Guide. A set of a-priori data and models are made available as well.

Recently, the second version of the GOCE User Toolbox (GUT) was developed to enhance the exploitation of GOCE level 2 data with ERS�]ENVISAT altimetry. The developments of GUT focused on the following issues: Data Extraction, Generation, Filtering, and Data Save and Restore Without any doubt the development of the GOCE user toolbox have played a major role in paving the way to successful use of the GOCE data for oceanography. The results of the preliminary analysis carried out in this phase of the GUTS project have already demonstrated a significant advance in the ability to determine the ocean's general circulation. The improved gravity models provided by the GOCE mission have enhanced the resolution and sharpened the boundaries of those features compared with earlier satellite only solutions. Calculation of the geostrophic surface currents from the MDT reveals improvements for all of the ocean�fs major current systems.

P01S3.03

P01S3 - General topics on ocean physics and chemistry

Oral

Recovering finer scale structures of the global mean ocean circulation using GOCE gravity models

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The Gravity and steady state Ocean Circulation Explorer (GOCE) satellite mission measures Earth's gravity field with an unprecedented accuracy at short spatial scales. Preliminary results have already demonstrated a significant advance in our ability to determine the ocean's general circulation. The improved gravity model provided by the GOCE mission has enhanced the resolution and sharpened the boundaries of those features compared with earlier satellite only solutions. Calculation of the geostrophic surface currents from the MDT reveals improvements for all of the ocean's major current systems. Furthermore, the finer scale features, such as eddies, meanders and branches of the current system are visible.

In this study, more recent gravity models from GOCE are combined with the DTU10MSS mean sea surface to construct a global mean dynamic topography (MDT) model. Both satellite only models such as the GOCE release 3 models and the combination models such as the Eigen-6c, have been applied. The model differences are described in the spectral domain in order to enhance the filtering to optimize the reduction of the remaining geoid signals and the recovery of the MDT and the associated geostrophic circulation. The results demonstrate that fine scale structures in the ocean circulation with speeds down to 5 cm/s may be recovered using gravity field models based on GOCE.

P01S3.04

P01S3 - General topics on ocean physics and chemistry

Oral

The vertical structure of time-mean estuarine circulation in a shallow, rotating, semi-enclosed coastal bay

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A reduced physics Ekman boundary layer solution is developed to infer the ver- tical structure of time-mean circulation in a shallow tidal environment when the horizontal density and surface slope gradients are misaligned. This gen- eralisation of the classic Heaps (1972) model shows that the time-mean depth weighted flow, or the residual circulation, is usefully constrained by knowledge of the surface velocity, instead of freshwater flux, and the horizontal density gradient. The generalised model is applied to Liverpool Bay. In regions where the Ekman depth scale is less than half the mean fluid depth the residual circulation is well modelled by a water column of uniform density, constant eddy viscosity and linear bottom drag. Lateral variability in long-term mooring observations of depth varying residual flow are attributed to the misalignment of sea surface slope and haline controlled density gradients.

A method to infer 3D time-average residual currents in regions of misaligned freshwater density and sea surface slope gradients is presented. The method blends CTD survey data with HF radar surface currents and simulation esti- mates of viscosity and friction. It is validated against ADCP data in Liverpool Bay. It is speculated that this method could be applied more generally, to correct model biases, as part of a coastal monitoring system.

P01S3.05

P01S3 - General topics on ocean physics and chemistry

Oral

Striated patterns in the World Ocean circulation

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This report provides update on the ongoing research of the structure and dynamics of new quasi-zonal jet-like features (striations), recently found in satellite and in situ observations of the ocean circulation and in solutions of high-resolution numerical models. Two main types of the striations include quasi-stationary features, resembling locally-induced beta-plumes, and propagating features, seen on snapshots as alignment of eddies. Our study indicates that striations are not a result of self-organization of the geostrophic turbulence. Instead, formation of new eddies and their organization are encouraged by underlying physics, not fully understood in previous investigations. Implications of striations for ocean mixing and for interaction between different scales are also discussed.

P01S4.01

P01S4 - General topics on ocean physics and chemistry

Oral

Assessing impact of the 18.6-year period nodal tidal cycle on PDO using a 4D-VAR data assimilation system

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The 18.6-year period nodal tidal cycle has been hypothesized as a candidate for bidecadal climate and ocean variability. A few previous studies, using proxy data reconstructed from tree-rings and state-of-the-art coupled climate model, have suggested that the nodal cycle influences on Pacific Decadal Oscillation (PDO), which reflects large-scale sea surface temperature anomaly (SSTa) in the North Pacific, and have various impacts on climate, fishery production and so on. However, the mechanism linking the nodal cycle and climate variability is still controversial. We conducted a numerical experiment by an ocean general circulation model (OGCM), based on a hindcast experiment provided by a 4-dimensional variational (4D-VAR) data assimilation system to estimate dynamical state of the global ocean from 1957 to 2009. Our experiment is different from the hindcast experiment only in that it takes into account the 18.6-year variation in localized strong tidal mixing. Comparison of two experiments revealed that SSTa induced by the 18.6-year variations propagates eastward from the east coast of Japan to the eastern Pacific in about 10 years, as shown in a previous study using an OGCM forced by climatological atmospheric fluxes. It was shown that this SSTa intensifies bidecadal variation in SSTa in the eastern Pacific in the hindcast, which is roughly corresponding to one of the centers of action for SSTa related to PDO. This suggests that bidecadal SSTa in the eastern Pacific may be induced by the 18.6-year period nodal tidal cycle through an ocean bridge, and intensified through an air-sea interaction.

P01S4.02

P01S4 - General topics on ocean physics and chemistry

Oral

The budgets of heat, salinity and buoyancy in NEMO

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The near steady state heat, salinity and buoyancy budgets under surfaces of constant depth are examined in the Nucleus for European Modelling of the Ocean (NEMO) model. It is seen that the heat fluxes in NEMO are difficult to reconcile with the idea of a deep ocean in advection-diffusion balance. Some reasons for this are that the resolved heat advection is downward above 2000 m, and that geothermal heating is, in fact, a major heat source in the deeper parts of the domain. The buoyancy budget is dominated by a sink term, which is due to the nonlinear equation of state. A common example of what goes in to this sink term is the process known as cabbeling, which is responsible for forming a water mass that is denser than the original constituents in a mixture of two water masses with equal densities but different salinities and temperatures. This buoyancy sink in the interior ocean is compensated for by having a net buoyancy flux in to the ocean at the sea surface. The net buoyancy gain at the surface happens because the ocean gains heat in warm areas and loses it in cold areas.

Isoneutral diffusion is found to give very large contributions to the budgets of salinity and heat, and the fluxes from isoneutral diffusion are in general upward. The large and upward heat and salinity fluxes from isoneutral diffusion are a consequence of the alignment of iso-surfaces of potential temperature and salinity with neutral surfaces in the Southern Ocean. The global budgets of heat and salinity between 200-2000 m depth are, in fact, dominated by the isoneutral diffusive heat and salinity fluxes in the Southern Ocean. The heat budget for the upper 100 m of the ocean is seen to be dominated by penetrative shortwave radiation, which is so influential that we would have a mixed layer of considerable thickness even in the absence of other sources of turbulent mixing. Penetrative shortwave radiation is therefore a considerable source of potential energy.

P01S4.03

P01S4 - General topics on ocean physics and chemistry

Oral

Effect on heat penetration of downward net heat flux below shallow seasonal thermocline in summer season

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Observational data of Argo profiles and J-OFURO2 were used to investigate the effects of seasonal changes in ocean heat content (OHC) and surface net heat flux (Qnet) on the thermal environment of the global upper ocean, particularly on variations in sea surface temperature (SST). Maxima of subsurface temperatures lagged behind SST maxima during the spring and fall because of the gradual penetration of the thermal effects of Qnet to waters below the shallow seasonal thermocline. Analysis in terms of the heat penetration depth (HPD), defined as the maximum depth influenced by spring-summer Qnet, allowed the seasonal heat budget balance in the upper ocean to be characterized as a simple one-dimensional vertical process in almost area because seasonal changes in OHC between the sea surface and the HPD agreed rather well with Qnet. If the heat gained from Qnet had accumulated only above the shallow mixed layer depth (MLD) during the spring and summer, the SST would have become unrealistically high, the rate of increase being as much as several times the observed rate. The hypothetical analysis suggests that the observed SST reflects mitigation of surface heating, part of Qnet being effectively discharged through the seasonal thermocline into the subsurface ocean. Indeed, the average areal integral of Qnet during May-August in the North Pacific was about 1.06×10^{16} W. Whereas the corresponding integral of d(OHCm)/dt above the shallow MLD was about 0.27×10^{16} W, and that between the MLD and the HPD was about 0.64×10^{16} W. This rough estimation suggests that over half of the Qnet warmed the water below the shallow MLD in the open ocean of the North Pacific, showing that the effect of vertical heat penetration below the shallow MLD is quite important to the thermal environment in the surface and subsurface layers. A rough estimation of vertical eddy diffusivity indicates that heat penetration below the seasonal thermocline is associated with breaking inertial gravity waves.

P01S4.04

P01S4 - General topics on ocean physics and chemistry

Oral

The carbon system under oceanic anoxia

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Periods of wide-spread oceanic anoxia have occurred a number of times during earths history. Proposedly, this has been caused by increased input of nutrients to the surface waters resulting in an enhanced organic production and an associated oxygen demand in the deep water. During sulfate reduction, alkalinity is produced. The main part of this alkalinity increase is short-lived as re-oxidation of hydrogen sulfide consumes an equal amount of alkalinity. Despite this reoxidation, the production of hydrogen sulfide results in a quasi steady state with enhanced deep water alkalinity. A fraction of the produced hydrogen sulfide reacts with iron minerals to form pyrite resulting in a further alkalinity increase. Here, we use a simple three box ocean-atmosphere model including cycles of carbon, oxygen and phosphate to scrutinise the potential effect on the carbon system due to an oceanic anoxic event. The model include a representation of a dynamic lysocline to capture changes in the carbonate deposition due to changes in the concentration of alkalinity.

P01S4.05

P01S4 - General topics on ocean physics and chemistry

Oral

On the description of the oceanic carbon system, or a plea for the use of source related variables

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The oceanic carbon system is commonly described in terms of total carbon, DIC, and alkalinity, Alk. Here we suggest the use of alternative source adapted state variables which represent respectively the supply to the system of carbon dioxide and dissolved carbonate. These variables tell us how much carbon dioxide or carbonate we actually have in the water despite the fact that the major part of the carbon resides in bicarbonate ions. We claim that using these «source-related variables» offer a number advantages, e.g. in the interpretation of observations as well as modelling results. Furthermore the usual way to define alkalinity is confusing and unnecessarily complicated being related to a measuring procedure rather than to the actual supply of material to the system. Here we propose as part of our analyses an alternative straightforward way to define alkalinity.

P01S4.06

P01S4 - General topics on ocean physics and chemistry

Oral

Influence of inland and marine waters mixing on pollution concentrations in a river mouth

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Important is to know concentrations of pollutants in a river mouth especially when some city is located in the mouth area. The river and sea waters often are mixed in the estuary. Fresh, riverine water flows seaward over more saline, marine water. Sometimes, the flow is bi-directional at a given river cross-section, as near-bottom, dense saline water flows against the direction of the surface, less-dense, fresh water flow. Sea water can intrude into the river channel over several kilometers and mix with river water. The mixing can decrease the concentration of pollution originating from the river basin. As a result, pollution load into the sea may be underestimated. It is necessary not only to take samples with high density in the river cross-section but also to know water fluxes between the river and sea sides in order to estimate the load with higher precision. One aim of the paper is to show that the influence of estuarine mixing is really significant. Detailed measurements of water flow and concentrations accomplished in the mouth of Pärnu River (where the sea water can intrude over 10 kilometers along the river channel) have been used. Other aim is to compare the measurements with theoretical calculations. Internal hydraulic theory is used to predict density-driven, bi-directional flow in the river mouth. Different models have been also used to predict mixing process of sea and river waters. It was found that the concentrations and flow predicted on the basis of theory coincide quite well with measurements. It is demonstrated that it is important to include in the theoretical analysis the internal head associated with the buoyancy fluxes. The problem can be discovered in other rivers that flow into the Baltic Sea.

P02PS.01

P02PS - Baltic and other regional seas

Poster

Pole tides in the Baltic Sea

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Pole tides, which are driven by the Chandler wobbles, have a period of about 14 months and typical amplitudes in the World Ocean of ~ 0.5 cm. However, in the Baltic Sea they are anomalously high. To examine this effect we used long hourly sea level records from 36 tide gauges and monthly records from 59 stations. The lengths of the series was up to 123 years for hourly and 210 years for monthly series. High-resolution spectra revealed a bunch of neighboring peaks with periods from 410 to 455 days. The results of spectral analysis were applied to estimate the integral amplitudes of pole tides from all available tide gauges along the coast of the Baltic Sea. The height of the pole tide was found to gradually increase from the entrance (Danish Straits) to the northeast end of the sea. The largest amplitudes - up to 4.5 cm - were observed in heads of the Gulf of Finland and Gulf of Bothnia. Significant temporal fluctuations in amplitudes and exact periods of the pole tide was during XIX and XX centuries.

P02S1.01

P02S1 - Baltic and other regional seas

Oral

About the advantages of vertically adaptive coordinates in numerical models of stratified shelf seas

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Shelf seas such as the North Sea and the Baltic Sea are characterised by spatially and temporally varying stratification that is highly relevant for their physical dynamics and the evolution of their ecosystems. Stratification may vary from unstably stratified (e.g., due to convective surface cooling) to strong vertical stratification with density jumps of up to 10 kg/m3 per m (e.g., in overflows into the Baltic Sea). Stratification has a direct impact of vertical turbulent transports (e.g., of nutrients) and influences the entrainment rate of ambient water into dense bottom currents which in turn determine the stratification of and oxygen supply to, e.g., the central Baltic Sea. Due to limitations of computational resources and since the locations of such density jumps cannot exactly be predicted a priori, a predefined layer distribution cannot sufficiently resolve the stratification evolving during runtime.This leads to substantial numerical mixing. To solve this problem, we have developed the concept of vertically adaptive coordinates for ocean models, where refinement of vertical coordinates at locations of strong stratification (and shear) is achieved by solving a diffusion equation for the position of the coordinates (with the diffusivity being proportional to the stratification or shear frequencies). It will be shown in this presentation for a coupled and nested model system of the North Sea and the Baltic Sea how numerical mixing is substantially reduced and model results become significantly more realistic when vertically adaptive coordinates are applied. Specific focus will be on summer thermocline dynamics in the central North Sea, inflow dynamics into the western Baltic Sea and tracer spreading in the Central Baltic Sea.

P02S1.02

P02S1 - Baltic and other regional seas

Oral

How exceptional are long lasting stagnation periods in the Baltic Sea from a model perspective?

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1 SMHI, Sweden

The Baltic Sea is one of the largest brackish sea areas of the world. The sensitive state of the Baltic Sea is sustained by a fresh-water surplus by river discharge and precipitation on one hand as well as inflows of highly saline and oxygen-rich water masses from the North Sea one on the other. Major inflows which are crucial for the renewal of the deep water occur very intermittent with a mean frequency of approximately one per year. Stagnation periods (periods without major inflows) lead for instance to a reduction of oxygen concentration in the deep Baltic Sea spreading hypoxic conditions. The longest observed stagnation period occurred from 1983 to 1993 and mechanisms forcing such clustering of the absence of inflows are still under discussion.

The goal of this study is to assess the mechanisms responsible for the clustering of major events and long lasting stagnation periods. Therefore, a climate simulation of more than 800 years has been carried out with the Rossby Center Ocean model (RCO). RCO is a biogeochemical regional climate model which covers the entire Baltic Sea. It is driven with atmospheric data dynamical downscaled from a GCM mimicking natural climate variability.

The analysis focus on the role of variations in river discharge, changes in wind speed and direction, and shifts in large scale pressure patterns (NAO). Hereby, the length of the simulation will allow to identify mechanisms working on decadal to multi-decadal time scales. Finally, it will be discussed in how far the observed stagnation period can be considered to be pure natural variability or whether climate change could be a driver.

P02S1.03

P02S1 - Baltic and other regional seas

Oral

Exchange of heat and freshwater between North Sea and Baltic Sea in climate change simulations

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1 SMHI, Sweden; 2 BSH, Germany

A small ensemble of scenarios with coupled regional climate models for the North Sea and Baltic Sea is analyzed with respect to changing seasonality of near surface temperature and salinity. The consequences of warmer and fresher surface water for the exchange between North Sea and Baltic Sea are investigated. The analyzed RCMs and RCP scenarios agree on a reduced amplitude of the seasonal cycle of near surface temperature. In the model simulations this is due to warmer winter temperatures. Their impact on the modeled hydrography and transports in Skagerrak and North Sea are discussed.

P02S1.04

P02S1 - Baltic and other regional seas

Oral

Modeling water exchange, nutrient loads and ecosystem in a brackish water bay

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Development of 1-D ecological model is an important step towards 3-D modeling, because the parameter estimation is possible with much shorter computing time needed for the system integration. Here, the modified Fasham type model describing the dynamics of the inorganic nutrients, plankton groups and detritus form of the nutrients is represented in 2-layer model in a semi-enclosed brackish water bay. Water mixing between stratified water layers caused by salinity gradient, inputs from the coast and exchange with the open sea regulate the nutrient balances. The nutrients taken into account are dissolved inorganic forms of nitrogen (nitrate and ammonium), phosphate and silicate. The phytoplankton is represented as diatoms and flagellates. Diatom growth is limited by inorganic forms of nitrogen, phosphorus and silicon. Flagellates consume inorganic forms of nitrogen and phosphorus but are not limited by silicon. Both are grazed by zooplankton or lost because of mortality consequently forming detritus, which is lost to the bottom layer by sinking and mixing, whereas inorganic nutrients and phytoplankton go down to the bottom layer only by mixing. The area of Pohjanpitäjänlahti Bay chosen for the model validation was considered to be appropriate for many reasons. First, these coastal areas have long historical data both on algal blooms as well as on nutrients and hydrography. Moreover, the data sets also include information on rarely measured parameters such as primary production, bacterial activity and sedimentation, which are important in describing marine ecosystems. Water exchange information with the open sea is obtained from a mareograph and inflows and nutrient loadings from the rivers and land area from the «Watershed Simulation and Forecasting System» and its water quality component running operationally in the Finnish Environment Institute.

P02S1.05

P02S1 - Baltic and other regional seas

Oral

Operational oceanography at SMHI – data for decision making and safety

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Several ocean forecasting models, covering the Baltic and North sea, are running in operational service 24 hours a day, every day. The data is being used by costumers such as the Oceanographic Warning Service, Swedish Maritime Administration, the Swedish armed forces, search and rescue operations, the maritime industry and many more. If sever conditions are forecasted warnings may be issued to the general public and the marine traffic. The warnings are for ice accretion and high or low waterlevels. During the winter season the ice service are producing daily ice charts to aid navigation and ice breakers. Some of the data from the oceanographic models is available right now and more will be released due to the INSPIRE directive. Furthermore SMHI can provide tailor made solutions for every need.

P02S2.01

P02S2 - Baltic and other regional seas

Oral

Regional marine climate scenarios for the Mediterranean Sea

Gomis, D. 1; Alvarez-Fanjul, E. 2; Jorda, G. 3; Marcos, M. 1; Aznar, R. 2; Padorno, E. 2; Rodriguez-Camino, E. 4; Sanchez-Perrino, J.C. 4; Rodriguez, J.M. 4; Martinez-Asensio, A. 1; Llasses, J. 1; Calafat, F.M. 5; Perez, S. 2; Perez, B. 2; Somot, S. 6; Sevault, F. 6; Adloff, F. 6

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A several-year study on 21st century marine climate projections for the Spanish coasts has just been completed. Funded by the Spanish Government, AEMET (the Spanish Met. Office) and Puertos del Estado (Spanish holding of harbours), the study intends to understand the physical processes underlying the projected changes and to provide coastal managers, harbour authorities and decission makers with useful information to undertake protection strategies. The work includes hydrography, currents, sea level and wave projections covering the Mediterranean Sea and a sector of the NE Atlantic Ocean (only the Mediterranean Sea will be shown here).

All hydrographic projections show a warmer Mediterranean Sea by the end of the 21st century due to the projected decrease in the surface heat losses to the atmosphere. SST would be about 3 degrees C higher in 2100, while the 3D mean temperature would increase by 1.0-1.5 degrees C. We have also studied the derived increase in the heat wave frequency and intensity, showing the potential impact on coastal ecosystems (e.g. on Posidonia Oceanica meadows).

Salinity projections show more disparity. The local forcing points towards a more salty basin as a consequence of the projected increase in the evaporation and the decrease of regional precipitation. However, a freshening of the incoming Atlantic waters could compensate the local forcing; the problem is that models show a disparity of results for the salinity of the nearby Atlantic.

Sea level will be discussed very briefly, since the results are presented in another, dedicated presentation. The projections indicate that Mediterranean mean sea level, excluding salinity effects, would be about 50-60 cm higher by the end of the 21st century. Changes in extreme sea levels would be small, apart from those derived from the increase in the mean sea level. Finally, we will show that all projections point towards a slight decrease in both, the mean wave regime and extreme wave events.

P02S2.02

P02S2 - Baltic and other regional seas

Oral

Sensitivity of the Mediterranean Sea to boundary forcings in an ensemble of 21st century climate change scenarios

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The Mediterranean climate is expected to become warmer and drier during the 21st century (IPCC 2007). This typical response and the associated changes may vary, depending on the chosen scenario. However, the regional ocean model behaviour could also be sensitive to the choice of the boundary conditions (Atlantic hydrography, runoffs and air-sea fluxes).

To assess and quantify the sensitivity of the Mediterranean Sea to boundary forcings, a set of numerical experiments was carried out with the regional ocean model NEMOMED8 set up for the Mediterranean Sea. The model is forced by air-sea fluxes derived from the regional climate model ARPEGE-Climate on a 50-km stretched grid. Freshwater inputs from the rivers and the Black Sea are prescribed. At the Atlantic boundary, temperature and salinity are relaxed towards values derived from a global model.

Historical simulations representing the climate for the period 1961-2000 were run to obtain a reference state. From this baseline, various sensitivity experiments were performed for the period 2001-2100, following IPCC-A2 scenario. In these simulations, the three main boundary forcings (river runoff, near-Atlantic water hydrography and air-sea fluxes) were alternatively changed to better identify the role of each forcing in the way the ocean responds to climate change.

Our numerical experiments suggest that the choice of the boundary forcings substantially impacts the response of the Mediterranean Sea to an IPCC-A2 scenario. The range of mean SSS anomalies (2070-2099 vs 1961-1990) spreads between 0.6 and 0.9 psu depending on the boundary conditions applied. The near-Atlantic surface water evolution, which is very uncertain in global ocean scenario simulations, has the strongest influence on the evolution of the Mediterranean water masses. We analyse the changes in the Mediterranean thermohaline circulation (MTHC). Finally, we address the question of the influence of the initial MTHC state on the ocean climate projections.

P02S2.03

P02S2 - Baltic and other regional seas

Oral

Circulation modeling of a Tyrrhenian coastal area, with validation through current-meter measurements

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Results of a high-resolution ocean circulation model of a southern Tyrrhenian coastal area are presented. The sigma-coordinate Princeton Ocean Model (POM) is implemented with a 1/144°-resolution in a domain that includes highly-urbanized coastal areas, such as the Gulf of Naples and the nearby gulfs of Gaeta and Salerno, that are particularly relevant from an oceanographic, ecological and social viewpoint. The model takes initial and boundary conditions from a 1/48°-resolution POM model of the whole Tyrrhenian Sea. The main forcing is provided by ECMWF wind data, but an alternative wind field obtained from the Italian Space Agency COSMO-SkyMed X-band Synthetic Aperture Radar data is also tested. Several simulations referring to different seasons, and episodes of Kelvin wave propagation are presented and compared with current-meter measurements, thus obtaining a significant validation of the modeling approach.

P02S2.04

P02S2 - Baltic and other regional seas

Oral

Observing bottom density current by a profiling float on the Adriatic shelf

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Pressure, temperature and salinity data collected during the winter of 2012 by an Argo profiling float over the Adriatic shelf have been used to document dense water formation (DWF) and subsequent bottom density current (BDC) normally occurring along the shelf slope. Both DWF and BDC were exceptionally strong, due to severity of the forcing, resulting in record-breaking densities observed during and after the event. The unprecedented dense water generation was preconditioned by a dry and warm year which resulted in a significant reduction of coastal freshwaters, superimposed on a long-term basin-wide salinity increase. The final event that triggered the DWF was an extended period of cold weather with strong and severe winds. Record-breaking potential density anomalies (above 30 kg/m3) were measured at several DWF sites. The profiling float was advected to the Jabuka Pit and neighboring shallow area (<275 m) after October 2010. The parking depth was set to approximately 150 m, enabling the float to mostly follow the seabed between December 2011 and July 2012. The profiler measured strong spatial-temporal changes in the BDC thickness (from a few to about 50 m) and the bottom density (between 29.46 kg/m3 and 29.88 kg/m3). These observations show that an Argo float has the capability to observe a bottom density current and suggest that it would be possible to systematically use such floats to investigate these processes on coastal shelves.

P02S2.05

P02S2 - Baltic and other regional seas

Oral

Regional patterns of sea level variability: Case of the Japan/East Sea

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Variability of sea level in the Japan/East Sea (JES), the Pacific-Asian marginal sea, is revisited using AVISO altimetry reference 1/4-degree-gridded weekly sea level anomalies spanning the almost 20-year record. The hydrography in the JES is substantially controlled by warm water inflow from the south through the Korea/Tsushima Strait (KTS). Strong transport variations in the KTS occurring on subinertial to decadal time scales affect sea level in the JES. Interacting (non-orthogonal) modes are revealed on seasonal time scale, representing synchronous oscillations and meridional sea level gradient in the JES, respectively. The highest sea level and sharpest gradient occur in October and the opposite extremes occur in March, while transport in the KTS is largest in October and smallest in January. The seasonal synchronous oscillations are mostly induced by steric sea level variations but they lag by one month behind the steric signal, implying contribution from other processes, such as changes in water volume in the JES due to inflow – outflow imbalance. Changing sea level gradient corresponds to variation of the mean currents, strengthening in the warm season and weakening in the cold season, unlike the wind-driven oceanic gyres. Intraseasonal and interannual synchronous oscillations also occur, the latter on the quasi-biennial (QB) and longer time scales, tending to follow decadal transport variations in the KTS but secular linear trend is not statistically significant. There are no intra- or interannual gradient modes, implying stability of sea level gradient with respect to short-lived intraseasonal and weak interannual oscillations which can be explained by vertical stratification. In contrast, the east – west sea level seesaw develops on semiannual, annual, QB, and 5-year time scales. It corresponds to the path variations of the Tsushima Warm Current in the southern JES and mesoscale variability in the northern JES.

P02S2.06

P02S2 - Baltic and other regional seas

Oral

Variability of eddy kinetic energy in the Japan/East Sea

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The Japan/East Sea (JES) is located in both subtropical and subarctic regions off the East Asia. The surface circulation, including intense mesoscale dynamic, is strongly affected by large supply of subtropical water from the Korea Strait. Mesoscale energetics in the JES is studied using eddy kinetic energy (EKE) computed from weekly altimetric sea level anomalies available from October 1992 onwards. Interacting (non-orthogonal) EKE modes covering 60% of the total variance capture seasonal variation of mesoscale energetics in the JES. It intensifies in summer and fall and weakens in winter, with the extremes in October to November and in March to April, respectively. The same seasonal variation is characteristic of the mean currents strength controlled by meridional density (sea level) gradient. Although mean EKE in the subarctic area is an order of magnitude smaller than in the subtropical area, spatial maxima of the leading mode are linked to zones of the mean currents and bathymetric features in the entire JES. This is consistent with the acknowledged mechanisms of EKE generation, such as dynamic instability and flow interaction with bathymetry. Baroclinic instability is considered as EKE source but the same seasonal variation of EKE and mean currents, even with their effect on EKE removed, implies a strong impact of shear instability. Another mode accounts for EKE variability in the subarctic area off the Russian coast, related to varying mesoscale structures detected from thermal contrasts on AVHRR satellite images. Seasonal variation is similar but less regular than for the previous mode and the annual time scale is strongest before 1998, while quasi-biennial scale is strongest after 2000. The change is coincident with the 1999 climate regime shift in North Pacific. As the spatial maxima are not linked to hydrographic or bathymetric features, wind forcing of EKE off the Russian coast is suggested.

P02S3.01

P02S3 - Baltic and other regional seas

Oral

Modelling the interaction between eutrophication, acidification and climate change in coastal seas

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The presentation will discuss recent modeling efforts using coupled land-sea models for the Baltic Sea and its drainage basin. In coastal seas the CO2 system under oxic and anoxic conditions needs to be considered and coupled to the physical and biogeochemical dynamics. The connection between eutrophication, acidification and climate change is through primary production and mineralization of both organic matters from the sea and from land. It is most likely that the carbon dioxide in the atmosphere will increase in the coming decades and that climate warming will continue with implication on several aspects that are related to the heat balance. With increasing temperatures the water balance will also be influenced through changes in precipitation and evaporation. For the Baltic Sea drainage basin we expect more precipitation in north and less in south, which may have large effects on the salinity as well as the biogeochemical cycles. Changes in nutrient cycles are much due to the development of agriculture practice and food consumption and may increase the nutrient load in the future. Increased temperatures and CO2 concentrations will also change the carbon cycle and increased transports of organic carbon from land into the sea. Future expected anthropogenic climate changes in heat and water cycles, nutrient and carbon cycles indicate increased threats to the marine ecosystems implying a strong need for management efforts both related to regional nutrient emission reductions and global CO2 emission reductions.

P02S3.02

P02S3 - Baltic and other regional seas

Oral

The Baltic Proper: Sink or source for atmospheric CO2?

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Increasing attention has been paid during the past years to the importance of coastal and semi-enclosed seas for the global carbon cycle and for the potential to store anthropogenic CO2. CO2 air/sea flux balances for the Baltic Sea are complicated by the heterogeneous physical and biogeochemical structure. Several studies have been performed in the past years which yielded conflicting results with regard to the role of the Baltic Sea and its sub-regions as a sink or source for atmospheric CO2. To estimate the CO2 fluxes in the Baltic Proper, we used fully automated surface water CO2 partial pressure (pCO2) measurements on a cargo ship that commutes regularly at 2 – 3 day intervals between the Mecklenburg Bight and the Gulf of Finland. The pCO2 data showed a distinct seasonality that was mainly controlled by biological production and vertical mixing. On average the pCO2 was below the atmospheric level from April to October and higher then the atmospheric pCO2 for the remaining months. However, the seasonal amplitude of the pCO2 showed a distinct increasing gradient from the southwest to the northeast of the Baltic Proper. The atmospheric CO2 concentrations were also measured and used to determine the CO2 partial pressure difference between the surface water and the atmosphere which together with the gas exchange transfer velocity yielded the CO2 flux. The net annual CO2 flux varied between different sub-regions of the Baltic Proper and showed also a pronounced interannual variability that was mainly caused by differences in the biological production and in the intensity of the winter deep mixing. The results clearly indicated that the Baltic Proper is a net sink for atmospheric CO2 with uptake rates ranging between 0.5 and 1.0 mol m-2 yr-1.

P02S3.03

P02S3 - Baltic and other regional seas

Oral

Tidal observations in the Baltic Sea

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The longterm hourly data from 36 tide gauges were used to examine tidal oscillations in the Baltic Sea. Despite their relatively small amplitudes, diurnal and semidiurnal tidal peaks were found to be the most prominent feature of the observed sea level spectra. Moreover, evident high-frequency radiational tidal peaks, multiple of solar day (3, 4, 5, 6 and 8 cpd), were identified at some stations (e.g. Narva, Daugava and Wladislawowo); the respective oscillations are supposed to be caused by breeze winds. High-resolution spectra, constructed for the longest records (123 years at Stockholm, Sweden; 31 years at Gorny Institute, Russia; and 18 years at Tallinn), revealed the fine structure of tides at these stations. Harmonic analysis of tides was provided for all 36 stations including 15 stations located in the Gulf of Finland; the results were averaged over the entire observational period. The calculated mean amplitudes and phases of major tidal constituents were compared with those resulted from known numerical tidal models. The anomalous amplitudes of diurnal tidal constituents in the Gulf of Finland are found to be formed under influence of strong resonant effects.

P02S3.04

P02S3 - Baltic and other regional seas

Oral

Comparing reconstructed past variations and future projections of the Baltic Sea ecosystem - results from multi-model ensemble simulations

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Multi-model ensemble simulations for the marine biogeochemistry and food web of the Baltic Sea were performed for the period 1850–2098, and projected changes in the future climate were compared with the past climate environment. For the past period 1850–2006, atmospheric, hydrological and nutrient forcings were reconstructed, based on historical measurements. For the future period 1961-2098, scenario simulations were driven by regionalized global general circulation model (GCM) data and forced by various future greenhouse gas emission and air- and riverborne nutrient load scenarios (ranging from a pessimistic 'business-as-usual' to the most optimistic case). To estimate uncertainties, different models for the various parts of the Earth system were applied. Assuming the IPCC greenhouse gas emission scenarios A1B or A2, we found that water temperatures at the end of this century may be higher and salinities and oxygen concentrations may be lower than ever measured since 1850. There is also a tendency of increased eutrophication in the future, depending on the nutrient load scenario. Although cod biomass is mainly controlled by fishing mortality, climate change together with eutrophication may result in a biomass decline during the latter part of this century, even when combined with lower fishing pressure. Despite considerable shortcomings of state-of-the-art models, this study suggests that the future Baltic Sea ecosystem may unprecedentedly change compared to the past 150 yr. As stakeholders today pay only little attention to adaptation and mitigation strategies, more information is needed to raise public awareness of the possible impacts of climate change on marine ecosystems.

P02S3.05

P02S3 - Baltic and other regional seas

Oral

Large-scale deepwater oxygenation by geoengineering – a method to revive dead bottoms and decrease the eutrophication of the Baltic Sea

NULL

The phosphorus content of the Baltic Sea increases steadily although the external loading has been halved since the 1980s, which shows that internal loading is the dominating source. It is coupled to anoxic bottoms that leak phosphorus. Experiments in coastal basins show that phosphorus leakage stops when the sediment surface becomes oxidized, a finding that may be applied to the Baltic proper. In a pilot study we have estimated that the periodically anoxic Bornholm Basin can be kept oxygenated by pumping about 1000 m3s-1of oxygen saturated, relatively fresh and cold water from about 30 m depth into the deepwater. This will increase the rate of density reduction in the basin which allows more of the inflowing new deepwater to penetrate deeper into the basin. The oxygenation of the basin would allow benthic animals to colonize the now dead bottoms and it would increase the volume of water with properties needed for successful cod spawning. It would also stop the phosphorus leakage from the deepest bottoms. We have estimated the cost of permanent oxygenation using 10 wind-driven pumps. It is suggested that this system is installed and evaluated before a system is build for the entire Baltic proper.

P03PS.01

P03PS - Ocean Mixing

Poster

Shear driven enhancement of turbulent dissipation at the base of the surface mixed layer

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The oceanic surface mixed layer is a critical interface in the Earth System, linking the atmosphere and the ocean. The processes which drive fluxes across the base of the surface mixed layer will therefore impact on the ocean-atmosphere exchange of heat and trace gases. Here we present water column structure and microstructure data collected at the Porcupine Abyssal Plain (PAP) in September 2012 in the aftermath of a storm. The data reveals episodic enhancement of the turbulent dissipation rate (a proxy for mixing) associated with periods of higher shear observed at the base of the surface mixed layer. An analytical model is used to demonstrate that the higher shear is a consequence of the alignment of the surface wind stress with near-inertial currents in the surface mixed layer.

P03PS.02

P03PS - Ocean Mixing

Poster

A comparison of tidal conversion parameterizations for tidal models

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The conversion of barotropic to baroclinic tidal energy in the global abyssal ocean is calculated using three different formulations. The calculations are done both ‘‘offline,’’ that is, using externally given tidal currents to estimate the energy conversion, and ‘‘online,’’ that is, by using the formulations to parameterize linear wave drag in a prognostic tidal model. All three schemes produce globally integrated offline dissipation rates beneath 500-m depth of;0.6-0.8TWfor theM2 constituent, but the spatial structures vary significantly between the parameterizations. Detailed investigations of the energy transfer in local areas confirm the global results: there are large differences between the schemes, although the horizontally integrated conversion rates are similar. The online simulations are evaluated by comparing the sea surface elevation with data from the TOPEX/Poseidon database, and the error is then significantly lower when using the parameterization provided by Nycander than with the other two parameterizations examined.

P03PS.03

P03PS - Ocean Mixing

Poster

Turbulence and diapycnal mixing above the southern Mid-Atlantic Ridge

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Mid oceanic ridges are sites of enhanced diapycnal mixing in the water column, caused by breaking of internal waves excited by interaction of tides and currents with the rough topography, and /or by hydraulically controlled flows through passages and over sills. These generation mechanisms imply that the strength and the location of mixing depends critically on the actual bathymetry of a given ridge segment.

During a cruise in early 2013, a large portion of the axis of the slow spreading southern Mid-Atlantic Ridge from 12°S to 32°S was mapped to estimate the strength of turbulent mixing over various segments with different bathymetric characteristics, using towed transects and vertical profiles of stratification and horizontal flow field, as well as microstructure measurements from an Autonomous Underwater Vehicle. Additional data along the ridge axis and ridge crest from 4°S to 10°S come from four cruises between 2004 and 2009. Turbulent diffusivities K_ρ were inferred from finescale parameterizations, and from density inversions via Thorpe scales.

First results show that average mixing rates in the lowermost 1000 m of the water column can vary over as much as two orders of magnitude, depending on the ridge morphology. High values of K_ρ in the order of 10^{-2} m^2 s^{-1} were observed over particularly rugged topography and deep rift valleys typical for slow spreading ridges, while lower values of the order of 10^{-4} m^2 s^{-1} were found over regions with smooth seafloor caused by young lava flows, and over segments with shallow axial valleys more characteristic for intermediate spreading ridges.

P03PS.04

P03PS - Ocean Mixing

Poster

Spatial and temporal patterns of the ocean's turbulent mixing from argo profiles

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The global distribution of Argo floats enables us to generate diapycnal mixing estimates over larger areas than is currently possible using ship-based observational methods. This is accomplished by applying the Gregg-Henyey-Polzin finescale parameterization to the 2000 m long Argo float density profiles to produce energy dissipation rate estimates, a measure of diapycnal mixing. Here we use six years (2006-2012) of data, yielding approximately 500,000 estimates of the energy dissipation rate. Mapping these estimates on a global scale unveils spatial patterns that correlate with environmental parameters such as bottom roughness and eddy kinetic energy. To place these results in context, we then compare our dissipation rate estimates with values derived from the microstructure approach that measures mixing on the turbulent scales.

P03S1.01

P03S1 - Ocean Mixing

Oral

Mixing and the overturning ocean circulation

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The meridional overturning circulation of the ocean exerts a strong control on the climate system by regulating the ocean uptake and storage of heat and carbon. The overturning circulation coexists with a finite density stratification and hence water masses change their density as they flow from the surface to the abyss and back. At the surface, the density change--water-mass transformation in oceanographic jargon--- is achieved through heat and freshwater exchange with the atmosphere. In the deep ocean, it is primarily driven by turbulent mixing resulting from breaking internal gravity waves. In this presentation we will use estimates of the energy conversion from tidal and geostrophic motions into internal waves, combined with a turbulent mixing parameterization, to show that internal wave driven mixing in the deep ocean sustains the 20-30~Sv of water-mass transformation. One third of this transformation is attributed to lee waves generated by geostrophic motions flowing over rough topography, primarily in the Southern Ocean. Currently, lee wave driven mixing is not represented in ocean and climate models.

P03S1.02

P03S1 - Ocean Mixing

Oral

Diapycnal transport in the ocean overturning circulation

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Analysis of the energetics of the ocean overturning circulation in previous work has constrained the overall amount of mixing in the global oceans. However, the nature and distribution of various mixing processes, and the power required to support them, remain outstanding and topical questions. Here, we present recent and surprising insights from a series of laboratory and high-resolution numerical studies that consider an idealised box ocean forced by a zonal gradient in surface buoyancy. The structure of the resultant overturning circulation allows convective mixing in the surface layers to be extraordinarily efficient and globally dominant in the mechanical energy budget of the box ocean. The mean abyssal density structure is also found to be relatively insensitive to the amount of mixing at depth, but is strongly influenced by the properties of the near surface waters, which are entrained into the dense sinking plumes and carried to great depth. We discuss the implications of these findings for the global oceans.

P03S1.03

P03S1 - Ocean Mixing

Oral

Turbulent mixing driven by mean-flow shear and internal gravity waves in oceans and atmospheres

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This study starts with balances deduced by Baumert and Peters (2004, 2005) from results of stratified-shear experiments made in channels and wind tunnels by Itsweire (1984) and Rohr and Van Atta (1987), and of free-decay experiments in a resting stratified tank by Dickey and Mellor (1980). Using a modification of Canuto's (2002) ideas on turbulence and waves, these balances are merged with an (internal) gravity-wave energy balance presented for the open ocean by Gregg (1989). The latter was augmented by a linear (viscous) friction term. Gregg's wave-energy source is interpreted on its long-wave spectral end as internal tides, topography, large-scale wind, and atmospheric low-pressure actions. In addition, internal eigen waves, generated by mean-flow shear, and the aging of the wave field from a virginal (linear) into a saturated state are taken into account.

Wave packets and turbulence are treated here as **particles** (vortices, packets) by ensemble kinetics so that the loss terms in all three balances have quadratic form. Following a proposal by Peters (2008), the mixing efficiency of purely wave-generated turbulence is treated as a universal constant, as well as the turbulent Prandtl number under neutral conditions. It is shown that: (i) in the wind tunnel, eigen waves are switched off:, (ii) due to remotely generated long waves or other non-local energy sources, coexistence equilibria of turbulence and waves are stable even at Richardson numbers as high as 10^3; (iii) the three-equation system is compatible with geophysically shielded settings like certain stratified laboratory flows. The agreement with a huge body of observations surprises. Gregg's (1989) wave-model component and the a.m. universal constants taken apart, the equations contain only one additional dimensionless parameter for the eigen-wave closure, estimated as Y = 1.35.

P03S1.04

P03S1 - Ocean Mixing

Oral

Assessment of fine-scale parameterizations of turbulent dissipation rates near mixing hotspots in the deep ocean

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Shear-based and/or strain-based fine-scale parameterizations of turbulent dissipation rates in the deep ocean become erroneous near topographic features where internal wave spectra deviate from Garrett-Munk (GM). Although the Gregg-Henyey-Polzin (GHP) parameterization incorporates this spectral deviation, the applicability remains uncertain. We evaluate «α« and «β« representing the local internal wave energy in the high frequency ($2f < \omega < N$) and low frequency ($f < \omega < 2f$) bands, respectively, scaled by their corresponding values in GM using fine-scale vertical shear and strain simultaneously measured near mixing hotspots. The local internal wave spectra are biased toward higher frequencies ($\alpha/\beta >> 1$) over rough bathymetry where high frequency internal waves are generated, whereas they are biased toward lower frequencies ($\alpha/\beta << 1$) at latitudes where high vertical wavenumber, near-inertial shears are created by *parametric subharmonic instabilities*. Compared with the shear-based and/or strain-based parameterizations, GHP more accurately estimates turbulent dissipation rates by compensating for deviations from GM.

P03S1.05

P03S1 - Ocean Mixing

Oral

An empirical shear-based finescale parameterization of turbulent dissipation rate

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An extensive microstructure data set along with hydrographic and shipboard ADCP is used to develop an empirical finescale parameterization for the dissipation rate of turbulent kinetic energy and to validate existing finescale parameterizations for the open ocean. The multi-cruise data set was collected in the tropical North Atlantic between 5 and 15 N east of 30 W, supplemented by data from midlatitudes from Polzin et al. (1995).

The empirical parameterization was obtained by fitting measured turbulent dissipation rates to finescale velocity and hydrographic data. Two predictors were used: finescale shear power spectral density and internal wave slope. The parameterization is particularly appropriate for shipboard ADCP when underway, with occasional knowledge of buoyancy frequency needed, but no internal wave strain required. Exponents of the parameterization are found to be different from the Gregg-Henyey-Polzin parameterization (GHP), particularly 4/3 in shear power spectral density compared to the canonical 2. Despite the different appearance of the two parameterizations, the dissipation rates measured in the tropical Atlantic also agree well with GHP predictions.

However, the data suggests a correlation between shear variance and frequency content (shear-to-strain ratio), both of them are used as predictors in the GHP parameterization. Whether this is a spurious relationship is unclear. Nevertheless, this correlation implies that when using GHP, internal wave shear and strain profiles need to be measured simultaneously. Estimates of turbulent dissipation rates using GHP, but based on shear or strain measurements exclusively, are subject to bias.

For the study region in the tropical North Atlantic, the proposed parameterization allowed to enhance the dissipation rate data coverage by tenfold. The resulting estimated area-averaged dissipation rate agrees with the outcome of a simultaneous large-scale tracer release experiment.

P03S1.06

P03S1 - Ocean Mixing

Oral

Turbulent dissipation due to stratified tidal flow over abrupt topography

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Tidal flows oscillating over open-ocean topography generate internal tides and strong near-local mixing, as observed at Hawaii and Luzon Straits. Here we present numerical simulations that demonstrate the essential physics of the strong local turbulence is an arrested high-mode hydraulic response in the lee of the obstacle that breaks and become turbulent. We then discuss ways of parameterizing this turbulent response in terms of the stratification, the topographic shape, and the tidal forcing. The parameterization is broadly applicable to include barotropic tides, internal tides, and mixed tides. We will also explore the role of «rough» topography, and three-dimensionality.

P03S2.01

P03S2 - Ocean Mixing

Oral

Rates and mechanisms of turbulent dissipation and mixing in the Southern Ocean: Results from the DIMES experiment

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Small-scale turbulent motions in the Southern Ocean play a vital role in setting the abyssal stratification and in determining the response of climate models to anthropogenic forcing. However, few direct observations of turbulent mixing in the Antarctic Circumpolar Current (ACC) exist. Further more, observations of the sources and mechanisms underlying the intensity and distribution of turbulent kinetic energy dissipation in the ACC are scarce. Consequently in 2009, the Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES), was initiated. DIMES is a mutli-component US/UK project focused on understanding patterns and processes of mixing in two contrasting regimes (the SE Pacific and the SW Atlantic) of the ACC.

Here, we report on turbulent mixing observations collected using free-falling microstructure instruments as part of the DIMES experiment. Turbulent dissipation rates, which vary between ~10^{-10} W kg^{-1} and ~10^{-9} W kg^{-1}, are found to be strongly related to the strength of bottom current speeds and the local topographic roughness. This observation, alongside detailed analysis of internal wave field properties, supports the hypothesis that abyssal turbulent dissipation is attributed to the breaking of internal waves generated by ACC - topography interactions. However, local turbulent dissipation appears to account for only a small proportion of the energy flux predicted by linear lee wave theory, opening questions as to the fate of much of the bottom-generated internal wave energy. This study represents the largest comparison of turbulent dissipation measurements and internal wave characteristics in the Southern Ocean, to date.

We also discuss the variability and forcing mechanisms of turbulent mixing east of Drake Passage over the last 20 years, using fine-structure data collected along the repeated SR1 section.

P03S2.02

P03S2 - Ocean Mixing

Oral

Eddy-induced modulation of turbulent dissipation over rough topography: first year results from the DIMES mooring array

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Given the ubiquity of mesoscale eddies in the ocean circulation, it is important to understand how their energy is dissipated. It has been argued that the interaction of strong Antarctic Circumpolar Current jets with rough topography causes an energy transfer between geostrophic flows and internal waves, with the breaking of these waves causing locally elevated dissipation focused near the sea floor. Results are presented from a one-year mooring cluster to test this hypothesis. The heavily-instrumented array was located over a small (10 km) topographic rise in a region of high eddy kinetic energy to the east of Drake Passage, and one mooring was equipped with an ADCP at 2800 m from which internal wave shear variance and dissipation rates were estimated.

Over the 360-day deployment, there was a predominance of upward-propagating internal wave energy and a statistically significant correlation (r = 0.45) between shear variance levels and subinertial near-bottom current speeds. In addition, the periods of strong near-bottom flow coincided with an increased convergence of eddy-induced interfacial form stress in the bottom 1500 m. Predictions were also made of internal wave energy radiation using measured near-bottom current speeds and multibeam bathymetry data, and the mean value of lee wave radiation (5.3 mW m^{-2}) was sufficient to support the dissipated power calculated from the ADCP finestructure. A significant temporal correlation was also observed between radiated and dissipated power. As rough topography and strong jets are found in all sectors of the Southern Ocean, this eddy to internal wave energy transfer is likely to be an important term in closing the global ocean energy budget.

P03S2.03

P03S2 - Ocean Mixing

Oral

Mixing intensity and sources in the Southern Ocean: An observational study surrounding the Kerguelen plateau

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Understanding the dynamics that maintain the deep ocean stratification structure is of fundamental importance to understanding large-scale ocean circulation. The Southern Ocean plays a crucial role in controlling the global climate system, with the Antarctic Circumpolar Current (ACC) allowing the exchange of properties between oceans. Here we use observational mixing estimates to better define open ocean mixing processes and involved energy sources in the Southern Ocean.

Eight EM-APEX floats were deployed near the Kerguelen Plateau where we expected the interaction of the ACC and the plateau would generate turbulence. Temperature, salinity, pressure and horizontal velocity observations from the floats are analysed. The distribution and intensity of diapycnal mixing is estimated along the 6550 km of float trajectory using shear-strain fine-scale parameterization.

We show that the mixing intensity is highly spatially variable. Mixing «hot-spots» nearby topographical features are identified with diffusivities as high as 1×10^{-2} m^2s^{-1}, well above local background values (3×10^{-5} m^2s^{-1}). We explore bottom roughness, current speed and wind work as primary drivers of the observed mixing. We also identify the Subantarctic Front as a boundary between two different dynamic mixing regimes.

P03S2.04

P03S2 - Ocean Mixing

Oral

Vertical near sea floor ocean mixing in the central valley of the Mid-Atlantic Ridge

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In the open ocean, the largest vertical mixing rates are found in deep-ocean canyons of mid-oceanic ridge systems. It is currently unclear, which physical mechanisms control the intense turbulent dissipation in deep ocean canyons. Recent studies point to a potential role of hydraulic jumps, which have been observed in shallow water studies. To be able to resolve rapid horizontal transitions in mixing rates associated with hydraulic jumps, high-resolution horizontal fields of near-seafloor turbulent kinetic energy dissipation were obtained in August 2010 in the central valley of the Mid-Atlantic Ridge near 37°N, using a microstructure velocity shear sensor aboard the autonomous underwater vehicle AUV Abyss. The campaign was complemented by "classical" lowered and mooring-based density and velocity measurements. In the deep ocean above complex bathymetry AUV-based measurements are thought to be far more efficient in resolving spatial patterns of mixing than the commonly used free-falling or lowered turbulence probes. During several dives within the central valley the AUV made multiple crossings over a deep sill – characterized by unidirectional bottom-intensified flow - separating two basins below 1800 m. Here we present first results of the spatial distribution of the observed dissipation rates in connection with the surrounding flow field in a deep-ocean canyon. The velocities are largest near the sill within the channel. Here, the largest dissipation rates are aboserved. In addition, the repeated horizontal maps of dissipation rates along the narrow channel show a high degree of spatial and temporal variability – possibly caused by the tidally varying flow field.

P03S2.05

P03S2 - Ocean Mixing

Oral

Variability in the internal wave field and associated mixing in the western tropical Atlantic

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Five years of mooring observations and CTD/LADCP measurements from five cruises are used to investigate both the influence of stratification and the Deep Western Boundary Current (DWBC) on the internal wave field and the associated vertical mixing at 16°N in the Atlantic. The data set resolves the entire energy cascade from the low frequency, large scale DWBC that generates internal waves due to interactions with the topography, to high frequency vertical mixing.

Two longterm moorings and measured CTD/LADCP transects are located in the flowpath of the DWBC and are used to study the influence of the DWBC strength on the internal wave field and vertical mixing intensities. During times of a pronounced DWBC diapycnal diffusivities obtained from shipboard measurements are significantly enhanced (up to 10^{-3} m^2s^{-1}) in the bottommost 1500m. Internal wave energy spectra show significant temporal variability in dependence on the DWBC strength. Spectral energy levels change substantially in depths below 1200m where a strong increase particularly in near inertial frequency waves is observed during times of high background velocities. The interaction of the high velocity flow within the DWBC with the bottom topography primarily generates the observed near inertial internal waves. Variability in the high frequency range, a proxy for turbulence, is significantly correlated with the DWBC strength. The high vertical shear inherit in near inertial waves in combination with the interaction of waves and topography lead to the observed intensification of vertical mixing.

At the Mid Atlantic Ridge mooring observations show a trapping of high frequency internal waves due to a local maximum in stratification. Breaking of the trapped internal waves leads to enhanced vertical mixing in this depth range.

P03S2.06

P03S2 - Ocean Mixing

Oral

A comparison of calculated internal tides energy flux with microstructure measurements

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A comparison of the model-derived vertical energy flux from the internal tide with micro-structure measurements is undertaken. The latter data set originates from two field surveys during the Brazil Basin Tracer Release experiment (BBTRE1, BBTRE2) as well as from a third field cruise of the LArval Dispersal along the Deep East-pacific Rise project (LADDER3). The model for estimating the time-dependent vertical energy flux is based on linear wave theory, and takes into account the the finite depth of the ocean, the spatial variations of the bathymetry and the spatio-temporal variations of the barotropic tide. The temporal average of the vertical energy flux over different periods just preceding the date of the observations is compared with the depth-integrated observed energy dissipation rate. A rather good correlation is found between the theoretical predictions and the microstructure data from the BBTRE2 field survey. The comparison made for the BBTRE1 survey yields a low correlation, although the model-based estimates of the vertical energy flux are of the correct order of magnitude and capable of distinguishing the internal-tide generation sites over the rough topography from those over the smoothly sloping abyssal plain. In the case of LADDER3, the comparison between the observations and the theoretical predictions shows a significant correlation, whereas the calculated energy flux is considerably higher than the observed dissipation. A possible reason may be that the dissipation is less local at the East Pacific Rise since the sharp topography there is limited to a few seamounts.

P03S3.01

P03S3 - Ocean Mixing

Oral

Generation of baroclinic tide energy in global three-dimensional numerical models with different spatial grid resolution

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In this study, the global energy distribution of the major semidiurnal M2 and S2 and diurnal K1 and O1 baroclinic tides is investigated by using a hydrostatic sigma-coordinate numerical model. Especially, we focus on how this global energy distribution is varied with the increase of the model grid resolution by conducing a series of numerical simulations using various horizontal grid spacings of 1/20° to 1/5°. For each simulation, the model topography is constructed by averaging the bathymetric data from ETOPO1 within each model grid cell. The series of numerical simulations shows that the conversion rate from barotropic to baroclinic tidal energy increases almost exponentially with the reduction of the horizontal grid spacing. The globally integrated baroclinic tidal energy conversion rate for the sum of the four tidal constituents is increased by 520GW (from 393 GW to 913 GW) as the horizontal grid spacing is reduced from 1/5° to 1/20°. It is found that the semidiurnal (M2, S2) baroclinic tidal energy conversion rate is much more sensitive to the horizontal grid spacing than the diurnal (K1, O1) one. The sensitivity of the baroclinic conversion rate is also dependent on the generation sites of baroclinic tides. Particularly, it becomes very sensitive in the regions characterized by geologically young seafloor having numerous small-scale rough topographic features such as the Mid-Atlantic ridges, the eastern Pacific ridges and the Mid-Indian Ocean ridges, while it is less sensitive in the regions such as the Indonesian archipelago and the western Pacific Ocean. This difference in the sensitivity can be parameterized by the forcing function which is dependent on barotropic tidal currents, bottom topography and density stratification. Based on this forcing function, we have estimated the global distribution of the baroclinic tidal energy conversion rate in the limit of zero grid spacing.

P03S3.02

P03S3 - Ocean Mixing

Oral

Global patterns of internal wave energy loss on the continental slopes

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Global patterns of diapycnal mixing in the ocean interior are largely set by internal wave generation, propagation, and dissipation. One of the largest open questions is what percentage of internal waves dissipate near their generation sites (e.g. over the rough topography where internal tides are generated) and what percentage escapes, breaking up to thousands of kilometers away. At the margins, loss of internal wave energy varies depending on the reflectivity of the continental slope to the internal wave modes. Using energy fluxes calculated from a global internal-wave model, and the reflectivity of mode-1 waves at the slopes, we make initial estimates of the lateral dependence of internal-wave energy loss along the continental slopes.

P03S3.03

P03S3 - Ocean Mixing

Oral

Bottom tidal enhancement in a vertical mixing scheme

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In a recent scheme(C10) for vertical mixing due to small scale turbulence, tidal interaction with bottom topography was described by a dissipation whose horizontal dependence was set by the output of an offline 2D tidal model and whose vertical dependence was taken to be an exponential decay with the same scale height everywhere. The model produced bottom enhancement but in some places enhanced mixing reached upward into the interior where it is not expected. While the horizontal dependence comes from a physical model, the vertical dependence rests on much less firm footing.

DeCloedt and Luther(DL) proposed a deep mixing parameterization based on fits to observations, which is intended to encompass other effects besides tides. Their parameterization consists of horizontal and vertical dependences that are functions of their measure of topographic roughness. DL's vertical dependence has the form $[1+(h/h_0)^2]^{-1}$, h being height above the bottom and h_0 a geographically variable scale height which decreases with increasing roughness.

The indication that in C10 the scale height may be too large over rough topography motivated us to replace it with the geographically variable vertical dependence of DL. We have compared two otherwise identical simulations, one with the C10 z-profile and the other with the DL vertical dependence. We have examined their outcomes run with the GISS model E-OGCM using the CORE forcing. Results to be presented include diffusivity maps, temperature and salinity drifts and Atlantic Meridional Overturning Circulation.

Canuto, V.M., A.M. Howard, Y. Cheng, C.J. Muller, A. Leboissetier, and S.R. Jayne, 2010, “Ocean turbulence, III: New GISS vertical mixing scheme”, Ocean Modelling, 34, p.70-91, cited as C10 .

DeCloedt, T., and Luther, D.S. , 2010, “On a Simple Empirical Parameterization of Topography-Catalyzed Diapycnal Mixing in the Abyssal Ocean”, Journal of Physical Oceanography, 40, p.487-508, cited as DL.

P03S3.04

P03S3 - Ocean Mixing

Oral

Control of Pacific thermohaline circulation and ventilation by far-field tidal mixing

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Vertical mixing in the ocean is a key driver of the global ocean thermohaline circulation (THC) and is important for global climate. Previous studies have focused on the role of intense tidal mixing near the sea bottom (near-field mixing) in THC. Here, we show that tidally induced mixing away from the sea bottom (far-field mixing) plays an essential role in controlling the Pacific THC. Near-field mixing causes very large vertical diffusivity (Kv) over the rough sea floor, but ocean general circulation model (OGCM) simulations indicate that this intense Kv has little effect on the Pacific THC when the mixing is confined to the sea bottom. Conversely, far-field mixing is essential for driving the Pacific THC which is sensitive to Kv below the thermocline; this Kv is enhanced by far-field mixing, not by the near-field mixing. Our OGCM simulation with a new tidal mixing parameterisation, addition of far-field mixing to a widely used tidal parameterisation, successfully reproduces the Pacific THC and, for the first time, the Δ14C minimum located in the eastern deep Pacific Ocean. Our results imply that far-field mixing can affect climate by controlling the ventilation of the deep Pacific Ocean, which is important for the ocean carbon cycle.

P03S3.05

P03S3 - Ocean Mixing

Oral

Internal wave driven mixing: Parameterizations and climatic impacts

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Diapycnal mixing plays a key role in maintaining the ocean stratification and meridional overturning circulation. In the ocean interior, diapycnal mixing is largely sustained by breaking internal waves which are generated by abyssal flows interacting with rough topography. Two classes of topographic internal waves in the ocean are: internal tides, generated by barotropic tides, and lee waves, generated by geostrophic flows. Internal wave energy dissipation occurs on scales too small for global ocean models to explicitly resolve, and has to be parameterized. In most recent OGCMs and climate models, only the local dissipation of internal-tide energy is parameterized, using the semi-empirical scheme of St Laurent et al. (2002). While this parameterization dynamically accounts for the generation of internal tides, the dissipation of their energy remains ad hoc, and only tackles the nearfield problem (high-mode waves). In this presentation, we investigate the climatic impacts of new parameterizations of the dissipation of internal wave energy, which are more dynamically based and/or account for processes currently disregarded in climate models (such as lee wave driven mixing, or the mixing associated with the dissipation of the low modes). We implemented such parameterizations in the GFDL CM2G ocean-ice-atmosphere coupled model and performed sensitivity experiments. We show that the ocean state is sensitive to both the spatial distribution of the energy flux into internal waves and its distribution in the vertical. The thermal structure of the ocean, meridional overturning circulation and large scale circulation are impacted by the addition of the new parameterizations. This work is part of the on-going Climate Process Team (NOAA/NSF) effort, whose goal is to refine, develop and implement dynamically appropriate parameterizations for diapyncal mixing due to internal-wave breaking for use in global climate models.

P03S3.06

P03S3 - Ocean Mixing

Oral

Diapycnal mixing parameterized by energy release from mesoscale eddies

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Most climate models use the widely popular Gent and McWilliams (1990; GM) parameterization for the effect of mesoscale eddies on the large-scale oceanic flow. The GM scheme implicitly assumes that the available potential energy released to baroclinic eddies is quickly and adiabatically damped, yielding no buoyancy flux across isopycnals. While the fate of eddy energy remains unclear, it has been proposed that some of it may transfer to the internal wave field and result in diapycnal mixing (Tandon and Garrett 1996). Furthermore, observational and theoretical arguments suggest that, as barotropic eddies impinge on rough topography, such an eddy-induced diapycnal mixing is likely be to bottom-enhanced (Marshall and Naveira Garabato 2008). Using the Geophysical Fluid Dynamics Laboratory Modular Ocean Model, configured for an idealized ocean basin representative of the Atlantic and Southern Oceans, we explore the large-scale dynamical effects of the GM scheme, modified to account for eddy-induced and bottom-enhanced diapycnal mixing. These numerical results are compared to a new scaling theory relating the deep meridional overturning circulation to diapycnal mixing, eddy transport, and, ultimately, Southern Ocean wind stress. Our new theory, dependent on both an eddy and a tidal source of energy to support diapycnal mixing, generalizes two previous scaling theories that are applicable to high and low wind stress climatologies, and predicts the existence of a minimum strength of the deep meridional overturning. It is shown that the simulated ocean circulation is sensitive to the level and spatial pattern of diapycnal mixing, and thus, the modified GM eddy parameterization has strong implications for climate model results.

P03S4.01

P03S4 - Ocean Mixing

Oral

Observation and modelling of turbulent mixing in the Kuril Straits and impact of its 18.6-year period tidal cycle on ocean and climate

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Direct turbulent observations in the Kuril Straits and Aleutian Straits reveal that tide-induced strong vertical mixing corresponds to strong shear of combined diurnal tidal and/or mean currents and significantly modifies the water-mass and potential vorticity distribution. Bi-decadal variability synchronized with 18.6-year period moon-tidal cycle were found in various parts of the ocean and climate indices: water-mass variability in the subarctic North Pacific, especially near the strong diurnal tide regions as Kuril Straits and Aleutian Islands, and in long-term climate indices as Pacific Decadal Oscillation (PDO) and El-Nino and Southern Oscillation (ENSO) in proxy-reconstructed records. In low-frequency part of the PDO and SOI records, negative (positive)-PDO and positive (negative)-SOI tend to occur in the 4-6-th (10-12-th) year after the maximum diurnal tide, which is consistent with the climate model experiments with locally enhanced vertical mixing around Kuril Straits showing that tidal mixing and its variability could generate bi-decadal variability in ocean and climate. Ocean and climate model experiments with parameterized tidal mixing explain some of the water-mass modifications and bi-decadal variability of water-masses and climate.

P03S4.02

P03S4 - Ocean Mixing

Oral

Tide-induced enhancement of cold water intrusion along the continental shelf and slope of the southwestern East/Japan Sea

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The bottom cold water in Korea Strait has often been observed mainly during summer. Hydrographic sections exhibit a dome-like isothermal feature near the edge of the continental shelf-slope region, which appears to be related with the intrusion of the bottom cold water from the deep basin of the southwestern East/Japan Sea into the Korea Strait. Although previous studies have suggested possible causes of the bottom cold water intrusion, its mechanism is not clear yet. Here we investigate the influence of tides on the bottom cold water intrusion using numerical simulations, which include both wind-driven oceanic currents and tides simultaneously. We use a fine-resolution regional ocean model with 1/108-degree grids and s-coordinated 20 layers. To investigate detail physical processes influencing the bottom cold water intrusion, numerical simulations are conducted as following five cases: 1) wind forcing only without tides, 2) M2 tides only with wind forcing, 3) K1 tides only with wind forcing, 4) all four major tides (M2, S2, K1 and O1) with wind forcing, and 5) all four major tides without wind forcing. Our simulation results demonstrate that tides play a crucial role in enhancing the intrusion of the Korea Strait bottom cold water by both near-bottom ocean mixing and internal tidal residual currents. Detail physical processes are under investigation and will be presented in the meeting.

P03S4.03

P03S4 - Ocean Mixing

Oral

Internal tides and ocean mixing on the continental shelf of the southwestern East/Japan Sea from observation and simulation

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We investigate internal tides and ocean mixing near the continental slope of the southwestern East/Japan Sea using two sets of 25-hr long hourly CTD and LADCP profiles and numerical simulations. The time series of profiles span the whole water column from the surface to about 260 m during spring and neap tidal periods. Our observations reveal strong semi-diurnal internal tides below the main thermocline (150-200 m) where the 5¨¬C-isotherm displaces more than 50 m. The Richardson numbers calculated from the observations show low values (0-0.25) in layers where large vertical displacements exist, suggesting internal tide induced mixing. Numerical simulations using an idealized vertical 2.5-dimensional numerical model based on the ROMS reveal that semi-diurnal internal tide is dominantly generated on the continental slope. Simulations using different configurations are conducted for further understanding of internal tide generation mechanism and its impact on ocean mixing in this region.

P03S4.04

P03S4 - Ocean Mixing

Oral

Energy partition between local dissipation and internal tide radiation for stratified tidal flow over a sill

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Diapycnal mixing in sill fjords is vital for renewal of the deep water inside the sill. Tides can cause such mixing, both by local turbulence at the sill associated with supercritical baroclinic flow and internal hydraulic jumps, and by radiation of internal tides away from the sill that dissipate elsewhere and cause turbulence and mixing there. Previous studies tend to look at these two processes as independent of each others, whereas they in reality are closely linked: The internal tide generation depends on the hydraulic conditions at the fjord sill, and the internal hydraulic jump strength depends on the upstream and downstream radiated columnar disturbances which over time constitute the internal tides. An effort is done to link the hydraulic theory and the internal tide generation theory, and the result is compared to intensive observations over the Oslo fjord sill, including high-resolution microstructure profiler transects and mooring data on and inside the sill. Also the vertical distribution of the observed local dissipation rates is investigated in order to estimate the importance of local mixing for the deep fjord basin.

P03S4.05

P03S4 - Ocean Mixing

Oral

Transition from partly standing to progressive internal tides in Monterey Submarine Canyon

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Monterey Submarine Canyon is a large, sinuous canyon off the coast of California, known to be an area of energetic internal tides and elevated turbulent mixing. The upper canyon was the subject of an internal tide and mixing observational program using moored profilers, upward-looking moored ADCPs, and a depth-cycling towed body. The mooring observations measured a near-surface stratification change in the upper canyon, likely caused by a seasonal shift in the prevailing wind that favoured coastal upwelling. This change in near-surface stratification caused a transition in the behaviour of the internal tide in the upper canyon from a partly standing wave during pre-upwelling conditions to a progressive wave during upwelling conditions. Using a numerical model, we present evidence that either a partly standing or a progressive internal tide can be simulated in the canyon, simply by changing the initial stratification conditions in accordance with the observations. The mechanism driving the transition is a dependence of down-canyon (supercritical) internal tide reflection from the canyon floor and walls on the depth of maximum stratification. During pre-upwelling conditions, the main pycnocline extends down to 200 m (below the canyon rim) resulting in increased supercritical reflection of the up-canyon propagating internal tide back down the canyon. The large up-canyon and smaller down-canyon progressive waves are the two components of the partly standing wave. During upwelling conditions, the pycnocline shallows to the upper 50 m of the watercolumn (above the canyon rim) resulting in decreased supercritical reflection and allowing the up-canyon progressive wave to dominate.

P03S4.06

P03S4 - Ocean Mixing

Oral

Internal tidal bores and turbulent mixing at the Celtic Sea shelf break: an ocean glider study

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A key mechanism for diapycnal mixing in our oceans is internal waves either via enhanced interfacial shear or wave breaking. One of the most dramatic examples of such processes are observed at the continental shelf break, generated through the interaction of stratified flow with steep topography. Here, energy is extracted from the barotropic tide to produce localized mixing hotspots and high amplitude internal waves that are able to radiate energy onto the shelf and into the open ocean. The influence of this energy on diapycnal mixing over the continental shelf is still poorly understood due to 1) the difficulty of making sustained measurements of turbulence in the pycnocline 2) the sporadic and small scale nature of pycnocline turbulence and 3) the spatial variability of the on-shelf interaction of topography with barotropic and baroclinic flow. Here we present new observations made in June 2012 of the dissipation rate of turbulent kinetic energy (ε) with supporting hydrographic measurements that show the on-shelf propagation of turbulent bore-like features generated at the nearby Celtic Sea shelf break. Measurements of ε are provided by both a 'traditional' ship deployed vertical profiler that provides two, typically short timeseries (38 hours and 13 hours), and a glider mounted microstructure package, which provides 9 days continuous data. Both instruments identify the regular delivery of turbulent bores onto the shelf that increase diapycnal mixing by several orders of magnitude. The extended capability of the turbulence glider however reveals the temporal variability of these features and produces measurements up to the ocean surface. This exciting new platform therefore significantly increases our understanding of shelf break turbulence, provides estimates of near surface mixing and improves confidence in our estimates of average diapycnal mixing rates.

P03S5.01

P03S5 - Ocean Mixing

Oral

Reduction of numerical mixing by means of vertically adaptive coordinates in ocean models

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During the IUGG Conference 2007 in Perugia (Italy), we presented numerical mixing due to discretisation of tracer advection as one major source of errors in ocean models (Burchard and Rennau, 2008). Specifically in coastal ocean models where strong tracers gradients require monotone and non-diffusive discretisation schemes for advection, this problem could be substantial. Efforts in refining mixing parameterisations for ocean models would be inefficient since the physical improvements could be blurred by dominating numerical mixing. Inrecent years, Burchard and Beckers (2004) and Hofmeister et al. (2010) have developed vertically adaptive coordinates for ocean models which are refined near increased vertical gradients (typically of horizontal velocity and density) and have isopycnal and vertically Langrangean tendencies such that the layer interface related vertical velocity is reduced as well as the vertical resolution near gradients, both being effective in reducing numerical mixing due to vertical advection. These effects are demonstrated for a number of idealised and realistic model simulations. Furthermore, perspectives for vertical grid-refinement towards biogeochemical properties are shown.

Burchard, H., and J.-M. Beckers, Non-uniform adaptive vertical grids in one-dimensional numerical ocean models, Ocean Modelling, 6, 51-81, 2004.

Burchard, H., and H. Rennau, Comparative quantification of physically and numerically induced mixing in ocean models, Ocean Modelling, 20, 293-311, 2008.

Hofmeister, R., H. Burchard, and J.-M. Beckers, Non-uniform adaptive vertical grids for 3D numerical ocean models, Ocean Modelling, 33, 70-86, 2010.

P03S5.02

P03S5 - Ocean Mixing

Oral

Oscillations and mixing in the Faroe Bank Channel Overflow

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Recent observations from the region downslope of the Faroe Bank Channel Overflow show that the dominant 3-5 days oscillations, previously observed only in the dense bottom layer, extend over the whole water column and are connected to a wave-like pattern in Sea Surface Height (SSH) along the slope. A CTD/LADCP/VMP section, repeated during four days show a barotropic velocity anomaly, rotating clockwise on the shallow (< 800 m) slope and counterclockwise on the deeper part of the slope, that is associated with an increase in plume transport (from 0.5 to 2.5 Sv) and interface height (from 100 to 200 m) as well as changes in dissipation rates and mixing. The entrainment velocity (W_E) varies with a factor of 10^{-2} over the oscillation period, and there is an inverse relation between W_E and plume thickness, i.e. high values of W_E are observed when the dense bottom layer is thin. High values of W_E coincide with a large percentage of critical Richardson numbers in the interfacial layer. Two concurrent satellite tracks running parallel to the slope show a distinct wave patter with a wavelength of 50-75 km and an amplitude of about 5 cm. The two tracks, separated in time by two days, are perfectly out of phase, suggesting a periodicity of about four days and an along slope phase speed of 15-20 m s^{-1}. A third track, more perpendicular to the slope, show an increase in SSH, centered roughly at the 600 m isobaths and extending about 60 km across the slope.

P03S5.03

P03S5 - Ocean Mixing

Oral

Dissipation-derived estimates of entrainment, stress, and mixing scales in the Denmark Strait overflow plume

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To examine processes controlling the entrainment of ambient water into the Denmark Strait overflow (DSO) plume/gravity current, measurements of turbulent dissipation rate were carried out by a quasi free-falling (tethered) microstructure sounde (MSS).The MSS was specifically designed to collect data on dissipation-scale turbulence and finestructure in any ocean layer to depth of 3500 m. The task was to perform microctructure measurements in the DSO plume in the lowest 300 m depth interval including bottom mixed layer as well as interfacial layer below the non-turbulent ambient water. MSS was attached to Rosette water sampler equipped with SeaBird CTD and LADCP, the tether's end fastened to the rack, for delivery of MSS to the chosen depth where it was remotely released from the rack for performing measurements in free-falling mode.

Using the measured vertical profiles of dissipation, the entrainment rate as well as bottom and interfacial stresses were estimated in the DSO plume at a distance of 200 km downstream the sill. Dissipation-derived estimates of entrainment are much smaller than bulk estimates of entrainment calculated from the downstream change of the mean properties in the plume, suggesting the lateral stirring due to meso-scale eddies rather than diapycnal mixing to be the main contributor to entrainment. Dissipation-derived bottom stress estimates are roughly one-third the magnitude of those from log velocity profiles. In the interfacial layer, the overturning scale extracted from conventional CTD data (the Thorpe scale) was found to be proportional to the Ozmidov scale calculated from turbulence dissipation rate and buoyancy frequency, with the proportionality constant of 1.1 ± 0.7 and the correlation of 0.77.

P03S5.04

P03S5 - Ocean Mixing

Oral

Thermohaline staircases in the western Mediterranean Sea

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Thermohaline staircase structures are commonly observed in the western Mediterranean Sea within the halocline-thermocline connecting the Levantine Intermediate Water at about 400 m depth with the western Mediterranean deep waters below 1500 m. In this halocline-thermocline where warmer, saltier waters overlie colder, fresher deep waters, staircases are observed with layers of order 75 m thickness containing nearly constant properties separated by sharp steps of order 5 m thickness with jumps in properties between the layers. Whilst the layers have nearly constant salinity, potential temperature and potential density, each property decreases very slightly downward through the layer so that it appears that salinity, heat and density are being put into the top of each layer and then convectively mixed downward through the layer. Such observations are consistent with salt finger processes that transport salinity, heat and density downward through the halocline-thermocline.

Using repeat occupations of stations across the southern western Mediterranean Sea in 2006, 2008 and 2010, we calculate a downward salt transport F_S of 5.35 x 10^{-8} psu m s^{-1}, a downward heat transport F_T of 12.4 x 10^{-8} °C m s^{-1}, and, after multiplying these fluxes by haline contraction β and thermal expansion α coefficients respectively, a downward density flux of 1.0 x 10^{-10} W kg $^{-1}$. The buoyancy flux ratio, αF_T / βF_S , then equals 0.74. The halocline-thermocline has a background vertical salinity gradient of 0.95 x 10^{-4} psu m^{-1} and a vertical temperature gradient of 4.1 x 10 $^{-4}$ °C m^{-1} so the density ratio is $R\rho = (\alpha d\theta/dz)/(\beta dS/dz)$ is 1.28. Dividing the downward fluxes by the background vertical gradients yields vertical diffusivities k_S = 5.6 x 10^{-4} m^2 s^{-1} and k_T = 3.0 x 10^{-4} m^2 s^{-1}. These downward fluxes of salt and heat are comparable with the long term increases in salinity and temperature in the deep western Mediterranean Sea over the past 40 years.

P03S5.05

P03S5 - Ocean Mixing

Oral

Finite amplitude double-diffusive interleaving

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Double-diffusive interleaving motions occur at oceanic fronts and are one of the sub-mesoscale processes that are responsible for the decay and death of mesoscale eddies. We examine fastest-growing double-diffusive interleaving as it grows into finite amplitude, through the phase where every alternate interface is doubly stable, and then into the stage where every alternate interface is of the "diffusive" kind. There are two options at this stage; either a steady state is reached or the "diffusive" interface is driven to convective instability by the stronger salt-fingering interface. We find that the "diffusive" interface must flux properties an order of magnitude faster than the laboratory studies would indicate in order for a steady state to be achieved.

P03S5.06

P03S5 - Ocean Mixing

Oral

Ocean mixing and ENSO

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The coupling between the ocean and atmosphere in the tropics on ENSO timescales is heavily influenced by the state of the thermocline in the equatorial ocean, which in turn is very much affected by oceanic mixing.We present recent observations and numerical experimentation that show that both conventional measurements and climate models are missing a significant source of that mixing. High resolution measurements reveal that the vertical shear in the thermocline is dominated by small vertical scale features that are strongly related to regions of active mixing. Sources for this small scale activity include wind-generated near-inertial waves and instabilities of the current system. Accounting for this mixing in a coupled GCM induces a large change in the state of the coupled system and the characteristics of the model ENSO.

P03S5.07

P03S5 - Ocean Mixing

Oral

Can Drake Passage observations match Ekman's classic theory?

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Ekman's (1905) theory of the wind-driven ocean surface boundary layer assumes a constant eddy viscosity and predicts that the current rotates with depth at the same rate as it decays in amplitude. Despite its wide acceptance, Ekman current spirals are difficult to observe primarily because the spirals are small signals that are easily masked by ocean variability. We present a method for estimating ageostrophic currents from shipboard acoustic doppler current profiler data in Drake Passage and find that Ekman theory is consistent with observations. By taking into account the sampling distributions of wind stresses and ageostrophic velocities we find eddy viscosity values in the range 0.08-0.12 m^{-2} s^{-1} that reconcile the observations with the classic theory. The eddy viscosity value that most frequently reconciles the observations with the classic theory is 0.0942 m^{-2} s^{-1}, corresponding to an Ekman depth scale of 39 m.

P03S5.08

P03S5 - Ocean Mixing

Oral

Competing roles of surface heating and the earth rotation in scaling the wind-induced mixing layer depth

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The stabilizing buoyancy flux (heating) at the ocean surface weakens wind-induced mixing and shoals the surface mixing layer. The Monin-Obukhov length, a length scale derived from local balance between the wind-induced mixing and the buoyancy stabilization within the logarithmic boundary layer, has been considered as a scale of the stabilized mixing layer depth (SMLD) (Kraus and Turner 1967; Qiu and Kelly 1993). In the present study, we analyzed observed SMLD (MILA-GPV) and the surface momentum and heat fluxes (J-OFURO2) and show that the Monin-Obukhov length fails to scale the observed SMLD. Primary reason of this failure is the earth rotation effect (or the Coriolis parameter) which is not included in the Monin-Obukhov length but does affect geophysical fluid turbulence (e.g., Rossby and Montgomery 1935). We further investigated dependence of SMLD on the surface momentum flux, the surface buoyancy flux and the Coriolis parameter to find that the scaling of the stable atmospheric boundary layer height, proposed by Zilitinkevich et al. (2002) and validated at only three field experimental sites for atmospheric boundary layer, is appropriate to scale global distribution of SMLD. We will also show global distribution of SMLD and discuss its physical reasons in terms of the wind-mixing and the buoyancy stabilization under the earth rotation effect. The present scaling will give rough but reasonable estimation of SMLD from the momentum and buoyancy fluxes, both of which can be estimated from satellites. Thus, this scaling will contribute to better prediction/estimation of several SMLD-related processes such as air-sea interaction, subduction of surface waters into deeper layers and spring blooming of phytoplankton biomass.

P03S6.01

P03S6 - Ocean Mixing

Oral

Shear at the base of the oceanic mixed layer generated by wind-shear alignment

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Observational data have been used to evaluate a simple theoretical model for the generation of shear spikes at the base of the oceanic mixed layer. The model predicted that large changes in shear squared were due to the alignment of the wind and shear vectors. Temperature, salinity and velocity data from a high spatial resolution cruise in Drake Passage have shown that the model is most effective at predicting changes in shear squared when it arises due to near-inertial wind-driven currents without requiring a rotating resonant wind stress. Rotary spectral and statistical analysis of an additional 242 Drake Passage temperature and velocity transects from 1999 to 2011 revealed the prevalence of this shear-spiking mechanism throughout the year.

P03S6.02

P03S6 - Ocean Mixing

Oral

Rapid injection of near-inertial kinetic-energy into the stratified upper ocean at an Antarctic Circumpolar Current front

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Observations were made during the passage of a short (~ 12 hours) but intense (wind speeds up to 50 knots) storm near Kerguelen Island in proximity to an Antarctic Circumpolar Current (ACC) front during November 2008. The storm was observed to cause a wind-induced deepening of the surface mixed-layer and generated an inertial current. Post-storm there was rapid re-stratification of the upper ocean possibly due to the close proximity of an ACC front. As a consequence the inertial current ended up in stratified surface ocean waters within 1 - 2 days of the storm event. The observations of post-storm near-inertial shear deviated strongly from the β-dispersion paradigm which predicts the passage of near-inertial shear into stratified waters over a time scale of weeks to months. The observations were compared to predictions from commonly used 'slab' models of the surface ocean which were found to over-predict the transfer of kinetic energy from wind to ocean. This over-prediction suggests that the models representation of boundary layer physics is incomplete and lacks the inclusion of a significant short (< 1/f) time scale ocean response to wind forcing. Such slab models are used in calculating global estimates of wind to ocean kinetic energy transfer presuming that most, if not all, of the estimated wind work ends up in the oceanic interior available for diapycnal mixing. Our findings add strength to recent conclusions that without the representation of boundary-layer physics such slab models may well be systematically over-estimating the magnitude of this transfer.

P03S6.03

P03S6 - Ocean Mixing

Oral

Observations of a breaking internal wave at the base of the mixed layer in the Labrador Sea

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High-frequency internal waves in the upper ocean have been shown to be a source of turbulence, mixing, and vertical heat fluxes downward through the base of the seasonal mixed layer. The shallow pycnocline that forms during restratification after deep convection is conducive to internal wave generation from wind events. With the weak background stratification after convection, internal waves are readily trapped on the pycnocline and can propagate laterally away from their generation site, and can break to produce turbulence. We present here microstructure measurements from the Labrador Sea during the spring restratification period after deep convection. These measurements were made with the Air-Sea Interaction Profiler (ASIP), a novel, autonomous, untethered, upwardly-rising microstructure instrument that is capable of measuring turbulence to within centimeters of the ocean surface. Thirty profiles of high-resolution temperature, conductivity, and shear microstructure over the upper 100m are presented, with a profile rate of about 8 per hour. ASIP's rapid profiling capabilities captured high frequency (1 cph) waves with 10-m amplitude on the 60-m deep pycnocline. An isolated patch of elevated turbulence was observed at the crest of one of the waves from a breaking event. The dissipation rates here equal or exceed those observed in other regions of deep convection.

P03S6.04

P03S6 - Ocean Mixing

Oral

The impact of oceanic near-inertial waves on climate

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The latest version of the Community Climate System Model (CCSM4) is used to assess the climate impact of wind generated near-inertial waves (NIWs). Even with high-frequency coupling CCSM4 underestimates the strength of NIWs, so that a parameterization for NIWs is developed and included into CCSM4. Numerous assumptions enter this parametrization, the core of which is that the NIW velocity signal is detected during the model integration, and amplified in the shear computation of the ocean surface boundary layer module.

It is found that NIWs deepen the ocean mixed layer by up to 30%, but contribute only little to the ventilation and mixing of the ocean below the thermocline. However, the deepening of the tropical mixed layer by NIWs leads to a change in tropical sea surface temperature and precipitation. Atmospheric teleconnections then change the global sea level pressure fields so that the mid-latitude westerlies become weaker. From the perspective of model development it is astounding that representing a single process, NIWs, leads to improvements in three different aspects of CCSM4 that were hitherto thought to be unrelated: mixed layer depth, tropical precipitation and mid-latitude wind stress.

Thus, it is paramount that the uncertainty of the observed air-sea flux of inertial energy (~ 50-80%) has to be reduced.

P04PS.01

P04PS - Oceanic Boundary Current Systems

Poster

Westerlies control on Agulhas Leakage: Impact on the large-scale Atlantic circulation

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The Atlantic warm-water route, constituting primarily of Agulhas Leakage, is showing a contemporary increasing trend, occurring as a result of changing wind patterns in the Southern Hemisphere that is associated with climate change. The precise mechanisms behind this dependency between the Agulhas Leakage and the wind field are studied within a suite of ocean/sea-ice models. A series of simulations have been designed to carefully and independently detangle the influence of the intensity and position of the Westerlies on Leakage. Slight perturbations are applied to the realistic wind-stress, effectively altering the momentum input to the ocean towards a different mean state. Results show that the magnitude Indo-Atlantic flux significantly responds to changes in the Westerlies strength. The response is transient leading to an initial Leakage increase that is proportional to the wind stress change to come to a halt. The timescale is set by the adjustment of the Southern Ocean where interactions between the Antarctic Circumpolar Current and Agulhas system become important. It is shown that the present-day increase in Leakage result from an unadjusted oceanic response to the continually increasing Westerlies. The implication on the Atlantic Overturning Circulation is investigated and will be presented.

P04PS.02

P04PS - Oceanic Boundary Current Systems

Poster

A laboratory study of western boundary currents, with application to the Gulf Stream separation due to inertial overshooting

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Various dynamical aspects of nonlinear western boundary currents (WBCs) have been investigated experimentally through physical modeling in the 5-m-diameter rotating basin at SINTEF (Pierini et al., J. Phys. Oceanogr., 41, 2063, 2011). The motion of a piston with a velocity U that can be as low as U=0.5 mm/s induces a horizontally unsheared current of homogeneous water that, flowing over a topographic beta slope, experiences westward intensification. First, the character of WBCs for various degrees of nonlinearity is investigated. By varying U, flows ranging from the highly nonlinear inertial Charney regime down to a weakly nonlinear regime can be simulated. In the first case, the dependence of zonal length scales on U is found to be in agreement with Charney's theory; for weaker flows, a markedly different functional dependence emerges describing the initial transition toward the linear, viscous case. This provides an unprecedented coverage of nonlinear WBC dependence on an amplitude parameter in terms of experimental data. WBC separation from a wedge-shaped continent past a cape (simulating Cape Hatteras) due to inertial overshooting is then analyzed. By increasing current speed, a critical behavior is identified according to which a very small change of U marks the transition from a WBC that follows the coast past the cape to a WBC (nearly dynamically similar to a full-scale Gulf Stream) that separates from the cape without any substantial deflection, as with the Gulf Stream Extension. The important effect of the deflection angle of the continent is analyzed as well. Finally, the qualitative effect of a sloping sidewall along a straight coast is considered: the deflection of the flow away from the western wall due to the tendency to preserve potential vorticity clearly emerges.

P04PS.03

P04PS - Oceanic Boundary Current Systems

Poster

The Kuroshio Extension bimodality as a relaxation oscillation of intrinsic oceanic origin

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In this communication a minimal model of the Kuroshio Extension decadal bimodality is discussed. The eddy-permitting model is based on the reduced-gravity shallow water equations and is forced by a time-independent wind field. The obtained chaotic decadal variability (of intrinsic oceanic origin) is explained in terms of a relaxation oscillation, and is shown (Pierini et al., J. Phys. Oceanogr., 39, 2212, 2009) to be in substantial agreement with altimeter observations (e.g., Qiu and Chen, Deep-Sea Res., 57, 1098, 2010; Sugimoto and Hanawa, J. Oceanogr., 68, 219, 2012) as far as (i) the spatial structure of the mean jet and of the elongated and contracted jet states, (ii) the jet path length and mean latitudinal position, and (iii) the time evolution and temporal scales are concerned. By applying the methods of nonlinear dynamical systems theory, we then explain relevant dynamical features of the modeled flow, such as the origin of the relaxation oscillation as a consequence of a homoclinic bifurcation, the spatio-temporal character of the bimodal behavior, and the degree of predictability of the flow in the different stages of the oscillation (evaluated through a field of finite-time Lyapunov exponents and its Lagrangian counterpart). The predictability issue is also addressed by using sequential importance sampling to assess the impact of observations on an ensemble prediction (Kramer et al., J. Phys. Oceanogr., 42, 3, 2012). This particle-filtering approach gives access to the probability density of the state vector, which allows the predictive power—an entropy-based measure—of the ensemble prediction to be determined. Optimal observation locations are found to correspond to regions with strong potential vorticity gradients. For the elongated state the optimal location is in the first meander of the Kuroshio Extension; during the contracted state it is located south of Japan, where the Kuroshio separates from the coast.

P04PS.05

P04PS - Oceanic Boundary Current Systems

Poster

Topographic Rossby waves in the Lofoten Basin from observations and high-resolution ECCO2 model

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A sub-Arctic hot spot of intense synoptic-scale variability is observed in the Lofoten Basin (LB) within the system of the Norwegian Atlantic Current. Using ERS-1/2 and Envisat satellite altimetry measurements, we discover a cyclonic propagation of the synoptic-scale sea surface height anomalies around the center of the LB. Surface drifter trajectories do not reveal an associated coherent near-surface cyclonic flow suggesting that the propagating signals have a wavelike nature. We identify a dipole and a quadrupole wave modes rotating around the center of the LB, obtained analytic dispersion relations for these modes, and demonstrated that the observed propagation is a manifestation of topographic Rossby waves. Most of the observed waves have a wavelength of about 500 km and phase speeds ranging from 2 to 10 km/day. We show that these waves are largely responsible for the localization and amplification of sea surface height variability in the center of the LB. By using a high-resolution ECCO2 model we study the sensitivity of the observed topographic Rossby waves to atmospheric forcing.

P04S1.01

P04S1 - Oceanic Boundary Current Systems

Oral

Numerical simulations of western boundary currents: from intraseasonal to interannual variability

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During the past ten years, the Drakkar group has developed global and regional numerical simulations at increasing spatial resolution (¼° to 1/12°). Analysis of the simulations, as well as numerous sensitivity experiments, allow us to review the structure of western boundary currents as well as their variability on time scales ranging from intraseasonal to interannual, with a focus on the Atlantic ocean. Simulations at increasing resolution show that the vertical structure and intensity of currents along the continental slopes are very sensitive to numerical details such as lateral boundary conditions (free slip vs. no-slip) and momentum advection schemes, even in 1/12° models. The accurate representation of free jets downstream of boundary current separation (such as the Gulf Stream and the North Atlantic current) remains a challenge for modellers. Intraseasonal variability of currents along the continental slopes has a different character on western boundaries and eastern boundaries. Sensitivity experiments with a 1/12° model demonstrate the role of instabilities and mesoscale eddies as generators of high frequency variability on western boundaries, in contrast with the leading role of high frequency winds at the eastern boundaries. Eddies and flow instabilities generate intrinsic variability on interannual time scales. Furthermore, velocity-temperature or velocity-salinity correlations resulting from eddy motions have a strong impact on basin wide transports of heat and salt in some latitude bands. A more robust representation of this eddy-driven variability in numerical models is needed in order to understand the impact of western boundary currents on climate variability.

P04S1.02

P04S1 - Oceanic Boundary Current Systems

Oral

Intrinsic low-frequency variability in Western Boundary Currents: Imprints and features from global eddying OGCM simulations

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Idealized numerical studies have shown that high-Reynolds number flows driven by constant or seasonal forcing are subjected to intrinsic chaotic variability at interannual-to-decadal timescales. Western Boundary Current systems (WBCs) are particularly prone to this chaotic low-frequency variability, although the exact role of mesoscale eddies in the sustainance of this phenomenon remains under debate. Ocean General Circulation Models can now be run at high resolution for decades or centuries; they reproduce these low-frequency modulations in realistic contexts that may be readily compared with actual observations. Characterizing the structure and features of this phenomenon is of particular relevance for the interpretation and attribution of observed variability.

At timescales longer than 1 year, our 1/4° global simulations show that in WBCs, intrinsic processes explain most of the variance of certain variables (e.g. sea-surface height, temperature, mixed-layer depths, etc) with little contribution of the atmospherically-driven variance. After a presentation of our simulation strategy and diagnostic approach, we will present the distribution and imprint of intrinsic low-frequency variability in the global ocean. We will then focus on WBCs, and in particular on the Gulf Stream system; the imprints and features of the low-frequency intrinsic variability will be described through the spectra and covariances of various dynamical indices characterizing this western boundary current system.

P04S2.01

P04S2 - Oceanic Boundary Current Systems

Oral

Observations of the East Greenland spill jet south of Denmark Strait

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Despite its importance to the Atlantic Meridional Overturning Circulation (AMOC), the transport and dynamics of the East Greenland Boundary Current System are poorly understood. The components of the system are the East Greenland Irminger Current (EGIC) in the upper layer, the Deep Western Boundary Current (DWBC) at the base of the continental slope, and the East Greenland spill jet which resides inshore and beneath the EGIC. Four repeat hydrographic sections were taken to the south of Denmark Strait between 2001 and 2007, with a special emphasis being placed on observing the spill jet, a recently discovered feature about which relatively little is known. The bottom-intensified spill jet was present in each occupation, transporting 5.0 ± 2.2 Sv equatorward in the mean, which is similar to the DWBC at this latitude (4.9 ± 1.4 Sv). It also displayed considerable variability between sections, which appears to be related to the geographical location of the upper-layer hydrographic front associated with the EGIC. When the front is located near the shelfbreak, the spill jet is confined to the outer shelf/upper slope and its transport is smaller. During these times there is less mixing and the water advected by the jet is generally lighter than that transported by the DWBC. In contrast, when the front is located seaward of the shelfbreak, the spill jet extends farther down the continental slope and its volume flux is larger. At these times, there is stronger mixing and the spill jet can transport water as dense as the Denmark Strait Overflow Water. Vorticity analyses indicate that the jet is subject to several instability processes including baroclinic, barotropic, and symmetric instability. These and other observations imply that the jet contributes significantly to the intermediate and, at times, deep limb of the AMOC.

P04S2.02

P04S2 - Oceanic Boundary Current Systems

Oral

Transports and intra seasonal variability in the western subpolar North Atlantic, 47°N

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The southwestern part of the subpolar North Atlantic east of Flemish Cap is a key area for the Atlantic Meridional Overturning Circulation (AMOC). The area is characterized by strong meridional currents: the southward flowing deep western boundary current (DWBC), the northward flowing North Atlantic Current (NAC), and an adjacent southward return flow. The circulation and water masses east of Flemish Cap were studied by six repeat hydrographic sections along 47°N (2003-2011), a two-year long time series of current velocity, temperature, and salinity at the continental slope (2009-2011), and the output of a 1/20° general circulation model of the North Atlantic. Two distinctive cores of southward flow are found in the DWBC, one located directly at the steep continental slope, with maximum velocities found at mid-depth. The second core is found above the continental rise and characterized by bottom-intensified currents. From shipboard observations the mean southward DWBC transport is 22 Sv, with two thirds at the slope and one third at the rise. The northward NAC transport varies between 40 and 160 Sv and the mean amounts to 90 Sv, 52 Sv of which in the deep water layer. Most of this northward flow recirculates just east of the NAC. The southward transport observed here amounts to 37 Sv in the deep water and 63 Sv in total, which reduces the net northward transport of the NAC to 27 Sv. The observed structures and transports are very similar in the model. The NAC variability in the model is highly correlated with it's recirculation, but not with the DWBC strength. The time series of the flow in the DWBC core at the continental slope show an mean southward transport of 19 Sv that agrees well with shipboard measurements. The flow varies between 10 and 30 Sv with only one exception were a northward flow was observed for a period of several days. The power spectral density of meridional velocity shows a maximum on time scales of 15 to 30 days.

P04S2.03

P04S2 - Oceanic Boundary Current Systems

Oral

Adiabatic eastern boundary currents

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The dynamics of the eastern boundary current of a high-resolution, idealized model of the oceanic circulation are analyzed and interpreted in terms of residual mean theory. In this framework it is clear that the eastern boundary current is adiabatic and inviscid. Nevertheless, the time averaged potential vorticity is not conserved along averaged streamlines, because of the divergence of Eliassen-Palm fluxes, associated with buoyancy and momentum eddy fluxes. In particular, eddy fluxes of buoyancy completely cancel the mean downwelling or upwelling, so that there is no net diapycnal residual transport. The eddy momentum flux acts like a drag on the mean velocity, opposing the acceleration due to the eddy buoyancy flux: in the potential vorticity budget this results in a balance between the divergences of eddy relative vorticity and buoyancy fluxes, which leads to a baroclinic eastern boundary current whose horizontal scale is the Rossby deformation radius, and whose vertical extent depends on the eddy buoyancy transport, the Coriolis parameter and the mean surface buoyancy distribution.

P04S2.04

P04S2 - Oceanic Boundary Current Systems

Oral

The Leeuwin Current System: A boundary current system along Western Australia

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It is often claimed that Australia is 'upside-down' referring to the northern hemisphere view of our island continent. However, when we examine the marine environment off Western Australia this is absolutely true. The resource rich marine environment off Western Australia is truly unique - covering tropical to temperate climate regions with rich species diversity, ocean current systems and geological formations. These features make the continental shelf and offshore region off Western Australia an ideal natural laboratory to examine physical biological coupling as they consist of contrasting physical environments as well as strong connectivity. The circulation is dominated by the presence of the anomalous Leeuwin Current, which transports warm, nutrient poor water poleward and has a strong influence on the local climate and biology. It is anomalous because it is a poleward flowing boundary current on an eastern margin of an ocean basin. In the summer months, strong sea-breezes, unique to the region, forces water northward along the shelf. The Capes Current is generated by the strong southerly winds as an upwelling current. There is localised upwelling due to the southerly winds and flow interaction with topographic features such as Rottnest Island and the Perth canyon. In the autumn and winter months the nearshore waters exits the continental shelf as a dense plume of bottom water. The shelf circulation also responds to continental shelf waves (both in summer and winter) propagating southward. The low frequency nature of these waves (~10 days) can result in large excursion rates of water parcels on the continental shelf.

P04S2.05

P04S2 - Oceanic Boundary Current Systems

Oral

Ningaloo Niño – an unprecedented warming of the Leeuwin Current in 2011

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Ocean circulation off the Western Australia coast in the southeast Indian Ocean is dominated by the poleward-flowing Leeuwin Current. Interannual and decadal variability of the Leeuwin Current is to a large extent driven by tropical Pacific climate variability, such that the current is stronger during La Niña events and weaker during El Niño events. Interannual variability of ocean temperature off the Western Australia coast is mostly forced by the Leeuwin Current heat advection and the buffering role of local air-sea heat flux. Unprecedented warm sea surface temperature (SST) anomalies were observed off the west coast of Australia in February–March 2011. Peak SST during a 2-week period were 5°C warmer than normal, causing widespread coral bleaching and fish kills. Understanding the climatic drivers of this extreme event, which we dub “Ningaloo Niño”, is crucial for predicting similar events under the influence of global warming. In this study we use observational data and numerical models to demonstrate that the extreme warming was mostly driven by an unseasonable surge of the poleward-flowing Leeuwin Current in austral summer, which transported anomalously warm water southward along the coast. The unusual intensification of the Leeuwin Current was forced remotely by oceanic and atmospheric teleconnections associated with the extraordinary 2010-2011 La Niña. The amplitude of the warming was boosted by both multi-decadal trends of the Pacific climate toward more La Niña-like conditions and intraseasonal variations in the Indian Ocean. A regional model is used to quantify the role of the Leeuwin Current transport during this extreme event.

P04S3.01

P04S3 - Oceanic Boundary Current Systems

Oral

Separation of the western boundary currents of the South Indian Ocean

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The northward and southward branches of the East Madagascar Current separate at the northern and southern tip of the island of Madagascar. The Agulhas Current separates from the African continent. All are separations of a western boundary current from a meridional boundary that terminates in mid ocean but their propagation characteristics are radically different. The large part of the Agulhas retroflects eastward. The remainder 'leaks' into the Atlantic as a series of anticyclones. The South East Madagascar Current immediately breaks up into a regular series of symmetric counter-rotating vortex pairs of ~ 250 km each that propagate southwestward. The North east Madagascar Current flows westward as a continuous free jet. The controls and dynamics of this different behaviour will be discussed during the talk.

P04S3.02

P04S3 - Oceanic Boundary Current Systems

Oral

Measuring Agulhas Current strength and leakage from satellite altimetry

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The Agulhas leakage is a flux of relatively warm and salty water from the Indian Ocean to the South Atlantic Ocean. It occurs south of the African continent where the Agulhas Current retroflects and sheds large anticyclonic eddies that quickly break up and mix with the surrounding water. This is one of the most energetic regions of the world ocean and the Agulhas leakage is therefore very difficult to quantify. In recent years two independent studies (Biastoch et al. 2009, Rouault et al. 2009) using different ocean models pointed out the possibility that the strength of the Agulhas leakage could have increased over the last decades. Unfortunately, several discrepancies exist between these two studies on the magnitude and the causes of this increase showing the limitations of numerical modelling in this area. In this work we use a combination of along-track and mapped satellite geostrophic velocities to compute the strength of the Agulhas Current and to follow Lagrangian particles released in its core. The results confirm an increase of the volume of Agulhas leakage over the last two decades. However, this increase is not continuous. A major change happened during the early retroflection event of 2000-2001. This extreme event pushed the Agulhas system into a new regime in which the variability of the retroflection position is twice bigger, the number of Agulhas eddies is increased and the volume of leakage too. We investigate the dependence of the leakage to upstream conditions like the Agulhas Current transport, the pattern and strength of the westerly winds and test previous theories on the relations between these factors.
Biastoch, A., Böning, C. W., Schwarzkopf, F. U. and Lutjeharms, J. R. E.: Increase in Agulhas leakage due to poleward shift of Southern Hemisphere westerlies, Nature, 462(7272), 495–498, 2009. Rouault, M., Penven, P. and Pohl, B.: Warming in the Agulhas Current system since the 1980's, Geophys. Res. Lett, 36(L12602), 2009.

P04S3.03

P04S3 - Oceanic Boundary Current Systems

Oral

Annual evolution of boundary currents in the western Arabian Sea from drifter and satellite data

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The circulation of the Arabian Sea reverses annually with the Indian monsoon winds. Two decades of drifter and satellite data allow us to describe robustly the monthly evolution of the western boundary currents and the interior circulations they link to, by examining a composite year and the leading modes of variance. We find several features that differ from, or fill in gaps in, current understanding.

First, northward flow appears along the length of the western boundary, together with a weak anticyclone at 6°N (a pre-cursor to the Great Whirl) as early as March or April, one or two months before the southwest monsoon winds. This circulation appears to be driven by the arrival of an annual Rossby wave, which is initiated by wind curl forcing during the previous southwest monsoon. We hypothesize that this could be a mechanism by which the strength of the previous monsoon circulation could feedback on the next.

Second, there is broad, strong eastward flow at the mouth of the Gulf of Aden throughout the southwest monsoon. Here alongshore winds drive offshore Ekman transport and a switch in sign of the wind stress curl along the axis of the atmospheric monsoon jet drives significant geostrophic flow.

Finally, we find that the eastward South Equatorial Counter Current (SECC) is present year-round, fed by the northward East African Coastal Current (EACC) at the western boundary. During the southwest monsoon the EACC overshoots the equator and splits, feeding both northward into the Somali Current and eastward into the SECC after looping back across the equator. But at the surface this circulation is obscured by strong, cross-equatorial Ekman transport. Surprisingly, the SECC is at its weakest not during the southwest monsoon when there is a component of opposing wind stress south of the equator, but during the northeast monsoon when the westward North Monsoon Current impinges on its flow.

P04S3.04

P04S3 - Oceanic Boundary Current Systems

Oral

The interannnual and decadal variability of the East Australian current

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The southwest Pacific Ocean is a major oceanic 'cross-roads' which links the mid-latitude gyre with the equatorial band in the north and provides a pathway from the Pacific to the Indian Ocean in the south. The complex topography in the region introduces a major level of complication into the regional circulation. The bathymetry is dominated by several ridges which radiate northward from the New Zealand continental land mass. The East Australian Current (EAC) is the major western boundary current of the South Pacific Gyre and completes the Gyre circulation. A compilation of CTD casts and Argo profiles resolve the broad-scale circulation features. Three eddy-resolving XBT sections enclosing the Tasman Sea make up the Tasman Box. Each of the sections has been sampled at eddy-resolving scales on precisely repeating locations to separate temporal from spatial variability of properties. The limited temporal sampling of the XBT transects is supplemented by estimates of the geostrophic transport from satellite altimetry. The transport time series resolve the full suite of temporal signals from eddy-scale, seasonal, interannnual to decadal and may be used to investigate the nature and mechanism of decadal variability in the EAC system and south Pacific subtropical gyre. A deep mooring array off Brisbane observes the mass, and TS fluxes of the EAC. The array has been designed using output from a high-resolution ocean model. The model provides a very accurate representation of the broad seasonal and interannnual changes in flow across the basin-wide sections. The main EAC flow separates into eastward and poleward flows. At decadal timescales these components are anti-correlated. This decadal variation confirms the EAC response to a spin-up of the South Pacific circulation forced by changes in the basin-wide winds and matches the changes in oceanic properties observed in the Tasman Sea.

P04S3.05

P04S3 - Oceanic Boundary Current Systems

Oral

The Antarctic coastal current in an eddy-permitting ocean model with icebergs

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Icebergs are explicitly represented as an ensemble of Lagrangian particles in an eddy-permitting global ocean model. Icebergs progressively melt along trajectories. Compared to a control experiment in which iceberg fluxes are included as coastal runoff, the Antarctica Coastal Current is strengthened, from ~7 Sv to ~9 Sv in the annual average. This is consistent with a reorganization of freshwater forcing around Antarctica, as a substantial fraction of the water flux from Antarctica is shifted offshore. Reduced freshwater input to the inshore region leads to local changes in temperature and salinity structure that increase horizontal density gradients and geostrophic transport in the coastal current. Differences between the two experiments are highly variable in time but coherent around Antarctica, with substantial strengthening of the coastal current arising on intra-annual timescales in the experiment with icebergs. Taken together, the experiments provide indirect evidence for meltwater control of a circumpolar boundary current that plays a key role in dense water formation and ecosystem dynamics.

P04S4.01

P04S4 - Oceanic Boundary Current Systems

Oral

Decadal variability, impact and prediction of the Kuroshio Extension system

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The Kuroshio Extension is an eastward-flowing, inertial jet in the subtropical western North Pacific Ocean after the Kuroshio separates from the coast of Japan. Being the extension of a wind-driven western boundary current, the KE has long been recognized as a turbulent current system rich in large-amplitude meanders and energetic pinched-off eddies. An important feature emerging from recent high-precision satellite altimeter measurements and eddy-resolving ocean model simulations, is that the KE system exhibits clearly-defined decadal modulations between a stable and an unstable dynamic state. The decadally-modulating KE dynamic state not only exerts a great impact on the regional sea surface temperature, heat content and water mass properties, it also brings about significant changes in marine ecosystems and fisheries in the western North Pacific Ocean. Here we show that the time--varying KE dynamic state can be predicted at lead times of up to 5~6 years. The long-term predictability rests on two dynamic processes: (1) the oceanic adjustment is via baroclinic Rossby waves that carry interior wind-forced anomalies westward into the KE region, and (2) the KE variability induces a negative feedback response in the overlying atmosphere that enhances the oceanic variance with a preferred timescale of ~10 years. This second process is a novel addition and is at the heart of the prolonged multi-year predictability of the KE dynamic state.

P04S4.02

P04S4 - Oceanic Boundary Current Systems

Oral

On the synchronization between the Kuroshio Extension bimodality and the North Pacific Oscillation

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The North Pacific Oscillation (NPO, the second dominant mode of sea level pressure variability in the North Pacific) is known to drive the North Pacific Gyre Oscillation (NPGO, Di Lorenzo et al., Geophys. Res. Lett., 35, L08607, 2008; Chhak et al., J. Climate, 22, 1255, 2009) and to excite Rossby waves that propagate the NPGO signature from the central North Pacific into the Kuroshio Extension (KE) region (Ceballos et al., J. Climate, 22, 5163, 2009). This, in turn, is suggested to be the cause of the synchronization between the NPGO and the KE decadal bimodality, as observed from satellite altimetry (Qiu and Chen, Deep-Sea Res., 57, 1098, 2010). In this communication modelling studies are presented, suggesting that such synchronization may be the result of the excitation -via the Rossby wave field- of a KE relaxation oscillation, whose spatial structure and evolution is basically driven by highly nonlinear intrinsic oceanic mechanisms. To arrive to this conclusion the concept of global bifurcation, of the resulting relaxation oscillations, and of the corresponding coherence resonance and synchronization with an external time-dependent forcing are first recalled in the context of dynamical systems theory by using a low-order QG ocean model (Pierini, J. Phys. Oceanogr., 41, 1585, 2011). These same notions are then applied to a reduced-gravity shallow water model of the KE bimodality (Pierini, J. Phys. Oceanogr., 36, 1605, 2006; 40, 238, 2010) in basic agreement with observations. Finally, the introduction of an idealized NPO time-dependent forcing is shown to produce a teleconnection mechanism and a timing of the KE relaxation oscillation in significant agreement with the above mentioned results. Conclusions concerning the possibility of reproducing phenomena of intrinsic low-frequency variability of this nature in ocean general circulation models are finally presented.

P04S4.03

P04S4 - Oceanic Boundary Current Systems

Oral

Similarities between optimal precursor and optimally growing initial error in predictability study of Kuroshio south of Japan

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Conditional Nonlinear Optimal Perturbation (CNOP) approach is used to investigate the relationships between optimal precursor (OPR) and optimally growing initial error (OGE) in the predictability studies of Kuroshio south of Japan within a 1.5-layer reduced-gravity model. The OPR is a kind of initial anomaly that most readily triggers Kuroshio LM path. The OGE refers to another kind of initial perturbation that has the largest effects on the prediction of the LM path. Three cases are investigated. Numerical results show that for each case, the spatial patterns of OPR and OGEs are similar and their dominant amplitudes are localized southeast of Kyushu. This feature of their spatial patterns is closely related to the potential vorticity (PV) distribution of the reference states, i.e., the large amplitudes of perturbations are located at the large PV gradient regions. The main features of the nonlinear evolutions of both OPR and OGEs are also similar, which implies that they have a similar development mechanism. The PV advections play dominant roles in the evolutions of OPR and OGEs. The exploration of similarities of the spatial structures of OPR and OGEs is helpful to implement targeted observations to improve the prediction of the Kuroshio path, because additional observations implemented over the sensitive area (identified by the patterns of OPR and OGEs) will not only be able to reduce the probability of the appearance of OGEs, but also can help to capture the OPR.

P04S4.04

P04S4 - Oceanic Boundary Current Systems

Oral

A model study of the Kuroshio path variation using a repeat annual cycle forcing

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The Kuroshio path variation is studied using a two-way nested-grid ocean general circulation model. The CORE normal year forcing, which does not include interannual variability, is employed to drive the model. For climatological or 10 % weaker wind forcing, both large-meander (LM) and non-large-meander (NLM) paths alternately appear, with each type of path continuing for a few years to a decade. This time scale and path transition processes are generally consistent with observations. For the LM path, the main balance in the depth-integrated vorticity equation for the upper ocean is shown to be between the beta, advection, and stretching terms. The stretching term is comparable to and has the same sign as the beta term at the western side of the meandering part, indicating that the stretching term has the effects of shortening the wavelength and stabilizing the LM path. Contrary to the above two cases, only the NLM path appears for 10 % stronger wind forcing. It is suggested that the strength of climatological wind forcing is near the upper limit that allows the LM path to occur. Since the forcing does not include the interannual variability, the path variation is caused by intrinsic processes in this model calculation.

P04S4.05

P04S4 - Oceanic Boundary Current Systems

Oral

Boundary currents' responses to remote forcing: observations from the North Atlantic Line W and the North Pacific PN-line

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Regular in situ measurements are made along Line W in the North Atlantic and the PN-line in the North Pacific. These sections each cross their respective basin's western boundary with stations descending the sloping topography offshore of the shelf break. Since 2004 moorings along Line W have measured the Deep Western Boundary Current (DWBC) – at high temporal and vertical resolution – as it flows equatorward between the shelf and the poleward-flowing Gulf Stream. In contrast, the PN-line crosses a wind-driven sub-tropical western boundary current, the Kuroshio. Regular hydrography at the PN-line has been conducted since the 1960's, with occasional mooring deployments providing higher frequency observations. A striking feature of the North Atlantic's DWBC transport, comprising Labrador Sea and Overflow Waters, is its tremendous variability, with equatorward transport at Line W sometimes exceeding 100 Sv (compared to a 30 Sv mean). Likewise, the Kuroshio at the PN-line exhibits strong mesoscale variability, with mooring-inferred transport ranging between 4 Sv and 30 Sv. Altimetry, hydrography, and wind-stress curl show that interannual variability at the PN-line is a combined response to the large-scale wind stress curl field at two time scales, related to barotropic and baroclinic modes that reach the western boundary from the interior via different waveguides. Analogous processes may be relevant for interannual variability at Line W. Annual-mean SSH on the onshore side of Line W is positively correlated at zero-lag with SSH along a PV contour that stretches from Cape Hatteras, northeastward. The correlation is weak near the Grand Banks, but is significantly enhanced in a conspicuous band that stretches northward along the boundary and into the interior near 55-60°N. In contrast, the offshore side of Line W is not correlated with remote SSH at zero-lag. These findings and their connection to the large-scale North Atlantic wind field will be discussed.

P05PS.01

P05PS - Arctic Ocean

Poster

Multiple constraints on net community production in the central Arctic ocean

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This study aims towards assessing the distribution, magnitude and variability of net community production (NCP) in the central Arctic Ocean based on proxies derived from measurements of continuous oxygen to argon ratios (O_2/Ar), underway pCO_2, discrete samples of dissolved inorganic carbon (DIC), and nutrients obtained during the TransArc (The Arctic Ocean in Transition) cruise with R/V Polarstern (ARKXXVI/3) between 5 August (Tromsoe) to 7 October (Bremerhaven) 2011.
To assess the NCP from underway pCO_2 measurements, DIC was calculated from these data and total alkalinity (TA) derived from a fixed salinity relation. DIC deficits were calculated from surface concentrations and preformed DIC concentrations derived from seawater (sw), sea-ice melt (sim) and river runoff (rro) fractions (f) and DIC concentrations. Fractions were calculated from salinity and total alkalinity. The fixed end-member values were taken from the literature. The deficit derived from nutrient data was based on surface concentrations and concentrations at the Polar Mixed Layer (PML) estimated from temperature minima, assuming characteristics of remnant winter water. All proxies were converted to DIC deficit equivalents according to the generic Redfield ratio. Preliminary results are presented as NCP (mmol C m^{-2} d^{-1}) assuming an average mixed layer depth of 20 m and a 100 day productive season.
Our preliminary data show reasonable agreement between the various proxies. Substantial differences in NCP were observed between the sub-basins of the central Arctic Ocean. Highest productivity was found in the central Nansen Basin (10-14 mmol C m^{-2} d^{-1}) and the lowest in the Amundsen Basin (-2-4 mmol C m^{-2} d^{-1}). Higher NCP tended to occur along the ice edge in general and potentially over some of the region's bathymetric features.

P05PS.02

P05PS - Arctic Ocean

Poster

On the reasons for uncertainty of future sea ice extent projection

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Future projections of Arctic sea ice extent from climate models as collected by CMIP5 show a large spread. This is connected partly to a generally too small decrease rate or too late sea ice drop. Reasons are to be seen in the different models' parameterizations and biases in atmosphere and ocean. In a regional Arctic climate model, we test the role of different sea ice albedo formulations and atmospheric circulation biases on the sea ice extent and its decline characteristics.

P05PS.03

P05PS - Arctic Ocean

Poster

Vertical heat fluxes in the upper 400-meter layer of Arctic Basin according to measurements at the drifting station in 2010-2011

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Results on the vertical heat flux space-time variability are presented. Heat fluxes was calculated in the upper 400-meter layer of the Arctic Ocean along the trajectory of the station “North Pole - 38” drift. Station drifted in central part of the Arctic Basin from 15 October 2010 to 29 September 2011. Measurements of water thermohaline characteristics and current velocity were fulfilled. Temperature and salinity were measured by the CTD-profilers SBE-19plus and SBE-37MicroCat. Current velocity and direction were measured by the acoustic Doppler current meters WHLS-75, WHS-300 and SonTec/YSI. Heatfluxes in the water column from the Atlantic Water (AW) core up to the lower ice surface were calculated by the method presented in the paper by *McPhee, Kikuchi, Morison, Stanton (2003)*. Mean heat flux value decreases from 1.5 Wm^{-2} in November 2010 to 0.7-1 Wm^{-2} in April 2011. Heat from AW don’t transmitted up to the lower ice surface because of the shielding effect of the Pacific Water. The heat flux value and direction are mainly affected by the temperature gradient. The role of the turbulent component is not clear. Results verify ocean-to-ice heat flux dependence on the weather conditions and, in large degree, on the region geographical location and water masses structure.

P05PS.05

P05PS - Arctic Ocean

Poster

The main features of land fast-ice melting in Sveabukta Bay (Van Mijenfjorden Gulf, Svalbard)

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The processes of heat- and mass transfer in Sveabukta Bay sea ice cover during Spring 2010 the particularity of which is conditioned by pollution from open coal storages situated on shore have been studied. Typical features of land fast ice radiation and thermodynamic properties were described and estimates for vertical distribution of coal particles concentration within ice body were obtained. The coal particles were shown to serve as tracers of transfer processes in the sea ice thickness. For computation of fast ice evolution characteristics the conceptual thermodynamic model which describes melting processes in the obvious form was used. According to calculations the melt pond forming on dirty ice under typical meteorological conditions begins one – three weeks earlier than that of clear ice depending on degree of contamination characterized by reflective ability of underlying surface. With decreasing of albedo the temperature of melt rises despite the fact that due to time difference the melting of clear ice occurs at higher temperatures.

P05S1.01

P05S1 - Arctic Ocean

Oral

Perspectives on changes in Arctic Ocean circulation and freshwater distribution

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In recent years, the Arctic Ocean has changed in two ways. First, starting in the early 1990s, the circulation of the Arctic Ocean became more cyclonic; more saline Atlantic-derived upper ocean waters projected farther around the Russian side of the Arctic Ocean and compressed the anticyclonic circulation of Pacific-derived waters to the east in the Canada Basin. This has been linked to an increase in the Arctic Oscillation (AO) index.

Second, Arctic Ocean change has included increased doming of the Beaufort Sea linked to a stronger Beaufort high. This has increased Canada Basin freshwater content (FWC) because anticyclonic wind stress drives convergence in the relatively fresh ocean surface layer. However, the strength of the Beaufort Sea anticyclonic circulation cannot be the only factor in freshening the Canada Basin. FWC in the Beaufort Sea increased at a time of reduced anticyclonic circulation in the early 1990s, and much of the recent freshening has been due to an influx of Eurasian runoff.

Satellite measurements of ocean bottom pressure (OBP) from the Gravity Recovery and Climate Experiment (GRACE) and dynamic ocean topography (DOT) from the Ice Cloud and land Elevation Satellite (ICESat) give the spatial and temporal coverage needed to reconcile these two aspects of Arctic Ocean change. Trends in ICESat DOT from 2005 to 2008 show a strengthening of both the anticyclonic Beaufort Gyre and a cyclonic DOT trough aligned with the Russian shelf break. Subtracting ICESat DOT trends from GRACE OBP trends determines basin-wide FWC trends. These reveal increasing FWC in the Canada Basin balanced by decreasing FWC along the Russian side of the ocean. The average FWC trend is slightly positive in agreement with the average trend based on hydrography. The trough in DOT, arguably driven by an increased AO, produces eastward velocity trends along the Russian coast that move Eurasian runoff eastward into the Canada Basin circulation, increasing FWC there.

P05S1.02

P05S1 - Arctic Ocean

Oral

Arctic Ocean liquid freshwater storage trend 1992-2012: Regional distribution, circulation and stratification

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Freshwater in the Arctic Ocean plays an important role in the regional ocean circulation, sea ice and global climate. Yet, state of the art climate models do not agree in the redistribution of freshwater toward the end of this century. From salinity observed by a variety of platforms we are able to estimate, for the first time, the trend over all upper Arctic Ocean basins during the last two decades: 600 ±300 $km^3 yr^{-1}$ from 1992 to 2012. Comparison to other studies suggests that this trend may be caused by an increased Bering Strait freshwater transport and enhanced net sea ice melt. The observations show an increase in the thickness of the upper layer, suggested by the North Atlantic-Arctic Ocean Sea Ice Model to be driven by wind-induced Ekman Pumping. The model also shows a reduced export of freshwater. In addition, a salinity deacrease in the upper layer was observed in most parts of the Arctic Ocean. The regional distribution shows that the majority of the liquid freshwater content increase occurred on the Amerasian side of the Lomonosov Ridge. However, the variability observed on the Eurasian side has strong implications for the stratification and vertical exchange of nutrients in the upper ocean.

P05S1.03

P05S1 - Arctic Ocean

Oral

Freshwater distribution and variability in the Arctic Ocean: The Switchyard time series in the pan-Arctic context

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The Arctic Ocean is covered by a freshwater lens that strongly influences its stratification and thus the mixing within the upper water column and the heat flux from the Atlantic Water to the sea ice cover. The strength and dynamics of the freshwater lens has significant impact on sea ice formation and melting and vice versa. The freshwater is derived from three main sources: Relatively fresh Pacific Water, Meteoric Water (River Runoff and P-E) and Sea-ice Meltwater. In addition to natural variability the freshwater lens is expected to undergo changes as part of the rapid system-scale Arctic change that has been observed in recent decades. We use data from a time series collected in the Switchyard region of the Arctic Ocean north of Greenland to quantify the freshwater inventories and components in the upper water column of this region. We discuss the variability of the total freshwater inventory and its components for the past 6 years. The data reveal significant changes in both freshwater inventories and composition. The changes in the total inventories are smoother than those of the individual components. Whereas the variability of the total freshwater inventory occurs on a time scale close to a decade, the variations in freshwater components appear to be much faster and significant transitions in their distributions have been observed from one year to the next. The freshwater inventories and components observed in the Switchyard region are placed into the context of the freshwater budget of the Arctic Ocean and its variability derived from icebreaker sections completed between 1987 and 2005.

P05S1.04

P05S1 - Arctic Ocean

Oral

Freshwater components in the East Greenland Current between Denmark and Fram Strait 2012

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The liquid freshwater content of the Arctic Ocean increased with over 8000 km^3 between 2003 and 2010. Riverine water subject to strong anticyclonic wind forcing has contributed to the observed accumulation in particularly the Canada Basin but also the central Arctic. Arctic freshwater leaves the Arctic Ocean both through Fram Strait and the Canadian Arctic Archipelago but anomalies can occur depending on prevailing circulation patterns. The relative contribution of meteoric water, sea-ice melt water and Pacific Water to Arctic freshwater can be quantified using oxygen isotopes, phosphate and nitrate as tracers. Here we show results from tracers that were taken on eight hydrographic sections along the East Greenland Current (EGC) between Denmark Strait and Fram Strait in summer 2012 and from one section in summer 2011. Tracer results on the Kogur line in the EGC north of Denmark Strait showed a clear presence of Pacific Water both in 2011 and in 2012. These results are in agreement with observations further north in Fram Strait where Pacific Water was first observed again since 1998 in 2011 while in the 2000s there were little changes in freshwater inventories. The contribution and lateral differences of the different freshwater components on several sections across the EGC as well as the freshwater fluxes are presented. Finally an estimate is made of the amount of freshwater leaving the EGC into the Nordic Seas.

P05S1.05

P05S1 - Arctic Ocean

Oral

Impact of enhanced melt from West Greenland on the Canadian Arctic Archipelago throughflow

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Here we investigate the impact of enhanced runoff from west Greenland on Baffin Bay, the transport of the Canadian Arctic Archipelago (CAA) and freshwater fluxes south through Davis Strait into the Labrador Sea. Simple modelling experiments using a regional eddy-permitting ocean/sea-ice general circulation model show a significant storage of the added freshwater in Baffin Bay on inter-annual timescales, with reductions of salinity in the upper water column and increases in freshwater content. The changes in freshwater content raise the dynamic height in Baffin Bay, reducing the height difference across the CAA. This leads to a reduction in volume and freshwater transports through the CAA and leads to enhanced transport at Fram Strait to compensate. The net result of the enhanced freshwater storage in Baffin Bay, combined with the reductions in CAA transport, is that little or no signal of the added runoff from west Greenland is seen flowing south at Davis Strait, at least on inter-annual timescales.

P05S1.06

P05S1 - Arctic Ocean

Oral

High-resolution modeling study on the Atlantic water inflow to the Arctic Ocean

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Many studies have pointed out that the inflow of warm Atlantic water supplies a vast amount of heat to the Arctic Ocean and maintains the warm water layer under the halocline in the Arctic Ocean. Because narrow currents (e.g., West Spitsbergen Current) contribute to the heat transport, and eddies affect the water exchange around the Fram Strait, high-resolution modeling should be conducted to investigate the effect of warm Atlantic Water inflow on the Arctic sea ice. We examine the mechanism of inflow of Atlantic water by using a realistically configured high resolution model. The horizontal resolution is ~ 3 km around the Fram Strait and Barents Sea Opening, and less than 5 km in the GIN Seas and Barents Sea. The sea surface heat and momentum flux are calculated using daily mean surface air properties, and the rain/snow fall is applied based on CORE dataset. The AOMIP river runoff is employed in the Arctic Ocean. The margin of sea ice is well reproduced and consistent with satellite observations in winter. The warm, saline Atlantic water enters through the Fram Strait and is transported by cyclonic boundary currents along the continental slope in the Arctic Ocean in our model. The Barents Sea branch of the Atlantic water inflow, which is cooled on its way through the Barents Sea, enters into the Eurasian Basin through the St. Anna Trough in our model. These routes of the Atlantic Water inflows are consistent with the observations and previous modeling studies. The model result shows that the mesoscale eddies affect the warm water transport through the Fram Strait. Here we closely examine the relationship between the eddy activities and heat flux.

P05S1.07

P05S1 - Arctic Ocean

Oral

Ice thickness distribution and drift velocities in axially symmetric solutions of sea ice dynamics models with elastic-plastic and viscous-plastic rheology

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The paper is devoted to the analysis of explicit solutions of equations describing large scale dynamics of drifting ice. Equations describing axially symmetric motions of the ice cover with elastic-plastic and viscous-plastic rheology are formulated and analysed when the ice drift is exited by cyclonic or anticyclonic wind vortex. The yield curve is performed by an ellipse in both cases. The sizes of the yield curve depend on the ice thickness and compactness. Elastic-plastic solutions consists of elastic kernel rotated with constant angular velocity, plastic ring with pure shear motion of the ice and elastic ring at the periphery of the plastic ring where the ice is in the rest. Viscous-plastic solutions include a kernel where the ice is in linear viscous state, plastic ring with pure shear motion and periphery ring with linear viscous state of the ice. The Coriolis force influences the increase of ice thickness from the periphery of the plastic ring to the kernel in anticyclonic ice vortex. In case of cyclonic ice vortex the ice thickness decreases from the periphery of the plastic ring to elastic or viscous kernel. This effect can influence lead opening in case of anticyclonic wind vortex and ice ridges build up in case of cyclonic wind vortex at the periphery of the plastic ring. The size and location of plastic ring in elastic-plastic model depends on elastic modulus of the ice and the yield curve. In case of viscous-elastic model the steady solutions have singularities in ice thickness in the origin in case of anticyclonic wind vortex and at the periphery of the viscous ring in case of cyclonic wind vortex. It is explained by gradual increase of the ice thickness under the influence of the Coriolis force due to viscous rheology of the ice. Respectively boundary conditions in the origin or at the periphery of the viscous ring are not satisfied.

P05S2.01

P05S2 - Arctic Ocean

Oral

Semidiurnal tides on the Laptev Sea shelf based on oceanographic moorings with implications for shear and vertical mixing

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Spatial, seasonal and interannual variability of semidiurnal tides and shear were investigated with 12 year-round records from six different oceanographic mooring locations across the Laptev Sea shelf. Tides are dominated by the M_2 followed by the S_2-constituent and show a strong depth-dependence in the clockwise currents clearly linked to stratification. S_2 displays considerable semiannual oscillations (3-9 cm s^{-1}), peaking in fall and spring. Total current magnitudes are stronger on the outer than on the inner shelf, and tides overall explain >80% of the current's variance throughout the year. On the inner shelf, tides play a comparatively greater role under sea ice (40-70%) as opposed to open water periods (20-50%) when wind-induced inertial motions dominate. Four years of an inner shelf mooring show variable vertical tidal structures, due to stratification that is more complex than on the outer shelf, where three years of data show comparatively constant tidal structures with maxima below the pycnocline. Each of the inner shelf records shows a downward progressing pycnocline coincident with a salinity decrease in mid-winter, implying downward export of fresh surface waters. Two September 2007 cross-shelf microstructure transects complemented the mooring records and showed episodes of intense turbulent kinetic energy dissipation in the pycnocline following the alignment of the semidiurnally rotating shear-vector and the surface forcing. Our data provide a comprehensive overview of semidiurnal tides, shear, stratification, and diapycnal mixing on the Laptev Sea shelf and highlight the potential of tides for vertical transport of freshwater, heat and nutrients.

P05S2.02

P05S2 - Arctic Ocean

Oral

Has the Arctic Ocean sea ice thickness a natural threshold around 2 meters?

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In this study we investigate the response of sea ice thickness to changes in the external forcing and particularly how this response depends on the surface albedo formulation by means of a 1-dim coupled ocean-ice-atmosphere model. The main focus is on the thickness response to the atmospheric heat advection *Fwall*, solar radiation and amount of snow precipitation. Different albedo parameterization schemes (ECHAM5, CSIRO, and CCSM3) representing albedos commonly used in global climate models are compared together with more simplified schemes. Using different albedo schemes with the same external forcing produces large differences in ice thickness. The ice thickness response is similar for all realistic albedo schemes with a nearly linear decrease in ice thickness with increasing *Fwall* in the perennial ice regime and with a steplike transition into seasonal ice when *Fwall* exceeds a certain threshold. This transition occurs at an annual mean ice thickness of 1.7-2.0 m. A general result is that the modelled ice cover is rather sensitive to positive perturbations of the external heat supply when it is close to the transition such that just a small increase of e.g. *Fwall* can force the ice cover into the seasonal regime.

P05S2.03

P05S2 - Arctic Ocean

Oral

The low frequency sea level variations at the gateway to the Arctic

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The North Atlantic water entering the Nordic Seas at the Iceland-Scotland Ridge is an important contributor to the currently observed Arctic warming. In this study, we combined the longest available tide gauge records and satellite altimetry data to assess the decadal-interdecadal variability between the North Atlantic and the Nordic Seas. Different techniques based on the Empirical Orthogonal Functions (EOF) were used to complete the missing observations in the tide gauge records. The reconstructed sea level fluctuations in the Grrenland-Iceland-Norwegian Sea and on the Northern European Shelf over 1950-2012 reveal pronounced decadal variabilities superimposed on a steady non-linear trend that can be interpreted in terms of sea level rise amplification since the 1990's. The sea level decadal variability seems to be closely linked to NAO/AO indicies while the interdecadal sea level fluctuations are mostly controlled by the dominant EOF of steric sea level in the North Atlantic that suggests an important contribution of the Subpolar Front currents to the warming of the Arctic Ocean.

P05S2.04

P05S2 - Arctic Ocean

Oral

Characteristics of ocean currents below drifting ice and around an iceberg in the Greenland Sea

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Deep knowledge of sea ice structure, drift characteristics and drag forces is required for successful offshore development in the Arctic. Information on under ice turbulence is useful for the estimates of dynamics of oil spill spreading under drifting ice. Field measurements of hydrographic properties and ocean currents were performed from the ice at two stations in the North Greenland Sea when research icebreaker Oden was moored to drifting ice floes. . The work on the ice stations included CTD profiling over the entire water column, synchronous CTD records on 5 depths and ADCP profiling. An RDI 1200 kHz ADCP was deployed in downward looking mode from the ice with sampling frequency 5 Hz for the investigation of under-ice turbulence. Vertical profile of mean water velocity below the ice, kinetic energy of turbulent fluctuations and their spectral characteristics, Reynolds stresses are analyzed with the collected data. Vertical profiles with CTD and ADCP were also performed from four sides of a drifting iceberg, down to 60 m depth. Deformation of the pycnocline around the iceberg was recognized by CTD data. Vertical profiles of water velocity are analyzed for the estimates of water drag force on icebergs drifting within the pack ice.

P05S2.05

P05S2 - Arctic Ocean

Oral

Prediction of the Arctic Ocean surface layer salinity: is it possible?

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The Arctic Ocean is known to be very sensitive to environmental conditions. It is obvious, that significant decreasing of the Arctic Ocean ice content over the recent years, as well as air temperature rising in the Arctic affect the state of the Arctic Ocean surface layer. It is known that surface layer constitutes the dynamical and thermodynamical link between the atmosphere, sea ice and the underlying waters. With mixed layer thickness and upper layer salinity and the upper halocline state the geographic distribution of sea ice and its climatic variability, as well as stability and development of the ice cover are often associated. In this context, the Arctic Ocean surface layer state can be a good indicator of climate change in the Arctic. Due to substantial climatic changes recently occurred in the Arctic, there is a question about the scenarios for the Arctic region future.

Given the Arctic Ocean water density depends more on water salinity, if we could predict the shape of salinity field we could predict the main features of the thermohaline circulation and ice circulation as well.

In order to analyze the interannual variability of the Arctic Ocean surface layer salinity the method of decomposition on Empirical Orthogonal Functions (EOF) was used. The decomposition was carried out for the mean salinity in the layer of 5-50 m for the winter season 1950-1993 and 2007-2010.

Based on the results of correlation analysis of Principal Components (PC) with different external factors, the multiple regression equations were constructed and predictors that describe interannual variability of PCs in a best way were identified. It was found that results of EOF decomposition for the period of 1950-1993 are differ from the results of the expansion, which include also 2007-2010. This fact indicates that the thermohaline structure of the surface layer has undergone significant changes in recent years.

P05S2.06

P05S2 - Arctic Ocean

Oral

Development of Envisat satellite altimetry data and sea level changes in Arctic Ocean

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Continuous monitoring of sea level variability from satellite altimetry can be considered as one of the most fundamental steps for a better understanding of oceanic processes in the deep ocean. For sun-synchronous satellites (e.g., ERS-2 and Envisat), the complexity of environments, such as extension of ice, corrupts altimetry measurements and limits their use in the Arctic Ocean.

In our presentation, three days gridded Envisat sea level maps are developed based on sun-synchronous satellite altimetry measurements in Arctic Ocean. Generally, the largest errors in the altimeter measurement system are due to poor orbit determination, introducing uncertainties at wavelengths greater than 1000 km. Hence the removal of orbit errors in sun-synchronous satellite altimetry is performed. Combined with Jason satellite altimetry, Envisat satellite altimetry tracks are crossover adjusted using bias and tilt. Then the adjusted sea level anomalies are gridded to a normal grid using collocation with a second-order Markov covariance function using spatial temporal interpolation, which takes into account data from nearby periods in case of missing data. Compared with existing Envisat altimetry sea level data products, the new developed dataset is improved in data coverage in high latitudes. The new Envisat data is used to study the sea level variability in Arctic Ocean. Significant sea level fall is presented from latest 8 years Envisat satellite altimetry data. The presentation is a contribution to the EU 7th FW supported projects MONARCH-A.

P05S2.07

P05S2 - Arctic Ocean

Oral

Russian drifting stations in XXI century

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The review of the main directions of field investigations executed on the drifting stations «North Pole -32» - «North Pole -40» in 2003 – 2012 years is presented. Some new results in polar oceanography, sea ice studies, sea ice albedo and snow properties, structure of atmospheric boundary and surface layers, processes of greenhouses gases exchange in presence of sea ice cover are shown.

P06PS.01

P06PS - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Poster

Using ADCP ancillary data analysis to detect zooplankton migration in Terra Nova Bay polynya (Ross Sea, Antarctica)

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Acoustic measurements are often used for the remote observation of the water column and are of particular advantage for long term investigation in the polar areas, where direct measurements are hampered by the presence of sea-ice. Despite devised for 3D currents measurements, the ancillary data provided by the ADCP (Acoustic Doppler Currents Profiler) such as echo intensity and the derived mean volume backscatter strength, have proved to provide useful information to support different scientific investigation such as the detection of vertical zooplankton migration and suspended sediments variability.

Time-frequency analysis was performed on one-year time serie of ADCP ancillary data collected in Terra Nova Bay (74°55.11' S; 164°20.4'E) polynya to investigate the seasonal evolution of zooplankton migration. Spectral analysis was performed on the mean backscatter volume time series by using a 240h-wide window moving at 1 day step. Assuming that the 24 hour period peak is associated to zooplankton diel vertical migration, the amplitude of the power spectral energy on this band was then extracted from each spectrum and the time series of amplitudes analyzed. The results evidence four "blooms", the first one occurring at the end of August and the others about each three weeks; the last one is at the end of October. At the mooring latitude the last sunset occurs on 1 May and the area is completely dark until 13 August. The occurrence of the first bloom indicates that, differently from the other antarctic regions, in the polynya, the sun light immediately penetrates into the water, stimulating an early productivity. This method of analysis has proven to be simple but efficient to give additional information for long-term ecosystem dynamics and productivity studies and models. It can be routinely applied to the available ADCP measurements that should be included into the monitoring observing systems.

P06PS.02

P06PS - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Poster

Southern ocean bottom water characteristics in CMIP5 models

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The depiction of Southern Ocean deep water properties and formation processes in climate models is an indicator of their capability to simulate future climate, heat and carbon uptake, and sea level rise. Southern Ocean temperature and density averaged over 1986-2005 from fifteen CMIP5 climate models are compared with an observed climatology, focusing on bottom water. Bottom properties are reasonably accurate for half the models. Eleven models create dense water on the Antarctic shelf, but it mixes with lighter water and is not exported as bottom water as in reality. Instead most models create deep water by open ocean deep convection, a process occurring rarely in reality. Models with extensive deep convection are those with strong seasonality in sea ice. Optimum bottom properties occur in models hosting deep convection in the Weddell and Ross gyres. Formation processes are poorly represented in models and are a key challenge for improving climate predictions.

P06PS.03

P06PS - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Poster

Dissolved iron sources and biological iron demand on the Ross Sea continental shelf: initial results from the PRISM project

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The Ross Sea polynya is the most productive region in the Southern Ocean, sustaining an average net primary production of ~23 Tg C/y. Field observations indicate that phytoplankton growth in this region in summer can be limited by availability of dissolved iron (dFe), which is drawn down to low concentrations (~0.1 nM) as early as mid November. Despite this, the polynya supports substantial production during the December-February period, implying sustained dFe inputs to surface waters over this time. The PRISM project aims to constrain these inputs by combining field observations and numerical modeling. Our observations from January-February 2011 revealed elevated benthic dFe concentrations, with an average of 30% of total water column dFe inventory residing within 100m of the seafloor. An estimate of the 'winter reserve' of dFe provided by convective resupply of this benthic dFe could support ~45% of the biological iron demand of 4.6 µmol Fe/m^2/y that is inferred from field and satellite data. Measured dFe concentrations in subsurface waters, estimates of dFe released by sea ice and glacial ice, and ROMS model simulations of regional circulation to suggest that melting sea ice and Circumpolar Deep Water provide dFe inputs that fuel ~35% of the biological iron demand during the growing season, whereas dFe inputs from melting of the Ross Ice Shelf appear to be negligible.

P06PS.04

P06PS - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Poster

A possible effect of ENSO and SAM over surface heat budgets in the Ross and Weddell Seas

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Operational analyses and re-analyses, provided by ECMWF for the period 1958-2010, were used to investigate the role of atmospheric forcing in the Ross and Weddell Seas. State variables have been used to estimate the surface heat fluxes via empirical formulae. Interactions between atmosphere and ocean are strongly influenced by the presence/absence of the ice cover. For this reason, SSM/I data were used to detect ice cover for the available period. Moreover a new algorithm was implemented to estimate the sea ice thickness from SSM/I brightness temperature in the study areas. The heat loss, in the Ross Sea, reaches its maximum in 2008 (-98 Wm^{-2}) and its minimum (-65 Wm^{-2}) in 1972. In the Weddell Sea it ranges between -67 Wm^{-2} (1990) and -96 Wm^{-2} (2008). The studied areas show synchronous or opposite variations depending on the period. Explanation of this behaviour may be linked to the signature of global climate variability expressed by El Niño Southern Oscillation (ENSO) and Southern Annular Mode (SAM) through their indices respectively SOI and SAMi. In order to detect any relationship the wavelet analysis was used. Main periods of variability of the two indices were evaluated. A change in the variability scale of the SAM was detected from 1993 to 2004, while other variability scales, from 1 year to about 5 years, are more stable for both phenomena. Successively, by means of cross-wavelet and wavelet coherence analyses, a different influence of the atmospheric phenomena over the seas was found. In particular short variability scales up to 2 years are usually more significant, and anti correlated, over the Ross Sea area. On the other hand longer variability periods of the indices seem to be more connected to the Weddell Sea surface fluxes with a change of the correlation sign in coincidence with the change observed in the SAMi typical variation scales.

P06PS.05

P06PS - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Poster

The structure of near-bottom layer in the abyssal Vema channel from experimental data

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The structure of the near-bottom layer in the channel from CTD and LADCP profiles of April, 2009 is considered. The cold flow of AABW entered the channel from south close to the area of work. Minimal potential temperature was -0.126° and the flow speeds were as high as 30-40 cm/s. The near-bottom mixed layer is one of the essential and permanent characteristics of the section. Its horizontal structure varies seasonally and from year to year, but it is always easily determined by temperature and salinity as an almost homogeneous stratum developed directly above the bottom to the different height. In the considered period, a powerful isothermal layer (IBL) about 200 m thick in the axial part of the channel was separated from the overlying strata by the well-developed deep thermocline with high gradients. The thickness of the layer to the boards was reduced, and the transition zone above them had no pronounced thermocline. Features of the velocity field, in general, correlated with the structure of the temperature field. The flow of stable north directions and speeds varying with height corresponded to the IBL. In the lowest levels of the IBL, the typical speed reduction and veering of velocity vectors to the bottom showed the development of the bottom boundary layer related to the process of Ekman slowdown due to friction. The intensity of these processes was related, in particular, with the level of stability of the temperature (density) stratification. As followed from the stability parameter profiles, the stratification is unstable or neutral within the IBL and stable above it. The highest level of stability was in the transition zones over the homogeneous layer. Distance from the bottom, where the maximum levels of the parameter were achieved in the thermocline directly correlated with the thickness of the IBL.

P06PS.06

P06PS - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Poster

Vorticity balance of the Antarctic Circumpolar Current from observations in Drake Passage and the Southern Ocean State Estimate

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The nonlinear vorticity balance of the Antarctic Circumpolar Current is examined using observations in Drake Passage and the data-assimilating, eddy-permitting Southern Ocean State Estimate (SOSE). Four years of near-bottom currents, bottom pressures, and bottom-surface round-trip sound travel time were collected by an array of Current and Pressure-recording Inverted Echo Sounders (CPIES) deployed at 37-km spacing in the Polar Frontal Zone (PFZ) in Drake Passage as part of the IPY cDrake experiment. Empirical relationships based on historical hydrography are used to convert travel time data to baroclinic streamfunction, while barotropic streamfunction and velocity are provided by measured bottom pressures and currents. Objective mapping enables computation of terms of the quasi-geostrophic vertical vorticity balance, including eddy fluxes. In the local vorticity budget in the PFZ, nonlinear vorticity advection, both mean and eddy, dominates over linear advection by a factor of ten and, in the depth integral, over bottom pressure torque by a factor of three. Wind stress curl and flat-bottom friction are negligible, and the contribution of cyclostrophic motion is small. Nonlinear advection and bottom pressure torque are anti-correlated in both space and time, and partially balance. The connection between the vorticity balance residual and strong near-bottom flows suggests a role for drag on the mesoscale velocity and vorticity fields by means of internal wave generation and breaking. The SOSE vorticity budget in Drake Passage strongly resembles the observed balance. Mean and eddy relative vorticity advection dominate and are balanced by divergence and sub-grid-scale eddy diffusivity. The depth-integrated divergence term is about half integrated ageostrophic divergence and half bottom pressure torque. The eddy advection term diminishes with spatial smoothing, but the dominance of nonlinear advection and divergence is preserved up to 200-km scales.

P06PS.07

P06PS - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Poster

Observations of circulation of warm deep-water at the Amundsen Shelf edge

Wåhlin, A.K. 1; Kalén, O. 1; Arneborg, L. 1; Björk, G. 1; Carvajal, G.K. 2; Ha, H.K. 3; Kim, T.W. 3; Lee, S.H. 3; Lee, J.H. 3; Stranne, C. 1

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The observed thinning and acceleration of the West Antarctic glaciers emptying into the Amundsen Sea region has implications on global sea level rise. The primary driver in the thinning process is the advection of relatively warm circumpolar deep-water (CDW) melting the floating ice shelf from below. The dense CDW is topographically steered onto the shelf area via bathymetric channels by deep ocean currents. The spatial and temporal properties of inflow and outflow of deep-water in the shelf-break area are not fully understood, both due to the lack of in-situ measurements as well as ocean models being too coarse to resolve these dynamics. In this study we present time series observations from 2009 to 2011 of hydrographic properties from two moorings in a western and an eastern channel, both leading to the Amundsen Sea ice shelf. Structure and variability of the time series of velocities and temperature are analyzed. The results suggest that there is a steady inflow of warm deep water in the eastern channel and an outflow in the western channel, which is slightly colder due to the heat loss to the melting of the ice shelf.

P06PS.08

P06PS - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Poster

Intrinsic low-frequency variability of the Argentine Basin flow, and its interaction with the Antarctic Circumpolar Current

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The dynamics of the Argentine Basin (AB) flow is of climatic relevance, as it yields strong mixing between Antarctic water masses (carried by the Malvinas Current) and subtropical water masses (carried by the Brazil Current). Such mixing is regulated by the Zapiola Anticyclone, a counterclockwise current that encircles the Zapiola Rise, the main topographic feature of the AB. Recent observations have evidenced a clear variability of the Zapiola Anticyclone over periods that range from a 25-day oscillation to an interannual signal controlled by the local topography. We investigate the intrinsic variability of the AB flow by using a sigma-coordinate model. The periodic domain of integration includes the Pacific/Atlantic sector of the Southern Ocean, so that the Antarctic Circumpolar Current (ACC) is also simulated; moreover, the forcing is provided by steady climatological surface heat and momentum fluxes. Results show several phenomena of both high and low-frequency variability which are found to be particularly sensitive to background stratification and the degree of smoothing of the bottom topography. The high-frequency variability is characterized by an anticyclonic wave around the Zapiola Rise: this is interpreted as a superposition of topographic Rossby normal modes which appear to be triggered by the intrinsic low-frequency variability. The latter evidences two distinct regimes of the flow with very different variance, that are connected by rapid transitions. A relatively low variable regime is characterized by a permanent Zapiola Anticyclone located over the Zapiola Rise; a more variable regime is characterized by strong eddy activity, mostly concentrated in the southern part of the basin, where the Sub-Antarctic Front is located. In general, the AB circulation is found to be strictly related to fluctuations of the position of the ACC fronts. Finally, interesting agreement is found when comparing our model results with altimeter data.

P06PS.09

P06PS - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Poster

Variability of warm deep water inflow in a submarine trough on the Amundsen Sea Shelf

Wåhlin, A.K. 1; Kalén, O. 1; Arneborg, L. 1; Björk, G. 1; Carvajal, G. 2; Ha, H.K. 3; Kim, T.W. 3; Lee, S.H. 3; Lee, J.H. 3; Stranne, C. 1

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The ice shelves in the Amundsen Sea are thinning rapidly, and the main reason for their decline appears to be warm ocean currents circulating below the ice shelves and melting the glacial ice from below. Ocean currents transport warm dense water onto the shelf, channeled by bathymetric troughs leading to the deep inner basins. A hydrographic mooring equipped with an upward-looking ADCP has been placed in one of these troughs leading to the deep shelf basins on the Central Amundsen Shelf. The two years (2010-2011) of mooring data are here used to characterize the inflow of warm deep water to the deep shelf basins. During both years the warm layer thickness and temperature peaked in fall, during March - April - May. The along-trough velocity is dominated by strong fluctuations that do not vary in the vertical. These fluctuations are correlated with the local wind, with eastward wind over the shelf and shelf-break giving flow towards the ice shelves. In similarity with the Marguerite Bay and trough, there exists a persistent flow of dense Lower Circumpolar Deep Water (LCDW) towards the ice shelves in the bottom layer. This bottom-intensified flow appears to be driven by buoyancy forces rather than the shelf-break wind. The years of 2010 and 2011 were characterized by a comparatively stationary Amundsen Sea Low, and hence there were no strong eastward winds during winter that could drive an upwelling of warm water along the shelf break. Regardless of this, there was a persistent flow of LCDW in the bottom layer during the two years. The average heat transport towards the ice shelves in the deep trough was estimated to be 0.95 TW.

P06S1.01

P06S1 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

The control of the Southern Hemisphere Westerlies on the position of the Subtropical Front

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In recent years the latitudinal position of the Subtropical Front (STF) has emerged as a key parameter in the global climate. A poleward positioned front may allow a greater salt flux from the Indian to the Atlantic Ocean and so drives a stronger Atlantic Meridional Overturning Circulation. Observed or predicted meridional shifts in the STF are usually attributed to climate induced shifts in the Southern Hemisphere Westerlies winds. Here, the accepted view that the STF aligns with the zero windstress curl (WSC) is challenged. Based on the STF climatologies of Orsi (1995), Belkin and Gordon (1996), and Graham and De Boer (2013), and on satellite scatterometry winds, we find that the zero WSC contour lies ~10°, ~8°, and ~5° poleward of the front for the three climatologies, respectively. Output from the eddy-permitting coupled climate model HiGEM indicates that the STF corresponds to the southern boundary of the subtropical gyre, as previously suggested, but the position of this boundary does not extend to the latitude of zero WSC. The transport between the gyre and the zero WSC contour is forced by strong bottom pressure torque that is a product of the interaction of the Antarctic Circumpolar Current (ACC) with the ocean floor topography. We suggest that the position of the STF is not simply controlled by the latitude of zero WSC but rather by the northward extent of the ACC and the complex dynamics that regulate the separation of the western boundary currents from continents. This work clarifies previous misconceptions and contributes to our understanding of how the STF and the Atlantic Meridional Overturning Circulation may respond to a wind shift under future warming.

P06S1.02

P06S1 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

The two dynamical regimes of the subtropical front

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Quaternary paleorecords and climate simulations of recent decades suggest that the Subtropical Front (STF) plays a key role in the global climate system. It is hypothesised that a poleward shift of the Southern Hemisphere Westerlies may push the STF southward and strengthen the Atlantic Meridional Overturning Circulation, by allowing a stronger salt flux from the Indian to the Atlantic Ocean. Confirmation this theory is limited by lack of data, but arguably more so by our poor understanding of what the STF is. Descriptions of the STF range from a frontal zone of weak, shallow and density compensated fronts, to a single front with transport of ~60 Sv and a depth of more than 1000 m. Confusion also exists over whether the latitude of the front corresponds to the maximum or zero wind stress curl, and if it experiences a large or small seasonal cycle. Here we use satellite sea surface temperature (SST) data to show that the traditional STF, as defined by water mass properties, is comprised of two distinct dynamical regimes. On the western side of each basin the traditional STF coincides with a deep current that has strong SST gradients and no seasonal cycle. We define this as the Dynamical STF (DSTF). Further east, the DSTF diverges from the traditional STF and tracks south-eastwards into the centre of each basin to merge with the Sub-Antarctic Front. The traditional STF continues to the eastern side of the basins where it coincides with the so-called Subtropical Frontal Zone (STFZ), a zone of shallow SST fronts that have little transport and large seasonal cycles. Distinguishing between these dynamical regimes resolves historic confusion surrounding the STF. This work provides a new framework to study the behaviour of the STF and interpret observations, paving the way for better predictions on the likelihood and impact of future STF changes.

P06S2.01

P06S2 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

The frontal structure south of Africa based on the data of satellite altimetry and the SR02section in December 2009

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The frontal structure in the region south of Africa is investigated on the basis of statistical analysis of weekly data of Absolute dynamic topography (ADT) developed by the French agency CLS (DT-Global-MADT-Upd product, http://aviso.oceanobs.com), and CTD- and SADCP-measurements along the SR02 hydrophysical section carried out onboard R/V “Akademik Ioffe” in December 2009 from the Good Hope Cape to 57 deg S at the Prime Meridian. Twelve jets of the Antarctic Circumpolar Current (ACC) were revealed. These were six jets of the Subantarctic Current, four jets of the South Polar Current (SPC), and two jets of the South Antarctic Current. The jet combining the Weddell Front and the Southern Boundary of the ACC was also revealed. All jets of the SPC were joined in a single “super-jet” according to the measurements. The others were manifested by the local velocity maxima in the surface layer. According to the altimetry data, the jets were distinguished as bands of enhanced ADT gradient in averaged statistical distributions of ADT gradient depending on ADT values. The jet axes were defined as ADT values corresponding to local maxima of ADT gradients. The averaging was implemented in a region of the Southern Ocean from 10 deg W to 25 deg E, and time intervals from one day to half year, including the date of the section SR02. It is shown that the jet axes were keeping about the same ADT values during the mentioned time intervals. The widths of the jets distinguished as described above were 10–15 cm (in ADT units) each. There is a good agreement between jet axes locations along the section revealed on the basis of CTD, SADCP, and altimetry data. The part of the SR02 section, from the Southern Subtropical Front to the Shelf-Slope Front near the African shore, crossed a large segment of the Agulhas Retroflection which was disintegrating into individual eddies. Two small cyclonic and one anticyclonic eddies of the Agulhas Current were also found.

P06S2.02

P06S2 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

Southern ocean fronts: controlled by wind or topography?

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The location of fronts has a direct influence on both the physical and biological processes in the Southern Ocean. Here we explore the relative importance of bottom topography and winds for the location of Southern Ocean fronts, using 100 years of a control and climate change simulation from the high resolution coupled climate model HiGEM. Topography has primary control on the number and intensity of fronts at each longitude. However, there is no strong relationship between the position or spacing of jets and underlying topographic gradients because of the effects of upstream and downstream topography. The Southern Hemisphere Westerlies intensify and shift south by 1.3° in the climate change simulation, but there is no comparable meridional displacement of the Antarctic Circumpolar Current's (ACC) path or the fronts within its boundaries, even over flat topography. Instead, the current contracts meridionally and weakens. North of the ACC, the Subtropical Front (STF) shifts south gradually, even over steep topographic ridges. We suggest the STF reacts more strongly to the wind shift because it is strongly surface intensified. In contrast, fronts within the ACC are more barotropic and are therefore more sensitive to the underlying topography. An assessment of different methods for identifying jets reveals that maxima of gradients in the sea surface height field are the most reliable. Approximating the position of fronts using sea surface temperature gradients is ineffective at high latitudes while using sea surface height contours can give misleading results when studying the temporal variability of front locations.

P06S2.03

P06S2 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

Upwelling in the Weddell Sea inferred from helium isotope disequilibrium

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Upwelling plays an important role regarding the physical and biogeochemical characteristics of the mixed layer, and it may also counteract the uptake of atmospheric gases like CO_2. However, estimates of upwelling velocities are rare, particularly in the Southern Ocean. Since upwelling velocities are too small to be measured directly - approximately a few meters per day - an indirect method to infer upwelling velocities from the helium isotope disequilibrium in the mixed layer is applied here instead.

Helium isotope data measured during austral summer 2010/11 in the Weddell Sea and south of 55°S along the Greenwich Meridian show a significant excess of ^3He in the mixed layer. The influence of the prevailing wind fields and the ice coverage was studied and first results of the upwelling velocities will be presented.

P06S2.04

P06S2 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

Slowing down of deep and bottom water ventilation and anthropogenic carbon storage in the Weddell Sea

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We use a 27 year long time series of repeated transient tracer observations to investigate the evolution of the ventilation time scales and the related content of anthropogenic carbon in deep and bottom water in the Weddell Sea. This time series consists of chlorofluorocarbon (CFC) observations from 1984-2008 together with first combined CFC and sulphur hexafluoride (SF6) measurements from 2010/2011 along the Prime Meridian in the Antarctic Ocean (1984-2011) and across the Weddell Sea (1992-2011). Applying the Transit Time Distribution (TTD) method we find that all deep water masses in the Weddell Sea have been continually growing older and getting less ventilated during the period of observations. The decline of the ventilation rate of Weddell Sea Bottom Water (WSBW) and Weddell Sea Deep Water (WSDW) along the Prime Meridian is in the order of 15-21%; the Warm Deep Water (WDW) ventilation rate declined much faster by 33%. About 88-94% of the age increase in WSBW near its source regions (1.8-2.4 years per year) is explained by the age increase of WDW (4.5 years per year). As a consequence of the aging, the increase of anthropogenic carbon in the deep and bottom water formed in the Weddell Sea slowed down by 14-21% over the period of observations.

P06S2.05

P06S2 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

Interannual variability of the Ross Sea shelf waters and correlation with climate indices

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The production of Antarctic Bottom Water (AABW) plays a major role in determining the strength of the global Meridional Overturning Circulation and, therefore, is an important element in the ocean's contribution to the global climate. Observations within the Southern Ocean's Pacific sector indicate a decadal trend of reduced salinity, which if continued might be expected to modify the formation rate of the AABW.

A 10 years time-series collected at bottom of the Glomar Challenger Trough (central Ross Sea), shows a big change in the thermohaline characteristics of the Shelf Waters involved in the formation of the AABW. In particular, it shows a freshening of the High Salinity Shelf Water of 0.04 from 1998 to 2006, and a strong reduction of the Ice Shelf Water presence, highlighted in an abrupt change of the temperature during the austral summer 2001/2002. The temperature anomaly time-series is strongly correlated to the NINO3.4 index (r=0.9), while the correlation with the SAM Index is only R=-0.6.

The CTD data collected along the Ross Ice Shelf show a freshening of the benthic layer of about 0.02 from 1995 to 2006 end of 0.07 to 2012.

Looking at the Ross Sea atmospheric conditions during the different phases of the two indices, it's clear that during a negative phase of the NINO3.4 index and a positive phase of the SAM index there is an anomalous low pressure system moving southeastward increasing the meridional winds (northward) close the Ross Ice Shelf and, possibly, also enhancing the Ross Sea polynya activity. On the contrary, during a positive NINO3.4 phase and a negative SAM phase, the low pressure system weakens and moves toward the central Ross Sea producing a decrease of the meridional winds; the latter occurred in 2001/02 austral summer when a strong change in our time-series has been observed.

P06S3.01

P06S3 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

What controls warm deep water flow onto the Antarctic continental shelves?

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Transport of Warm Deep Water (WDW) onto the Antarctic continental margins from intermediate depths offshore strongly impacts coastal circulation, associated ecosystems, and mass loss from the marine margins of the Antarctic ice sheet. Onshore flux of WDW around Antarctica is however highly heterogeneous, being largest in the Bellingshausen and Amundsen seas. These West Antarctic regions are currently experiencing pronounced sea ice reduction, ice shelf thinning and retreat, and land-ice loss contributing to global sea level rise. It has been proposed that WDW might flood onto other continental-shelf regions, with similar impacts, under future climate scenarios. An improved grasp of the processes controlling onshore WDW flow is essential to prediction of these changes.   Currents in a steady state, weakly stratified ocean tend to follow bottom depth contours. The rapid depth change associated with the shelf break is therefore a dynamic barrier to cross-slope WDW flow. Processes that circumvent this constraint include: (1) Along-slope flow leads to cross-slope Ekman fluxes, either upslope or downslope depending on mean flow direction, in the frictional boundary layer. (2) Sufficiently strong along-slope flow can become dynamically unstable, forming meanders and eddies that pump water across the shelf break. (3) The offshore flux of dense shelf water, formed on the inner shelf or beneath ice shelves, requires a corresponding onshelf flow to preserve volume continuity. (4) Regionally strong tidal currents can pump water across the shelf break. (5) Migratory weather systems can lead to pumping of water across the shelf break. Further, seasonal and interannual fluctuations in wind stress fields and in the Antarctic Circumpolar Current can impact temperature, current speeds and upwelling at the continental slope, hence, offshore availability and nature of the WDW.   This presentation addresses these processes, using examples drawn primarily from the West Antarctic region.

P06S3.02

P06S3 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

Observations of ACC forcing and across-shelf warm deep water transport in the Amundsen Sea region

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In the Amundsen Sea region, warm deep water (WDW) flowing southward and under the ice sheet is believed to contribute to the ongoing erosion of the West Antarctic ice sheet. Across-shelf canyons channel the WDW southward and under the ice sheet. This southward deep heat transport was observed in two years of ADCP, temperature, and salinity data from a moored time series near the mouth of the westernmost canyon on the Amundsen shelf. Upstream of the mooring, the Antarctic Circumpolar Current (ACC) is focused by bathymetry into a stable double-jet structure between 210 and 235 E and -57 to -52 N. These jets break into energetic, strongly barotropic eddies, many travelling towards the Amundsen shelf break. The eddy pathways are influenced by bottom topography and the mean flow in which they're embedded. We use Ocean Surface Current Analyses Real-time product (OSCAR) surface currents, which are based on altimetry, wind, and SST, to characterize the offshore large-scale flow in the area and its role in forcing of onshore WDW fluxes. It is observed that the ACC pathways are sensitive to the local bathymetry, with distinct regional flows. The up-canyon flow depends on these regional branches of the main ACC, which are tied to bathymetry, although this not necessarily true for Ekman currents. Our analyses will address offshore mean flow and variability in the ACC, eddy formation and distribution, and estimates of potential up-canyon transport. The regional interannual and seasonal timescales for variation of both surface currents and winds will be analyzed and compared with the timescales observed in the barotropic and baroclinic signals of up-canyon flow. We will show that detailed characterization of regional flow patterns in the ACC is essential to understanding the role of large-scale offshore flow in driving WDW across-shelf.

P06S3.03

P06S3 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

To assess the Amundsen Sea system in the context of the Western Antarctic warming

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The Western Antarctic warmed up by >1 degree C since 80's, according to the long-term climate data. Thinning and retreat of the ice sheet are the immediate outcome of the warming, however the ice melting triggers an array of subsequent changes in the ocean, from circulations to the biogeochemistry. The Amundsen Sea in particular draws keen scientific interests, because we know little about the ocean system and its reaction to the temperature rise. With the commissioning of the IBRV Araon in 2009, Korea Polar Research Institute launched an ocean research program to study why and how the Amundsen Sea is warming, and what the impacts are. The Korean Amundsen Project (KAP) is an integration of interdisciplinary studies and multinational collaborations, harboring many diverse research modules. KAP made thorough field observations and collected long-term data via mooring, during 2 cruises in 2011 January and 2012 February to March. The data revealed the deep warm water penetrates to the coastal shelf area and drives the circulation within. Heat content of the shelf water varied over time and space, and we could estimate the heat exchange between the shelf and the slope. Primary production measured in situ in the polynya was in good accordance with the pCO_2 data and the net community production (O_2/Ar), and in a range comparable with the previous estimates via satellite telemetry. Despite the high POC production in the surface, only a few percent of the POC was caught by sediment traps, indicating most of the POC was released into water column in dissolved forms via the microbial food web, which was supported by our observation of the high bacterial activities. The carbon that escaped the deposition on the shelf floor was transported out to the open sea in a relatively short time scale by the shelf water circulation. It is not likely the exported carbon would enter the phase of long-term sequestration, if the current patterns in the open sea are taken into account.

P06S4.01

P06S4 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

Cold core eddies and fronts of the Antarctic Circumpolar Current south of New Zealand from in situ and satellite altimetry data

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The meridional heat flux required to balance the heat lost by ocean to the atmosphere at high latitudes must be accomplished by some mechanism other than mean advection and heat flux by eddies crossing the Antarctic Circumpolar Current (ACC) may be a candidate. In this study the positions of the main ACC fronts are determined basing on 23 XBT transects collected south of New Zealand from 1994 to 2010 and compared to those detected through satellite altimetry. Cold core anomalies in XBT sections are identified and satellite altimetry is used to follow the spatial-temporal evolution of these cold, low sea level anomalies. Mean values of main parameters such as speed (0.35 Km/h), lifetime (79 weeks) and diameter (105 Km) are estimated. Moreover the estimation of rotational speed (0.9÷76.8 cm/s) and eddy Available Heat Anomaly (Mean AHA: $9.74*10^{9}Jm^{2}$) give a wider description of the detected eddies. In our study area spawning of eddies is found to occur downstream of the Southeast Indian Ridge, in correspondence of the Polar Front (PF). After originating, these eddies cross the Polar Frontal Zone moving along the edge of the Campbell Plateau, reach the Southern Subantarctic Front (SAAF) and eventually cross it while another series of eddies is sometimes generated in correspondence of the SSAF at the southern edge of the plateau. The contribute of eddies to the global heat budget is linked to their ability to cross the ACC fronts, but also to the capacity of keeping partially unaltered the properties of the water inside them. Analysis of the relation between the translation and rotational speed shows that the detected eddies may effectively be a significant part of the net meridional heat transport. The mean heat anomaly/content associated to a single eddy is $-7.65*10^{19}J$ that is about the 0.8% of the $9.46*10^{21}J$ that, according to literature, must be transferred across the PF per year.

P06S4.02

P06S4 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

Antarctic circumpolar current response to atmospheric variability in eddying global ocean simulations

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We investigate the response of the Southern Ocean mesoscale eddy field and of the large-scale ocean circulation to recent changes in Southern Hemisphere atmospheric forcing. To this end, a suite of realistic global ocean simulations at increasing horizontal resolutions (1/2°, 1/4°, and 1/12°) are carried out with the ocean circulation model NEMO-LIM forced by the CORE atmospheric reanalysis from 1948 to 2007. A two-way nesting technique is used to refine the ocean grid up to 1/12° in the Southern Ocean, thereby resolving much of the mesoscale eddy spectrum. The mechanisms of interannual-to-decadal variability of eddy kinetic energy (EKE) are explored. In some regions (e.g. Kerguelen Plateau) the atmospheric forcing plays a dominant role in setting the EKE interannual variability, whereas in other regions (e.g. Southwest Indian Ridge) stochastic variability prevails. On decadal time scales, low-frequency modulations of the ocean circulation appear to be a relevant driver of EKE changes. In previous studies, mesoscale eddies were hypothesized to reduce the sensitivity of the Antarctic Circumpolar Current (ACC) and of the meridional overturning circulation to wind increases. The present simulations point to a counteracting effect of wind-driven and buoyancy-driven effects (namely, warming of Antarctic Bottom Waters) in driving long-term trends of the ACC, whereby the role of mesoscale eddies therein is under investigation.

P06S4.03

P06S4 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

Observed eddy heat fluxes across the Antarctic Circumpolar Current in northern Drake Passage

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The cDrake experiment 11/2007 – 11/2011 had a local dynamics array of 24 current and pressure recording inverted echo sounders (CPIES) centered near 57°S, 63°W. It spanned a maximum eddy kinetic energy region between the Subantarctic Front and Polar Front. The CPIES array provides full water-column estimates of velocity and temperature, mapped daily with mesoscale resolution to quantify and characterize eddy heat flux. The dynamically important component of eddy heat flux is the divergent field, which modifies its environment and transfers energy from mean to eddy field; the non-divergent component just recirculates. Optimal-interpolation mapping was used to separate the total eddy heat fluxes into non-divergent and divergent parts. The observed time-average total eddy heat fluxes are large and rotate around elevated mean temperature variance regions. In contrast, divergent eddy heat fluxes (DEHFs) are oriented down-gradient and have magnitudes a few times smaller than the total eddy heat fluxes. DEHFs arise from nearly depth-independent geostrophic currents that can cross the temperature front. The mapped annual-mean DEHFs have spatial structure that is remarkably consistent from year-to-year, exhibiting strong poleward flux just downstream of a prominent topographic ridge (Shackleton Fracture Zone). The vertical structure of DEHFs is maximum near 300 m depth with typical value 40 kW m^{-2} and decreases to 7 kW m^{-2} by 1200 m depth, below which the DEHFs are relatively constant. Vertically-integrated poleward divergent fluxes are 60 MW m^{-1}. Time series of daily heat flux show that the means accumulate from many poleward pulses that last just a few days; they arise during interactions between the deep barotropic eddies and the upper baroclinic jet in actively-growing baroclinic instability events. Consequently the time-averages of DEHF are rather stable after only 1-2 years.

P06S4.04

P06S4 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

The Filchner Overflow – past, present and future observations

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Cold Ice Shelf Water formed below the Filchner-Ronne Ice Shelf in the southwestern Weddell Sea, Antarctica, escapes the ice shelf cavity through the Filchner Depression at a rate of 1.6 Sv and contributes significantly to the production of Weddell Sea Bottom Water. Here we follow the Filchner Overflow from its discovery in 1977 to the latest scientific cruise in January 2013, exploring its origin, variability and the effect topography and continental shelf waves on the cold, dense overflow plume. Future plans and newly developed instrumentation for long-term monitoring of the overflow will also be presented.

P06S5.01

P06S5 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

Water property changes between 1996 and 2012 in the Indian and western Pacific sectors of the Southern Ocean

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In recent decades, accumulated data in the Southern Ocean has shown significant changes including a volume decrease in Antarctic Bottom Water (AABW), warming and freshening both in mid-depth and deep depths. It has also been shown that significant bottom warming observed in the North Pacific is a result of wave propagation of warm anomaly originating from the Australian and Pacific sectors of the Southern Ocean. In order to examine such water property changes in decadal time scales in the Indian, Australian, and Western Pacific sectors, RV Mirai has conducted CTD and bottle sampling observation along the World Ocean Circulation Experiment (WOCE) hydrographic sections P14S (meridional across the Antarctic Circumpolar Current (ACC), south of New Zealand) and S4I (zonal nominally along 62°S between 40°E and 170°E) in the 2012/2013 season. This is reoccupation of the hydrographic section first observed in 1996 under the WOCE programme. The data from the P14S section confirmed significant changes reported upstream of the ACC and elsewhere; contraction of AABW and consequent bottom warming on isobaric surface, warming and oxygen decreases in the Upper Circumpolar Deep Water densities on isopycnal surfaces around the Polar Front, cooling and freshening on isopycnal surfaces of the upper Antarctic Intermediate Water around the Subantarctic Front. Our high-resolution data shows these changes were enhanced towards the surface, suggesting surface origin. Rapid freshening of the AABW was also confirmed. Towards the south, not only was the freshening signal stronger, but also dissolved oxygen increased, which can be explained as decrease in salinity and thus in density of AABW recently produced around the Antartcic continental shelves. The zonal distribution of these AABW changes was also examined using the S4I data.

P06S5.02

P06S5 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

Seaglider observations of processes on the Antarctic continental shelf and slope

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In early 2012 the GENTOO project deployed three Seagliders for up to two months to sample the water to the east of the Antarctic Peninsula in unprecedented temporal and spatial detail. Variations in currents in this region have global significance for ocean circulation, climate and krill ecology. The Seagliders provided extended spatial and temporal coverage to a dedicated two week science cruise, collecting complementary measurements and glider sensor validation data. One Seaglider was equipped with a novel echosounder to measure krill distributions in addition to standard ocean parameters. The other two Seagliders measured temperature, salinity, dissolved oxygen, chlorophyll fluorescence and dive-averaged current in the upper 1000 m along sections across the Antarctic continental shelf and slope into the Weddell Sea. We present an analysis of the Seaglider data together with the supporting ship-based hydrographic and biological measurements. We discuss evidence of exchanges across the shelf-break front (the Antarctic Slope Front), including observations of dense water spilling off the continental shelf, and of a subsurface lens of Warm Deep Water on the shelf emanating from offshore. Using the glider dive-average current to reference geostrophic shear, we deduce the transport of the Antarctic Slope Current and discuss its short-term and spatial variability. We discuss the spatial and temporal variability of the water mass properties, currents and krill distribution. GENTOO demonstrated the capability of ocean gliders to play a key role in future polar ocean observing systems. We conclude with an overview of the opportunities and challenges in using gliders in polar environments.

P06S5.03

P06S5 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

Fitting observations from Drake Passage to the Southern Ocean State Estimate (SOSE)

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A Southern Ocean State Estimate (SOSE) based on an eddy-permitting version of the MITgcm for the years 2005 to 2007 has been extended through 2010 to include the IPY period. The SOSE provides a potential framework for combining and interpreting observations from various IPY field programs. We use recent observations from Drake Passage to evaluate the state estimate prior to assimilation and to track changes in the solution post-assimilation.

Accurate model simulation of the ocean requires reproducing several metrics, including ocean heat content, geopotential height, mass transport and eddy kinetic energy. The IPY cDrake experiment is used to evaluate the representation of these metrics in the SOSE. The observations consist of near-bottom currents, bottom pressure, and round-trip vertical acoustic travel time between sea floor and sea surface from an array of 44 bottom-moored Current and Pressure-recording Inverted Echo Sounders (CPIES) deployed from 2007 to 2011, as well as hydrography and direct velocity observations from multiple cruises.

P06S5.04

P06S5 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

First air-sea flux mooring measurements in the Southern Ocean

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The Southern Ocean is a key component of the global climate system: insulating the Antarctic polar region from the subtropics, transferring climate signals throughout the world's oceans and forming the southern component of the global overturning circulation. However, the air-sea fluxes that drive these processes are severely under-observed due to the harsh and remote location. This paucity of reference observations has resulted in large uncertainties in ship-based, numerical weather prediction, satellite and derived flux products. Here, we report observations from the Southern Ocean Flux Station (SOFS); the first successful air-sea flux mooring deployment in this ocean. The mooring was deployed at 47 °S, 142 °E for March 2010 to March 2011 and returned measurements of near surface meteorological variables and radiative components of the heat exchange. These observations enable the first accurate quantification of the annual cycle of net air-sea heat exchange and wind stress from a Southern Ocean location. They reveal a high degree of variability in the net heat flux with extreme turbulent heat loss events, reaching -470 Wm-2 in the daily mean, associated with cold air flowing from higher southern latitudes. The observed annual mean net air-sea heat flux is a small net ocean heat loss of -10 Wm-2, with seasonal extrema of 139 Wm-2 in January and -79 Wm-2 in July. The novel observations made with the SOFS mooring provide a key point of reference for addressing the high level of uncertainty that currently exists in Southern Ocean air-sea flux datasets. Results from ongoing analysis of measurements made on subsequent SOFS deployments in 2011-2012 will also be presented.

P06S5.05

P06S3 - Investigating the Southern Ocean – what have we learnt 5 years on from IPY?

Oral

The southern mode revisited: on what timescale do Antarctic circumpolar transport variations stop being barotropic?

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It is well established that intra-annual variations in circumpolar transport in the Southern Ocean occur via a wind-driven barotropic mode, known as the Southern Mode, which closely follows the Antarctic continental slope, and is well correlated with the atmospheric Southern Annular Mode. However, the Antarctic Circumpolar Current itself follows a path which is very different from the Southern Mode, and has an important depth-dependent component. There must be some timescale at which transport variations change in character from a barotropic Southern Mode to a depth-dependent mode less closely trapped to the continent. We present diagnostics from 50 years of an eddy-permitting ocean model run, together with observed sea level and bottom pressure measurements, to show that the change in character starts at periods around 3 years and that, whereas circum-Antarctic bottom pressure retains a strong relationship with transport at all periods, circum-Antarctic sea level shows greater variability at longer time scales. Thus, while southern pressure remains a good monitor of transport at all modelled time scales, it ceases to be the dominance of a Southern Mode which is responsible for this.

P07PS.01

P07PS - Bio-physical and -geochemical interactions in the marine environment

Poster

Modeling the impact of reduced sea ice cover in future climate on the Baltic Sea biogeochemistry

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In warming future climate the sea ice cover is expected to decrease with very likely large consequences for the marine ecosystem. We investigated the impact of future sea ice retreat on the Baltic Sea biogeochemistry at the end of the century using an ensemble of regionalized global climate simulations. We found that the spring bloom will start by up to one month earlier and winds and wave-induced resuspension will increase causing an increased transport of nutrients from the productive coastal zone into the deeper areas. The internal nutrient fluxes do not necessarily increase because they also depend on oxygen and temperature conditions of the bottom water. Winter mixing increases in areas having reduced ice cover and in areas having reduced stratification due to increased freshwater supply. The reduced sea ice cover therefore partly counteracts eutrophication because increased vertical mixing improves oxygen conditions in lower layers.

P07PS.02

P07PS - Bio-physical and -geochemical interactions in the marine environment

Poster

The variability of marine ecosystem in the upper layer of the Canary upwelling region as simulated by a 3-D model

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A 3D eco-hydrodynamical model with resolution (0.25° x 0.25°, 27 sigma-levels) is used to simulate the seasonal and inter-annual variability of ocean circulation and marine ecosystem in the Central-Eastern basin of the North Atlantic including the Canary upwelling region in the period 1958-2006. Simulated temperature and salinity fields both qualitatively and quantitatively agree well with satellite and expeditionary observations. Simulated surface phytoplankton distributions averaged for the period of 8 days are in qualitative agreement with surface distributions of chlorophyll «a» derived from satellite data. Comparison of the interannual variations of satellite-derived and model integral primary production demonstrates a satisfactory qualitative agreement between them. The model distribution of the concentration of chlorophyll «a» and integral primary production to the north of 19oN is characterized by a narrow band of low values near the coast. Satellite-derived and ship data do not show such a feature. This band of low concentrations of chlorophyll «a» and the integral primary production is formed as follows. Strong upwelling near the shore leads to lowering the temperature here to 16-18 °» C and the increase in the concentration of nitrate to 10-12 mmol N m-3. Lowering the temperature reduces the primary production of phytoplankton, while the growth of nitrates increases it. In this case, the effect of temperature is stronger, resulting in reduced values of phytoplankton biomass, chlorophyll «a» and the primary production. Note also the presence of subsurface maxima in the vertical distribution of chlorophyll «a» and its absence in the distribution of phytoplankton biomass. This chlorophyll maximum, located in the thermocline directly under the mixed layer, is due to the sharp growth of nutrients in thermocline, effect of which prevails over the effect of lowering the photosynthetic available radiation with depth.

P07S1.01

P07S1 - Bio-physical and -geochemical interactions in the marine environment

Oral

Temperate seasonal stratified shelf seas: A wind driven CO2 pump?

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Air-sea CO2 fluxes inferred from measurements of sea surface pCO2 identify temperate seasonally stratified shelf seas as significant sinks of atmospheric CO2. The sea surface pCO2 deficit which drives the drawdown is a consequence of primary production within the surface mixed layer. Once the spring bloom has subsided, primary production within these regions is sustained within the subsurface chlorophyll maximum (SCM). The SCM is sustained through diapcynal mixing which supplies nutrients to the euphotic zone. Two key questions in understanding the response of the seasonally stratified continental shelf sea sink are therefore (i) what is the impact of the diapcynal mixing on the seas surface value of pCO2 and (ii) what are the key physical processes driving the diapcynal fluxes which link the nutrient rich deep water with the euphotic zone? In this presentation we will assess the individual and integrated contributions of various sea water properties to setting the sea surface pCO2 value, in response to the diapcynal mixing. In particular we will examine the compensatory effects of the consequent heat, salt and nutrient fluxes for a number of locations within the Northwest European Continental Shelf Seas. We will then identify the various physical mixing processes which drive the fluxes.

P07S1.02

P07S1 - Bio-physical and -geochemical interactions in the marine environment

Oral

Hydrological patterns and spatial distribution of deep water rose shrimp in the Strait of Sicily (Central Mediterranean)

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The deep water Rose shrimp (*Parapenaeus longirostris*, Lucas 1846) is the main target of trawling fisheries in the Strait of Sicily, amounting to about 60% of the shrimp yield of the whole Mediterranean. The Strait of Sicily is known to be characterized by mesoscale oceanographic features, such as upwelling regions, fronts, vortices and filaments, which affect biological processes. In this study, rose shrimp abundance data in the Strait of Sicily are analyzed together with remotely sensed sea surface temperature and ocean color surface parameters (chlorophyll, diffuse light attenuation coefficient, particulate and CDOM absorption and scattering coefficients), to explore environmental factors that are expected to condition patterns of this species' distribution, in space and time. Preliminary results show that individuals tend to be found in correspondence of colder and biologically richer surface waters, even though *P. longirostris* is a bottom-dwelling species. Further investigation on ecological processes in the water column, connecting the surface to the bottom, are therefore necessary to explain the correspondence between rose shrimp and surface hydrological parameter distributions.

P07S1.03

P07S1 - Bio-physical and -geochemical interactions in the marine environment

Oral

The role of dynamic and hydrographic processes in anchovy spawning and larvae distribution in the Strait of Sicily

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The European Anchovy (*Engraulis encrasicolus*, Linnaeus, 1758) is one of the most important resources of the Mediterranean Sea. Despite its abundance and relevance, the anchovy population off the Mediterranean coasts exhibits a patchy distribution. Moreover, its biology and the influence of environment on its variability is poorly known. We here use data from ichthyoplankton-surveys carried out during the peak spawning season in order to analyze abundance and age of anchovy larvae in the Strait of Sicily, with respect to sea surface dynamic and hydrographic parameter patterns. The Strait of Sicily dynamics is characterized by upwelling regions, fronts, vortices, and filaments, with a consequent complexity in the spatial distribution of oceanographic parameters and anchovy larvae. To investigate the role of mesoscale features and oceanographic environment on the latter, anchovy larvae observations were paired to remote sensing data (such as sea surface temperature, chlorophyll, primary production, surface wind speed as well as light attenuation, absorption, and particle backscattering coefficients) and Lagrangian and Eulerian numerical simulations results for ocean currents and larval transport. The subsequent analysis shows and quantifies how the Atlantic Ionian Stream (AIS, a meandering current of Atlantic origin) path and variability, as well as the upwelling-induced south Sicilian coastal current, have consequences for anchovy spawning and larvae distribution. These currents transport anchovy larvae towards the Sicilian coast's south-eastern tip, where larvae are then retained in a frontal structure. However, significant cross-shore transport events due to relatively cold filament-like baroclinic instabilities generated by wind-induced coastal upwelling were also observed. Finally, the larval age distribution qualitatively agrees well with this transport pattern.

P07S1.04

P07S1 - Bio-physical and -geochemical interactions in the marine environment

Oral

How submesoscale physics affect primary production rates and phytoplankton community structure

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Using a submesoscale-permitting biogeochemical model representative of the seasonally varying subtropical and subpolar gyres, we explore two aspects of bio-physical interactions at the sub-mesoscale. First, due to non-linearities in the biological interactions, submesoscale heterogeneity in the concentrations of biogeochemical components can create some departure from the mean field approximation, whereby plankton dynamics are evaluated from mean distributions at coarser-scale. Here we compute the magnitude of these biological Reynolds effects and compare their strength to those of the more widely studied advective Reynolds terms. Second, we examine how phytoplankton diversity and community structure is affected by the physical dispersion induced by ocean currents. This is done by using a complex marine ecosystem model seeded with many phytoplankton types, which allows the community structure to emerge from a wide set of possibilities.

P07S1.05

P07S1 - Bio-physical and -geochemical interactions in the marine environment

Oral

Variability of Japanese sardine in relation to Kuroshio environmental variability

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Multi-decadal variability of Japanese sardine (Sardinops melanostictus) is examined with the focus on the relationship between recruitment and environment for sardine larvae. By introducing Kuroshio stream coordinate, significant correlations were found between recruitment and winter-spring SST and winter MLD (mixed layer depth) along the Kuroshio jet where sardine larvae were actually transported. The winter deeper mixed layer along the Kuroshio front on the northern side of the Kuroshio jet is found to lead to spring more abundant phytoplankton in the downstream Kuroshio regions. The winter SST and MLD decadal-scale variability along the Kuroshio jet are associated with variabilities of Kuroshio velocity and local winter cooling. Direct turbulence measurements revealed that strong turbulence on the northern side of the Kuroshio jet enhances upward nitrate diffusive fluxes which maintain surface biological activity after stratification. These imply that Kuroshio environmental variability forced by climate variability and vertical mixing influence food and temperature conditions for sardine larvae and lead to large stock variability.

P07S1.06

P07S1 - Bio-physical and -geochemical interactions in the marine environment

Oral

On the spatial relationship of phytoplankton and nutrients: a test for theories of plankton patchiness

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The balance of biological and physical processes responsible for the generation of complex patterns observed in phytoplankton spatial distribution remains unclear. Light may be shed on this problem by comparing patchiness in phytoplankton to distributions of directly interacting components of the ecosystem like nutrients, which are also patchy. Theoretical studies suggest that spatial variability in phytoplankton and nutrients, when quantified by the slope of their power spectrum, should be identical.

In this study, simultaneous spectra for phytoplankton and nutrients have been calculated using chlorophyll-*a* and nitrate data from the North Atlantic, allowing these theoretical predictions to be tested for the first time. Both phytoplankton and nutrients display a knee-shaped spectrum exhibiting power law behavior either side of the range 100 m – 8 km which was unsampled. For the range 8-60 km, the spectra have an identical slope. At smaller scales (10-100 m), the slopes steepen but more importantly diverge, contradicting the theory.

Nonetheless, the existence of power law behavior for both nutrients and phytoplankton may offer, by means of scaling, the opportunity to improve parameterization of biogeochemical models at subgrid scales.

P07S2.01

P07S2 - Bio-physical and -geochemical interactions in the marine environment

Oral

Biological and physical triggers of the North Atlantic Spring Bloom

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There is a debate over what triggers phytoplankton blooms in the subpolar North Atlantic. The traditional explanation stems back to the seminal work of Riley and Sverdrup. According to their explanation, stirring by winter cooling and winds stir phytoplankton into deep waters, where there is too little light to prosper. In spring, when atmospheric forcing weakens and turbulent stirring subsides, phytoplankton experiences sufficient sunlight to grow and a bloom develops. Behrenfeld has recently turned the problem upside down suggesting that winter turbulence triggers blooms rather than preventing them. The hypothesis is that phytoplankton losses due to processes such as consumption by zooplankton and respiration are actually reduced by turbulent stirring that spreads biomass over deep mixed layers limiting encounter rates of phytoplankton and zooplankton. In this work we will present in-situ observations, collected with floats, and theoretical results, based on a simple NPZ mode, to analyze which hypothesis appears to best describe the onset of the North Atlantic Spring Bloom.

P07S2.02

P07S2 - Bio-physical and -geochemical interactions in the marine environment

Oral

Seaglider observations of upper ocean physics and biogeochemistry at the Porcupine Abyssal Plain time series site

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The Ocean Surface Mixing, Ocean Sub-mesoscale Interaction Study (OSMOSIS) aims to develop new, physically-based parameterisations of processes that deepen and shoal the ocean surface boundary layer. As part of this project, 2 Seagliders were deployed in September 2012 at the Porcupine Abyssal Plain (PAP) site in the North Atlantic, to measure the structure and evolution of the ocean surface boundary layer over the seasonal cycle. The gliders, turned around every 4 months, measure temperature, salinity, dissolved oxygen, dive-averaged currents, chlorophyll fluorescence, CDOM fluorescence, particulate optical backscatter and photosynthetically available solar radiation (PAR). We present results from the first 9 months of the Seaglider deployments, examining particular case studies of deepening/shoaling events and their impact on the biogeochemistry. Shoaling events appear to be more abrupt than deepening events. We assess the annual cycle in the upper ocean of each measured parameter and demonstrate the rapid onset and decay of mixing events.

P07S2.03

P07S2 - Bio-physical and -geochemical interactions in the marine environment

Oral

On the impact of Southern Ocean eddies on phytoplankton

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The Southern Ocean (SO) is a region of intense eddy activity and high spatio-temporal variability of phytoplankton biomass, yet the long-term mean influence of eddies on phytoplankton is essentially unknown. Eddies are expected to impact the distribution of phytoplankton by modifying lateral transport (eddy stirring and advection) as well as by changing the environmental conditions that are vital for phytoplankton growth (vertical mixing, up- and downwelling). We investigated the long-term mean association of SO eddies and variations in phytoplankton biomass by tracking more than 100,000 eddies in the SO over the time period 1997 to 2010 and determining the changes in phytoplankton biomass using satellite based chlorophyll-a (CHL) measurements as a proxy. Our findings reveal significant eddy-related CHL anomalies in the long-term mean with magnitudes of more than ±10% over large areas of the SO. The anomalies have a zonal structure with positive anomalies north of the Antarctic Circumpolar Current (ACC) and negative anomalies within the circumpolar belt of the ACC and south of it for cyclonic eddies. The pattern is similar but of opposite sign for anticyclonic eddies. The seasonality of the eddy-related CHL anomalies is weak north of the ACC whereas it is pronounced in the vicinity of the ACC. The distinct spatial structure and seasonality of the long-term mean chlorophyll anomalies associated with the eddies suggest that the dominant mechanisms determining the CHL-response are advection of trapped properties within each eddy as well as local stimulation of phytoplankton growth. In contrast, it appears as if the stirring due to rotation of eddies is of secondary importance.

P07S2.04

P07S2 - Bio-physical and -geochemical interactions in the marine environment

Oral

Physical and biological drivers of marine snow formation in the oceans

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Marine snow is an important component of many biological and chemical processes in the oceans. Sinking detrital particles provide food for meso- and bathypelagic organisms and transport important elements from the surface to the deep ocean. The formation and characteristics of these particles depend on a combination of physical and biological processes that determine particle collision rates, adhesion, particle composition, density and sinking rates. Models of marine snow formation have generally concentrated on representing the physical processes determining collision rates and sinking rates. New modeling efforts are concentrating on teasing apart the biological, physical and chemical processes that are important for marine snow formation and particle flux with a view to understanding how they might be affected by environmental change.

In this talk I will report on several approaches that are underway to model marine particle aggregation on both small and large scales. These approaches are aimed at furthering our mechanistic understanding of the chemical, physical and biological processes affecting marine snow formation and sinking, and their relative importance. At small scales, molecular dynamics simulations have shown how changes in adhesion affect the structure of aggregates. At larger scales, various models have furthered our understanding of the relative importance of physical and biological processes in the fate of marine snow. However, global biogeochemical and climate models use highly simplified parameterizations to represent particulate processes. The ongoing challenge is how to combine these approaches and thereby improve our understanding and ability to predict as to how these processes may change in a changing environment.

P07S2.05

P07S2 - Bio-physical and -geochemical interactions in the marine environment

Oral

Oceanic front maps combine thermal and colour features to explore biophysical interactions

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We have developed novel Earth observation (EO) methods for visualing and inferring the spatio-temporal distribution of dynamic oceanic fronts, in order to reveal new informaiton on the surface physical and biological oceanography. This talk will describe how front contours derived from EO thermal and colour data can be combined to best exploit these complementary data sources and to explore biophysical interactions caused by mesoscale processes. Ocean colour may reveal additional physical processes even if there is no thermal signal. Combined thermal and colour front maps will be presented and animated at a range of scales from coastal through to basin-scale.

This research is based on the *composite front map* approach, which is to combine the location, strength and persistence of all fronts observed over several days into a single map, improving interpretation of dynamic mesoscale structures (Miller, 2009). These techniques are robust and generic, and have been applied to many studies of physical oceanography and marine animal distribution, and as an indicator of pelagic diversity for assisting the designation of marine protected areas.

Miller, P.I. (2009) Composite front maps for improved visibility of dynamic sea-surface features on cloudy SeaWiFS and AVHRR data. *Journal of Marine Systems*, 78(3), 327-336. doi:10.1016/j.jmarsys.2008.11.019

P07S2.06

P07S2 - Bio-physical and -geochemical interactions in the marine environment

Oral

Chemical and biological interactions in the North Atlantic in May 2011

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The extended Ellett Line is a hydrographic section between the UK and Iceland that is occupied each year. It runs due west from the coast of Scotland to Rockall, across the Hatton Bank and then north along the 20W line to Iceland. However in 2011 weather conditions were so poor at the onset that a decision was made to detour to the east of the Hebrides travel through the Minches to the Northwest of Scotland and then swiftly pass across the Iceland Basin to the north of the storm track. This was fortuitous as it permitting surface sampling and measurements of physical and biological parameters along two oblique crossings of the Iceland Basin. The timing also coincided with the eruption of the Icelandic Grímsvötn volcano on 21 May and the ship passed through the descending ash cloud resulting in some interesting biogeochemistry in the waters. This together with other biological and chemical distributions seen during the cruise will be discussed and inferences drawn regarding the effect of the prevailing weather conditions and the impact on anthropogenic carbon uptake.

P07S3.01

P07S3 - Bio-physical and -geochemical interactions in the marine environment

Oral

How submesoscale dynamics organize ocean biodiversity

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Models and observations both demonstrate that as spatial sampling resolution increases, so does the measured strength and variability of the vertical motions in the ocean. These submesoscale vertical motions, driven by strongly nonlinear dynamics, can have profound effects on the local structure and dynamics of the planktonic ecosystem, and through the food web up to the top predators' foraging behavior. In particular many modeling and observation studies now provide evidence of differential responses among a variety of phytoplankton groups to mesoscale and submesoscale turbulence. In this talk we will review some aspects of marine ecosystem response to submesoscale dynamics in terms of structure and functioning. We will discuss the underlying mechanisms such as vertical motions (nutrient pulses) horizontal stirring (plankton patchiness) or trophic cascade and the importance of time scales (ephemeral structures). The combined effects of submesoscale features, even though they concern a relatively small fraction of the total area, may be disproportionately important to biological dynamics in terms of diversity.

P07S3.02

P07S3 - Bio-physical and -geochemical interactions in the marine environment

Oral

Biogeochemical responses to the passage of mesoscale eddies in the northwestern subtropical North Pacific

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To acquire physical-biogeochemical data which could resolve mesoscale phenomena in the western North Pacific, JAMSTEC launched an interdisciplinary project «Western North Pacific Integrated Physical-Biogeochemical Ocean Observation Experiment (INBOX)» in 2010. INBOX aims to quantify impacts of physical processes on biogeochemical phenomena, so that we could also ultimately utilize biogeochemical information for understanding physical processes. As the first phase of INBOX, profiling floats with oxygen sensors were intensively deployed around the biogeochemical mooring station S1 maintained since spring 2010 at 30oN, 145oE, south of the Kuroshio Extension. In summer 2011, we have deployed about 20 floats with profiling cycles of 2 days in the 150 km-square area centered at the S1. The S1 mooring has a profiling buoy equipped with conductivity-temperature-depth-oxygen sensors, a scalar irradiance sensor, and a fast repetition rate fluorometer measuring the top 150 m every one or two days. It also has an acoustic Doppler current profiler measuring horizontal velocity every hour above 500 m depth with 8 m resolution, and time-series sediment traps at 200 m, 500 m and 5000 m. A cyclonic eddy passed through the float array from July to October. The floats detected substantial increase in dissolved oxygen at the shallow oxygen maximum apparently due to nutrient supplied by heaving of deep isopycnals into the euphotic zone. The sediment trap data captured significant increase in downward flux of organic carbon during the period of the eddy passage. Quantitative comparison between the float data and the mooring data indicates that the passage of mesoscale eddies has significant impact on the primary production in this region.

P07S3.03

P07S3 - Bio-physical and -geochemical interactions in the marine environment

Oral

The importance of physical forcing to a Gulf estuary hypoxia

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Perdido Bay Estuary (PBE), a typical bay on the Florida/Alabama coast along the Gulf, was simulated using an existing calibrated model (Xia et al., 2011). Hindcasts of Perdido Bay bottom hypoxia is provided in response to river runoff and local wind forcing. Observed average wind speeds of 3 m sec-1 during July were capable of redistributing hypoxia stressing the entire estuarine ecosystem. Easterly and westerly winds resulted in greater hypoxia near the shore, which put stress on near-shore habitats such as oysters and result in phenomenon like jubilees. Westerly and southerly winds resulted in significantly larger areas of anoxic conditions due to longer water-residence times. Northerly and easterly winds, in contrast, promoted water transport toward the Gulf of Mexico, enhancing the freshwater discharge direction from Perdido River. Wind speeds over 3 m sec-1 were sufficient to enhance the advection of dissolved oxygen into bottom waters through vertical mixing and resulted in significant reductions in areal coverage of hypoxia. The effect of river discharge to the 3-D hypoxic conditions within the estuary will also be discussed.

P07S3.04

P07S3 - Bio-physical and -geochemical interactions in the marine environment

Oral

Impact of Climate Change on Coral Reefs : Indian scenario

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Coral reefs are the most diverse marine habitat, which support an estimated 0.5 to 2.0 million species in the world oceans. They are among the most sensitive of all ecosystems to temperature changes, exhibiting bleaching (a phenomenon in which the symbiotic zooxanthellae are expelled by coral polyps) when stressed by higher than normal sea temperatures. The hypothesis that corals and associated reef organisms might be the first to show adverse effects of global warming has been widely recognized. . In the Indian Seas, coral reefs are prominent in five regions, viz., Andaman Sea, Nicobar Sea, Lakshadweep Sea, Gulf of Mannar and Gulf of Kachchh. Indian reefs have experienced 29 widespread bleaching events since 1989. The events were recorded in 1989, 1998, 1999 and 2002. Among these, events in 1998 and 2002 were intense. The impacts of 1998 bleaching were worst in the Indian Ocean, where virtually every reef was affected. The level of thermal stress at the vast majority of these coral reef regions was unmatched in the period 1901-2002. Sea surface temperature at these coral reef regions have significantly warmed over this period and the frequency of warm events of extreme increase in SST (Sea Surface Temperature) has increased since the late 1980s. Coral reefs need immediate conservation attention, and many of the actions most important for their survival are already recognized and best administered at local to regional scales. We need to increase the urgency and effectiveness with which we manage the stressors that already place reefs as risk. Programs to reduce pollution, sedimentation, anchor and net damage, and overfishing, and to establish marine protected areas will give corals their best chance to respond to climate change naturally. If we do not heed the warning of climate-induced ecosystem collapse provided by mass coral bleaching events, similar catastrophies will follow throughout marine, freshwater, and terrestrial systems.

P07S3.05

P07S3 - Bio-physical and -geochemical interactions in the marine environment

Oral

Bio-physical-geochemical changes due to the stir of the severe cyclones in the Arabian Sea

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In recent years Arabian Sea experienced strongest cyclones (Cat 3, 4 & 5) during pre and summer monsoon seasons and few in northeast monsoon season. In this study the author investigated the bio-physical-geochemical change due to the cyclone at different stages (pre, during and post cyclone) in the Arabian sea. Multi-satellite data products and Argo observations are used to the above study. Pre-cyclone ocean environment played an important role in this case. The magnitudes of sea surface cooling at different places were similar, other physical and biophysical responses were quite different. The amplitude of the cooling is moderately well correlated with the cyclone strength and is as large as 4°C. When the cyclones move rapidly, the maximum cooling occurs well to the right of the track (~70-100km), whereas for slowly moving cyclones the maximum cooling occurs near or on the track. The chl-a concentration (>1-10 mg/m3) increased in the Arabian Sea after the cyclone passage in comparison with the mean climatological (1998-2012) value. The speed of upwelling and wind stress curl is also higher cyclone than pre cyclone period. Moreover, the mixed layer deepened about ~10-70m. These reveal that the enhancement of chl-a concentration was triggered by strong vertical mixing and upwelling. Along the track of cyclone, the maximum sea surface cooling (1-7°C) took place in the Arabian Sea where the translation speed of typhoon was 1.4-4m/s and the mixed layer depth was about 20 m in pre-typhoon period. In addition, the region with the largest decline of the sea surface height anomaly can indicate the location where the maximum cooling occurs. This study implies that to insight into the ocean surface responses to cyclone, the subsurface dynamics need to be analyzed via both the in situ and satellite-based observations, and the physical and biological models.

P08PS.01

P08PS - Thermohaline Circulation and Deep Currents

Poster

Hydrographic changes in the Deep Western Boundary Current at Line W and their connectivity to changes in the Labrador Sea

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Hydrographic sections along Line W extending from the continental shelf south of Cape Cod towards Bermuda were occupied annually or semi-annually during the mid 1990s and from 2003 to the present. In the mid-1990s there was a sharp increase in CFC-11 concentration and decrease in salinity in Labrador Sea Water (LSW) reflecting flow of water in the Deep Western Boundary Current (DWBC) formed in the Labrador Sea during the period of strong convection in the early 1990s. In the first decade of the 21st century there were alternating periods of high CFC/ low salinity and low CFC/high salinity water and the best ventilated water, identified by high CFC concentrations, shifted to a less dense strata of LSW. There was also a sharp increase in CFC concentration in the Denmark Strait Overflow Water (DSOW) core in the mid-1990s, which was accompanied by an increase in salinity. After 2003, increases in CFC concentration were usually accompanied by a small increase in temperature with little change in salinity, except for 2011 when CFC, temperature and salinity all increased. Since the early 1990s Line AR7W between Labrador and Greenland has been occupied at least annually; some similar patterns of variation in water properties have been observed, but generally with a larger amplitude. The extent that variability in water mass properties in the DWBC at Line W is connected to variability in water mass properties in the Labrador Sea is being investigated by comparing variability in temperature, salinity, and CFCs observed at both locations and using transit times calculated from I-129 and CFC data to help establish lag times for the propagation of the signals. These results will be presented.

P08PS.02

P08PS - Thermohaline Circulation and Deep Currents

Poster

Formation of salinity maximum water and its contribution to the overturning circulation in the North Atlantic

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The formation of salinity maximum water in the North Atlantic is investigated using a simulated passive tracer and its adjoint. The results show that, although some of the salinity maximum water enters the equatorial region as part of the shallow subtropical cell, most of this water reaches the subpolar region in the depth range of the thermocline. Its pathway involves a three-dimensional circulation. The warm, fresh surface water from the southern hemisphere turns eastward in the northern subtropical gyre. As a result of large excess of evaporation over precipitation, this water gradually gains its salinity on the route, until it reaches a salinity maximum in the central subtropical gyre. From there, the salinity maximum water is subducted and flows back to the western boundary. With its higher salinity nature, a major portion of this water penetrates into the subpolar region in the western boundary current, where it re-enters the winter mixed layer and directly contributes to the deep thermohaline circulation as part of the North Atlantic Deep Water.

P08PS.03

P08PS - Thermohaline Circulation and Deep Currents

Poster

An abrupt cold event in the pre-industrial control run of ECEARTH induced by the AMOC

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During an 1150-year pre-industrial control run, an abrupt colling episode occurred after 450 years, lasting for about a century. The signal is clearly seen in the Atlantic Multidecadal Oscillation index, featuring an anomaly of -0.8 for about 100 years. The temperature-anomaly over the European continent was about 0.5 degree, but over Scandinavia and the British Isles the average cooling surpassed more than a degree. The maximum signal is over the Labrador Sea where temperature dropped with 3 degrees and salinity with 1.5 psu. The halocline stopped deep convection there and was caused by anomalous export of sea-ice from east of Greenland. There, the coupled system tipped into an anomalous state in which sea-increase induced a thermal high that caused north-easterly winds to further increase sea-ice cover. This positive ocean-atmosphere-sea-ice feedback was halted when sea-ice melt in the Labrador Sea caused an even larger thermal anomaly and high-pressure field in the Labrador Sea. Analysis with a special toolkit for critical transitions shows clear signs of a noise-driven transition from one state to another in many ocean variables, and early warning signals in net downward shortwave radiation over the Labrador and Greenland Seas.

P08PS.04

P08PS - Thermohaline Circulation and Deep Currents

Poster

Western and Eastern Boundary measurements at 34.5°S in the South Atlantic: Preliminary results of MOC-related variability

Meinen, C.S. 1; Speich, S. 2; Piola, A.R. 3; Perez, R.C. 4; Dong, S. 4; Garzoli, S.L. 4; Baringer, M.O. 1; Campos, E. 5

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Direct estimates of the basin-wide absolute transport at 34.5°S in the South Atlantic Ocean are obtained using just under two years of overlapping data from two small arrays of pressure-equipped inverted echo sounders deployed on the western and eastern continental slopes. These arrays are designed to measure the Brazil Current and the Deep Western Boundary Current (DWBC) in the west, and the Benguela Current and a deep southward flow near the eastern boundary, however the data from the two arrays can together provide an estimate of the time variability of the absolute transport of the upper limb of the basin-wide Meridional Overturning Circulation (MOC). At this latitude the cold lower limb of the MOC is thought to be carried mainly in the deep slope flows on the western and eastern boundaries, while the warm upper limb of the MOC is believed to be carried primarily in the Benguela Current and in Agulhas rings. Analysis of the data from these two arrays demonstrates that daily estimates of the upper limb of the MOC have a peak-to-peak range of 45 Sv (1 Sv = 10^6 m^3 s^{-1}) and a standard deviation of 8 Sv, with strong variations at periods of 10-20 days and around 60 days. The observed results will be compared to both estimates from concurrent trans-basin hydrographic sections and estimates from the output of high-resolution global general circulation models.

P08PS.05

P08PS - Thermohaline Circulation and Deep Currents

Poster

The fate of the Atlantic Deep Western Boundary Current

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The role of the Deep Western Boundary Current (DWBC) as a primary pathway for the cold, lower, limb of the Meridional Overturning Circulation has been well documented in the North Atlantic Ocean. However the pathways and variability of the DWBC in the South Atlantic Ocean are less well known. Near 8°S the DWBC appears to break up into rings as it flows southward. According model simulations, the transport of North Atlantic Deep Water into the South Atlantic Ocean in this latitude range is accomplished by migrating eddies rather than by a continuous flow. These model results were supported by observations that indicated that a mean DWBC exists at 5°S, but does not exist at 11°S because the DWBC dissolves into a sequence of deep eddies between the two latitudes. These results contradicted previous findings obtained from direct current measurements and geostrophic current estimates that indicated the existence of a DWBC between 20 and 28°S with a southward transport that ranges between 2 and 10 Sv. Recent observations at 34.5°S confirm the presence of the DWBC at that latitude. Surprisingly, similar results are obtained at the eastern boundary, where a southward flow is also found with water masses characteristics of the DWBC and a mean transport of 3 Sv, is observed. The objective of this work is to analyze different model products to determine the pathways of the DWBC in the South Atlantic and to study the ocean dynamics that establish those pathways. Particle trajectories for floats launched at the high-resolution Ocean General Circulation Model for the Earth Simulator (OFES) are analyzed.

P08PS.06

P08PS - Thermohaline Circulation and Deep Currents

Poster

Investigation of the Holocene carbon cycle with a model of intermediate complexity: The role of Southern Ocean Ventilation

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The University of Victoria Earth System Climate Model of intermediate complexity (v. 2.9) is used to investigate the Holocene carbon cycle from 8000-150 years before present (BP). This particular model's strengths are its comprehensive representation of ocean circulation with an ocean GCM as well as its ability to perform transient simulations over the entire Holocene period. Without the explicit representation of peatlands, coral reefs and land-use change, the UVic model's natural Holocene carbon cycle produced a decline in atmospheric carbon dioxide concentration from 260 ppm to concentrations in the range of 245-254 ppm from 8000 to 150 BP, in contrast to the increase from 260 ppm to 280 ppm actually observed during this period. Our experiments thus suggest a net decline in atmospheric CO_2 would have occurred naturally from the mid-Holocene to the beginning of the Industrial era (instead of the 20 ppm increase), regardless of the winds or initial ocean state. However, these findings were discovered to be highly sensitive to the configuration of land ice shelves near Antarctica, with more extensive land ice leading to deeper vertical circulation in the Southern Ocean and a much higher atmospheric CO_2 concentration of 260 ppm at 150 BP. Furthermore, simulations forced to follow the observed CO_2 trend indicate that 400 PgC would need to be released into the atmosphere by the Earth System in order to account for the 280 ppm seen by the beginning of the Industrial era. Because this would require an improbable large release of carbon from terrestrial vegetation, the UVic model suggests that changes in the ocean circulation and the ocean chemistry associated with coral reef migration are likely responsible for much of the 20 ppm increase in atmospheric CO_2 between 8000 and 150 BP.

P08PS.07

P08PS - Thermohaline Circulation and Deep Currents

Poster

Formation of the intermediate, deep and bottom water mass structure in the Atlantic Ocean and its decadal variability

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A new principle scheme of intermediate, deep and bottom water mass structure in the Atlantic Ocean was created.

The principle scheme was created with use of the extended optimal multiparameter analysis [Karstensen, Tomczak, 1998]. The whole analysis included 2 layers: 500-3000 m and 3000-bottom on the transatlantic sections: 32°N, 24°N, 8°N, equator, 8°S, 24°S; and WOCE meridional sections A16, A17, A20. The authors managed to establish the contribution of waters from intermediate layer into the deep structure of the Atlantic Ocean. The contribution of Mediterranean waters estimated about 15-20% in the NADW upper component, while the contribution of the Central Water of the Western Basin is negligible. Contribution of Antarctic Intermediate Water (AAIW) into the deep structure is especially large in the southern part of the Atlantic Ocean and makes up to 40%. To the north the contribution reduces but AAIW is traced even to the Newfoundland with 10%.

The authors managed to establish the origin of Antarctic Bottom Water Mass (AABW) in the southern part of the Atlantic Ocean. Accepted that AABW had 40-45% of Weddell Sea Deep Water (WSDW) and 55-60% of Lower Circumpolar Water (LCPW) in the Argentine basin but going northward and influenced by NADW in the Brazil basin AABW had 20% of WSDW, 60% of LCPW and 20% of common NADW.

In the present work average characteristics of water masses were detected using repeating section measurements. According to this approach it was possible to reveal the trends of thermohaline characteristics changes in deep and bottom water mass layers using the method [Bindoff, McDougall 1994]. Volume mean values were calculated for the whole water parcels, therefore the authors found out above mentioned deep and bottom structure's long-term variability. Derived thermohaline trends in the southern part of the Atlantic Ocean didn't reveal any warming deeper 500 m as it shown in [Levitus et al, 2012]. In the layer of AABW cooling has been shown.

P08PS.08

P08PS - Thermohaline Circulation and Deep Currents

Poster

The shutdown and recovery of the AMOC in HadCM3: the role of the advective feedback

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The fresh water advection into the Atlantic ocean by the overturning circulation (Fov) has been suggested as an indicator of the stability of the Atlantic Meridional Overturning Circulation (AMOC) through an advective feedback. This feedback is explored in transient simulations with a global climate model with and without flux adjustments. Flux adjustments are shown to alter the model near surface salinity, changing Fov from a net importer, to a net exporter of fresh water, mainly through correcting an Atlantic saline bias.

The AMOC recovers in strength from a collapsed state, however that in the experiment with flux adjustments recovers much later and more slowly than that without flux adjustments. This difference is traced back to the sign of Fov, confirming the indicator's importance for the AMOC and suggesting that model biases affecting Fov need to be addressed in order to assess the likelihood of irreversible changes in the AMOC.

P08S1.01

P08S1 - Thermohaline Circulation and Deep Currents

Oral

Review of the meridional overturning circulation in the North Atlantic: Observations

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The Meridional Overturning Circulation (MOC), characterized in the North Atlantic by a northward flux of warm, saline upper-ocean waters and a compensating southward flux of cool, fresh deep waters, plays a fundamental role in establishing the mean climate state and its variability on interannual to longer time scales. Variability in the North Atlantic MOC has been linked via modeling studies to rainfall variability over the African Sahel, India and Brazil; Atlantic hurricane activity; sea level variability; and summer climate variability over Europe and North America. An understanding of the observational linkages between the MOC and these variables, however, is lacking, principally because observations of the MOC have been so sparse. Efforts over the past decade, however, have begun to fill the MOC measurement gap. In this talk, I will review the modern observational record of the MOC in the North Atlantic and discuss our current understanding of its variability. In particular, I will discuss the observational evidence for a relationship between the production of deep water masses in the northern North Atlantic and the meridional overturning, a relationship that has been assumed mutually causal for decades. With this causality, the strength of the meridional overturning is believed to depend upon the spread of dense water masses produced via local overturning at high latitudes in the North Atlantic. Likewise, the return of surface waters as part of the upper limb of the overturning has been assumed to impact local overturning at high latitudes by weakening or strengthening the surface stratification, depending upon the salinity and/or temperature of the returning waters. Understanding this causality is crucial to efforts aimed at predicting the consequences of the warming and freshening of high latitude surface waters to the climate system.

P08S1.02

P08S1 - Thermohaline Circulation and Deep Currents

Oral

Variability of the Atlantic MOC in a model forced with NCEP Reanalysis

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The net heat transferred from the South to the North by the Atlantic Meridional Overturning Circulation (AMOC) is one of the main sources of the energy that drives Earth's climate. To understand the AMOC and its variability some observational efforts have been set forth, mainly in the North Atlantic. Among these is the Rapid-Mocha experiment, which has been monitoring meridional fluxes across the latitude 26.5N since 2004. A similar effort has just started along 34.5S in the South Atlantic: the SAMOC program. Several model experiments are also being conducted to contribute with the understanding of this important mechanism. The present work is based on a simulation with the Hybrid Coordinate Ocean Model (HYCOM) forced with products from the NCAR/NCEP Reanalysis, from 1948 to 2012. A comparison with data from the Rapid-Mocha array shows that the model reproduces quite remarkably the mean values and the inter-annual variability of volume and heat transports across 26.5N computed with the observed data in the period April-2004 to March-2011. In the South Atlantic the model also presents a good agreement with values computed at 34.5S with XBTs and Argo floats data and with results of other numerical studies. In general, the results show an energetic decadal variability with a negative trend that suggests the weakening of the Atlantic MOC in the period from 2004 to 2011, in agreement with the Rapid-Mocha data.

P08S1.03

P08S1 - Thermohaline Circulation and Deep Currents

Oral

Examining the relationships between low-frequency SST and AMOC variability

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Observations indicate that Atlantic sea surface temperatures (SSTs) exhibit significant low-frequency variability. The impact of Atlantic SST variability on important climate variables, such as surface air temperature, precipitation, and the frequency and intensity of Atlantic hurricanes, has been documented. However, the origin of low-frequency Atlantic SST variability is not understood. Prior studies have linked variability of the AMOC to decadal Atlantic SST variability, but the mechanisms of such links are poorly understood. In particular, it is not known whether lagged correlations between the AMOC and SST observed in models are due to (1) AMOC variability which leads to Atlantic ocean heat transport variability, whose convergence leads to SST anomalies or (2) upper-ocean temperature anomalies which subduct and lead to AMOC variability in accord with the thermal wind relation.

In this presentation I use a recent state estimate from the Estimating the Circulation and Climate of the Ocean (ECCO) project to examine the relative roles of atmospheric forcing and ocean dynamics in creating low-frequency SST/upper-ocean heat content (UOHC) anomalies. In particular, I will discuss the portion of the observed UOHC variability that can be explained by local atmospheric (wind and buoyancy) forcing and atmospheric forcing integrated along Rossby wave characteristics. In the interior of the subtropical gyre, UOHC variability is dominantly forced by local atmospheric forcing. In contrast, along the Gulf Stream path, UOHC variability is dominantly forced by changes in geostrophic advection, which are related to variability of the Gulf Stream path. Changes in the Gulf Stream path are the result of stochastic windstress curl forcing anomalies, integrated over Rossby wave characteristics. These preliminary results suggest that on the interannual timescales resolved by ECCO, changes in the deep AMOC need not be invoked to explain the observed SST anomalies.

P08S1.04

P08S1 - Thermohaline Circulation and Deep Currents

Oral

Observed and simulated variability of the AMOC at 26•N and 41•N

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Timeseries of the Atlantic meridional overturning circulation (AMOC) have recently become available, but so far no meridional coherence has been documented between them. Here, we analyze the variability of the 26•N RAPID and the 41•N ARGO-based AMOC estimates on seasonal timescales, and we compare them to a simulation from a high-resolution NCEP-forced ocean model. In our analysis of the observed timeseries, we find that the seasonal cycles of the geostrophic component of the AMOC between 26•N and 41•N are 180-degrees out-of-phase. Removing the mean seasonal cycle from each timeseries, the residuals have a non-stationary covariability. Our results demonstrate that the AMOC is meridionally coherent between 26•N and 41•N at seasonal timescales. We find the same coherence in the model, though the phasing differs from the observed phasing. This offers the possibility of inferring AMOC variations and associated climate anomalies throughout the North Atlantic from discontinuous observations.

P08S1.05

P08S1 - Thermohaline Circulation and Deep Currents

Oral

Variability of the DWBC at 26°N from moorings, sea surface height altimetry and bottom pressure

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The meridional overturning circulation (MOC) sustained a striking period of low transport in 2009–10, the question remains as the the source of this reduction and whether it signals a continued weakening of the MOC and its associated northward heat transport. Here, we use the time series of the MOC at 26°N in the Atlantic from Apr 2004–Oct 2012, to examine the interannual variability, particularly of the lower return flow of the MOC: the deep western boundary current (DWBC). Combining independent datasets with the mooring array, we investigate the variability in the barotropic flow of the Atlantic on timescales of days to decades.

Two major findings result. Firstly, the barotropic response to fluctuations in wind-driven Ekman transport is measured below 2000 m depth, with a signature that maps onto isopycnal displacements at the interface between the Labrador Sea Water and Denmark Strait Overflow Water layers. Secondly, using sea surface height anomalies to reconstruct the barotropic transport variability on interannual and longer timescales suggests that the observed interannual variability of the DWBC from the RAPID mooring array may be part of a longer period cycle, rather than a secular trend.

P08S2.01

P08S2 - Thermohaline Circulation and Deep Currents

Oral

Intermediate and deep waters in the Southwest Atlantic and the global meridional overturning circulation

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The Southwest Atlantic Ocean presents a rich variety of deep waters derived from high northern and southern latitudes, as well as substantial contributions from intermediate and deep waters recirculated and transformed along their path within the Antarctic Circumpolar Current. Though the influence of the later water masses is apparent throughout the South Atlantic Ocean, their circulation and mixing and their influence on the meridional overturning circulation is still poorly understood. In this presentation we will use historical and recent hydrographic observations to describe the characteristics and modifications of the deep and intermediate water masses along the western boundary of the South Atlantic. Combination of these observations with data from an array of inverted echosounders from the northwest Argentine Basin near 34.5°S provides a coherent picture of the large-scale circulation, which suggests intense recirculations of intermediate and deep components of the western boundary current. The impact of the intense flow along the boundary is indicated by the configuration of bottom sediments over the western slope of the Argentine Basin, which is closely associated with the vertical structure of the water masses.

P08S2.02

P08S2 - Thermohaline Circulation and Deep Currents

Oral

Flows of Antarctic bottom water in the abyssal channels of the Atlantic

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The study is based on recent CTD and LADCP observations of bottom flows in the Vema Channel, Romanche and Chain fracture zones, Kane Gap, and Vema Fracture Zone. A strong flow of Antarctic Bottom Water from the Argentine Basin to the Brazil Basin through the Vema Channel (32-27 deg. S) is studied on the basis of 23 visits with CTD + LADCP casts. The flow in the Vema Channel is mixed in the vertical direction but horizontally stratified. The mean speed of the flow is 30 cm/s and water transport is approximately 3.5 Sv. A temperature increase was found in the deep Vema Channel, which has been observed for 30 years already. The further flow of bottom water in the Brazil Basin splits in the northern part of the basin. Part of water flows to the East Atlantic basins through the Romanche and Chain fracture zones. The other part is a northwestern flow to the North American Basin. Part of the northwesterly flow propagates through the Vema Fracture Zone (11 deg N) into the Northeastern Atlantic basins. Recent measurements in the Kane Gap (9 deg N) show that the flow of bottom water there is characterized by alternative transport in time. The Northeastern Atlantic basins are filled with the bottom water flowing through the Vema Fracture Zone. The flows of bottom waters through the Romanche and Chain fracture zones do not spread to the Northeast Atlantic due to strong mixing in the equatorial zone and enhanced transformation of bottom water properties.

P08S2.03

P08S2 - Thermohaline Circulation and Deep Currents

Oral

Fate and impact of anthropogenic Agulhas leakage increase

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Recent work suggests that the changes of the Southern Hemisphere (SH) winds led to an increase in Agulhas leakage and a corresponding salinification of the Atlantic. Climate model projections for the 21st century especially predict a progressive southward migration and intensification of the SH westerlies. The potential effects on the ocean circulation of such an anthropogenic trend in wind stress are studied here with a high-resolution ocean model. The model suggests an increase of 4.5 Sv in Agulhas leakage in response to the SH wind changes. The change in leakage is reflected in a concomitant change in the transport of the South Atlantic subtropical gyre, but leads only to a small increase in the Atlantic Meridional Overturning Circulation (AMOC). A main effect of the increasing inflow of Indian Ocean waters with potential long-term ramifications for the AMOC is the salinification and densification of upper-thermocline waters in the South Atlantic, which extends into the North Atlantic within the first decades. To explicitly study the timescales and pathways of Agulhas leakage a Lagrangian analysis with virtual floats was used. Consistent among different model resolutions, typical timescales for the advective fate into the subtropical North Atlantic fall between one and two decades. They are associated with a relative direct path via the South Equatorial Current, the North Brazil current and Florida Current.

P08S2.04

P08S2 - Thermohaline Circulation and Deep Currents

Oral

The 2009/2010 minimum in the AMOC at 26.5°N in ocean data assimilating reanalyses and initialized hindcasts

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In 2009/2010, the Atlantic Meridional Overturning Circulation (AMOC) observed by the RAPID-MOCHA 26.5°N array was ~30% lower than in the previous five years. Following this transient reduction in overturning, there was a substantial and sustained cooling of the upper 1000m of the sub-tropical Atlantic.

We present results from two data-assimilating ocean reanalysis products based on UK Met Office Forecast Ocean Assimilation Model (FOAM) implemented using the ¼ degree NEMO ocean model. We find that ocean state estimates performed for the initialization of the Met Office Global Seasonal Forecast system (GloSea5) faithfully reproduce the observed anomalies in the AMOC and associated overturning heat transports at 26.5°N.

In addition, we present historical forecasts (hindcasts) of the AMOC from GloSea5, and evaluate the potential for the observed AMOC anomaly to have been predicted.

P08S2.05

P08S4 - Thermohaline Circulation and Deep Currents

Oral

Study of deep dynamic in the Liguro-Provençal subbasin during winter 2005-2006

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Historical data have identified the Gulf of Lion as the main important site for the formation of dense water responsible for the ventilation of the deep water in the western Mediterranean basin. However, new hydrological data performed during the last decade report interesting episodes of deep convection also in the Ligurian Sea indicating significant changes in temperature and salinity of the Western Mediterranean Deep Water (Smith et al 2008, Marty et al 2010).   Between 2004 and 2009, in the framework of the ENVAR long term monitoring program, six moorings were deployed along a distance of about 70 km and at variable depths starting from 500 m down to 2300 m. Although the primary goal of the project was the study of the Var submarine canyon system, a large amount of current data were also gathered.   The analysis of this huge current dataset revealed long periods of strong near bottom currents not attributable to the turbidity flows acting along the submarine canyon, but rather imputable to processes of water sinking due deep water convection. This is the case of the event recorded from February 2006, which shows abrupt increases of current speed (with peaks reaching 40 cm s-1). This variation, recorded simultaneously by all current meters deployed, highlighted the occurrence of a mesoscale phenomenon whose effects transfer on a vast thickness of the water column (about 500 m). In support of this study, monthly hydrological profiles of temperature and salinity were retrieved from the Ifremer SISMER (Système d'Informations Scientifiques pour la MER) database.   The combined analysis of both hydrographic and current data allowed us to obtain a synoptical view of the events acting in the whole Var area and to verify that the strong current speed signals measured on winter 2006 may be effectively related to deep convection processes already observed in this area and not only to the activity of the submarine Var canyon.

P08S3.01

P08S3 - Thermohaline Circulation and Deep Currents

Oral

The Southern Ocean overturning circulation: A review

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The overturning circulation refers to the flow of dense deep and bottom waters away from their sources and the compensating return flow of less dense ocean water. The sources of deep and bottom water are limited to a few high latitude sites in the present day ocean. In the Southern Ocean, bottom waters are produced at specific sites around the Antarctic continent, including the Weddell Sea, Ross Sea and Adelie Land. Newly-formed Antarctic Bottom Water (AABW) mixes with overlying deep water as it spreads northward and fills the abyssal basins of the Atlantic, Indian and Pacific Oceans. An important element in the overturning circulation is the diapycnal mixing, driven by air-sea buoyancy forcing and interior mixing, which is needed to transfer water between density layers and close the overturning cell. These diapycnal transports must be included and quantified in any complete description of the overturning circulation in the Southern Ocean and its link to lower latitudes.

This talk will provide a review of the Southern Ocean overturning circulation including Antarctic Bottom water formation, deep abyssal circulation and ocean interior mixing; all essential components of any description of Southern Ocean overturning circulation.

P08S3.02

P08S3 - Thermohaline Circulation and Deep Currents

Oral

The thermohaline streamfunction and diffusion coefficients: estimated from observations

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The flow through the global interconnected ocean, often referred to as the 'Thermohaline Circulation', has strong influence on the ocean's stratification, distribution of water masses, heat transport and cycling and storage of chemical species (e.g. carbon dioxide). This Thermohaline Circulation is a key player in the Earths climate system. Understanding of the underlying physical processes that drive the Thermohaline Circulation and quantifying its different branches is of great importance for Climate Science purposes and is an intensively studied subject. Different approaches like tracer tracking, lagrangian trajectories, inverse methods and various overturning stream-functions, have been used to study the Thermohaline Circulation. We study the Thermohaline Circulation in temperature and salinity coordinates by applying an inverse method to observed air-sea heat and freshwater fluxes in combination with the ocean's interior hydrography to obtain a thermodynamic model of the Thermohaline Circulation. It allows us to estimate the thermohaline streamfunction, interior diapycnal transports, interior isopycnal and diapycnal mixing coefficients and overturning timescales. With this method we hope to gain new insight in the physics underlying the thermohaline circulation; this view is essentially a thermodynamic take on the global conveyer.

P08S3.03

P08S3 - Thermohaline Circulation and Deep Currents

Oral

Understanding the processes controlling Atlantic MOC thresholds

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Many studies over the past 50 years have pointed to the possibility that the Atlantic MOC may exhibit threshold behaviour under increasing fresh water forcing, based on the salinity advection feedback first proposed by Stommel (*Tellus* 1961). However in recent years many other processes have been proposed to influence the stability of the AMOC, including feedbacks from atmospheric and sea ice processes. It is important to establish the extent to which simplified models can capture the processes that control AMOC thresholds, if we are to understand whether such thresholds might emerge in the real world.

Recently it has become possible to explore AMOC thresholds systematically using complex coupled climate models (GCMs, e.g. Hawkins et al. *Geophys. Res. Lett.* 2011). Here we report on analysis of AMOC thresholds in the HadCM3 climate model and its low resolution counterpart FAMOUS, under a range of atmospheric CO2 forcing, and test whether this behaviour can be explained quantitatively using simpler models. We find that Stommel's salinity advection feedback is a key process in the GCMs, but that some other common assumptions in simple models (such as the constant relationship between meridional density gradient and AMOC) break down under certain defined circumstances (e.g. stabilistaion of CO2 concentrations).

The physical insight developed through this multi-model analysis allows us to improve our conceptual understanding of the thresholds and make more robust inferences about the future of the AMOC.

P08S3.04

P08S3 - Thermohaline Circulation and Deep Currents

Oral

Downgradient flow in the global overturning circulation

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At the very largest global scales, including the Atlantic, Pacific, Indian and Southern Oceans, the observed overturning circulation is down-gradient, from high to low pressure, based on observations of the sea surface height and adjusted (absolute) steric height within the deep water layers and the Antarctic Bottom Water layer. Such down-gradient flow is a feature of theories of the very largest scale circulation, and can be explained as a balance between pressure gradient and weak diffusivity in the down-“stream” direction (with geostrophic balance in the cross-“stream” direction). The observations are the well-known global maps of sea surface height derived independently from surface drifter observations, altimetry, and absolute steric height from hydrographic observations. The mid-depth (2000 to 3000 m) and abyssal (4000 m and below) maps are based on hydrographic observations with geostrophic reference velocities selected for mass continuity and consistency with tracer observations. These fields are consistent with southward transport of North Atlantic Deep Water through the Atlantic, northward transport of Antarctic Bottom Water into the Atlantic, Pacific and Indian, and the inter-ocean circulations that move upper ocean waters into these formation regions. The Pacific stands higher than at the surface than the Atlantic because it is fresher, which is also the principal argument for the Pacific-Atlantic asymmetry in deep water formation.

P08S3.05

P08S3 - Thermohaline Circulation and Deep Currents

Oral

Ocean-basin geometry and the salinification of the Atlantic Ocean

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A coupled atmosphere--sea--ice--ocean model is used in an aqua-planet setting to examine the role of the basin geometry for the climate and ocean circulation. The basin geometry has a present-day like topology with two idealized northern basins and a circumpolar ocean in the south. A suite of experiments is described in which the southward extents of the two (grid-point wide) ''continents'' and the basin widths have been varied. When the two basins have identical shapes, the coupled model can attain a symmetric climate state with northern deep water formation in both basins as well as asymmetric states, where the deep water formation occurs only in one of the basins and Atlantic--Pacific like hydrographic differences develop. A difference in the southward extents of the land barriers can enhance as well as reduce the zonal asymmetries of the atmosphere--ocean circulation. This arises from an interplay between the basin boundaries and the wind-driven Sverdrup circulation, which controls the inter-basin exchange of heat and salt. Remarkably, when the short ''African'' continent is located near or equatorward of the zero wind line in the southern hemisphere, the deep water formation becomes uniquely localized to the ''Atlantic'' like basin with the long western boundary. In this case, the salinification is accomplished primarily by a westward wind-routed inter-basin salt transport. Furthermore, experiments using geometries with asymmetries in both continental extents and basin widths suggest that in the World Ocean these two fundamental basin asymmetries should independently be strong enough for uniquely localizing the Northern Hemisphere deep water formation to the Atlantic Ocean.

P08S4.01

P08S4 - Thermohaline Circulation and Deep Currents

Oral

Sensitivity of the Atlantic ocean circulation to freshwater input due to the melting of the Greenland Ice Sheet

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The Atlantic ocean circulation, in particular its Meridional Overturning Circulation (MOC), is sensitive to the surface freshwater flux. In this presentation we show results on the differences between the (decadal time scale) response of a coarse-resolution (non-eddying) global ocean model and a fine-resolution (strongly eddying) version of the same model to a (relatively large) freshwater perturbation due to melting of the Greenland Ice Sheet. We focus on the effect of the freshwater anomaly on convection, watermass transformations and the basin wide circulation. One main result is that, contrary to the response in the coarse-resolution model, the effect of the salt advection feedback in the decrease of the Atlantic MOC seems to be very limited in the fine-resolution model.

P08S4.02

P08S4 - Thermohaline Circulation and Deep Currents

Oral

Flow of grounded abyssal ocean currents along zonally-varying topography in spherical geometry

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Many of the abyssal currents in the oceans, associated with the equatorward motion of deep water masses produced by atmospheric cooling in high latitudes, are organized as mesoscale topographically-steered geostrophically-balanced grounded gravity currents, which flow along sloping continental boundaries. These currents form an important component in the deep "leg" of the meridional overturning circulation in the oceans. The spatial extent of these abyssal currents is hemispheric in scale. This raises the question of the role of planetary sphericity and differential rotation (from the viewpoint of the underlying local geostrophic balance) in determining the large scale kinematic structure of these flows. A steady nonlinear planetary-geostrophic model in spherical coordinates is presented describing the hemispheric-scale meridional flow of grounded abyssal currents on a sloping bottom. The model, which corresponds mathematically to a quasi-linear hyperbolic partial differential equation, can be solved explicitly for a cross-slope isopycnal field that is grounded (i.e., intersects the bottom on the up slope and down slope sides). The solutions possess decreasing abyssal current height in the equatorward direction while maintaining constant meridional mass flux and exhibit westward intensification as they flow toward the equator.

P08S4.03

P08S4 - Thermohaline Circulation and Deep Currents

Oral

The coupled ocean-atmosphere hydrothermohaline circulation

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The ocean thermohaline circulation is in the present work linked to the hydrothermal circulation of the atmosphere. The ocean thermohaline circulation and the atmosphere hydrothermal circulation are generally analysed as two separate systems although they interact with each other at the surface between the atmosphere and the ocean. We will in the present work analyse and thus visualise how the ocean and atmosphere are acting as a number of overturning cells, expressing the mixing of air and water masses. In order to do so we will use two recently introduced stream functions, one for the ocean and one for the atmosphere. The ocean thermohaline stream function, makes it possible to analyse and quantify the entire world-ocean conversion rate between cold/warm and fresh/saline waters in one single representation. The atmosphere analogue is the hydrothermal stream function, which instead captures the conversion rate between cold/warm and dry/humid air in one single representation. We will in the present study combine and also try to merge the overturning analyses of the ocean and atmosphere. In order to do so we have explored and used different ways to relate the salinity of the ocean and the humidity of the atmosphere, which have been used in the past. By using simulations integrated with the Climate-Earth system model EC-Earth, we have succeeded to produce the hydrothermohaline stream function of the coupled ocean-atmosphere overturning circulation in one single picture. This shows how the atmospheric hydrothermal cell and the ocean thermohaline Conveyor-Belt cell are closely linked to each other along a «line» corresponding to the Clausius-Clapeyron relationship. A geographical description of how and where this occurs together with this new hydrothermohaline stream function will be unveiled at the conference.

P08S4.04

P08S4 - Thermohaline Circulation and Deep Currents

Oral

The nonlinear equation of state and the global water mass distribution

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A vertical section through the South Atlantic shows a salinity maximum at mid-depth consisting of North Atlantic Deep Water (NADW), and fresher water both below (Antarctic Bottom Water, AABW) and above (Antarctic Intermediate Water, AAIW). What causes this structure? In particular, why does the fresher water from Antarctica split into an upper and an lower branch, while the saltier Atlantic water occupies the center? It is here shown that the nonlinear eqution of state (EOS), and in particular the thermobaric and cabbeling nonlinearities, play a crucial role for this. Simulations are done with NEMO, a general ocean circulations model, with a horizontal resolution of one degree. Several different versions of the EOS are used. First, a simple but nonlinear EOS is used, with only two nonlinear terms: the thermobaric term and the cabbeling term. The coefficients are adjusted so that the water mass distribution remains approximately the same as when the exact EOS is used. Next, the sign of the thermobaric term is switched. The layering between NADW and AABW then reverses, so that the Atlantic water is below the Antarctic water. The explanation is that when the thermobaricity switches sign, the temperature expansion coefficient decreases with incresing depth. Therefore, at depth the warmer but saltier Atlantic water becomes denser than the Antarctic water. Finally, the cabbeling term is omitted. In this case, the AAIW almost vanishes. Apperently, cabelling is crucial for the formation of AAIW. Cabbeling is particularly strong in this region, since the neutral surfaces slope steeply in the Antarctic Circumpolar Current, causing baroclinic instability and strong mixing along the neutral surfaces, and since the salinity gradient along these neutral surfaces is strong. In summary, the thermobaric nonlinearity is responsible for the layering of AABW and NADW, while the cabbeling nonlinearity is crucial for the formation of AAIW.

P08S4.05

P08S4 - Thermohaline Circulation and Deep Currents

Oral

How does heat get into the deep ocean?

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The role of the ocean's overturning circulation in transporting heat vertically is uncertain. Classical theories describe a thermally direct circulation where cold water downwells and warmer water upwells, cooling the deep ocean. More recently, the upper limb of the overturning circulation has been described as adiabatic, where water downwells and upwells at the same temperature leading to little vertical transport of heat. Here, possible states of the overturning circulation are described ranging from thermally direct to a combination of thermally direct and mechanically direct. In the latter relatively warm water of the upper limb is pumped downward and mixes in the deep ocean with cold waters of the lower limb. The various states have contrasting driving mechanisms and imply contrasting climate sensitivity. A range of multi-millennial climate simulations and forced eddying ocean hindcasts are diagnosed. Apparently credible simulations can exhibit the full range of states. Strategies are proposed for determining which models and hence which thermodynamic state best represents the real ocean.

P09PS.01

P09PS - Ocean Observations and Climate Change

Poster

Interannual variability of physical-chemical parameters of the water column in the Terra Nova Bay polynya (Antarctica)

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A rare long time series of hydrographic profiles, collected from 1995 to 2012 in the Terra Nova Bay (TNB) polynya in the western sector of the Ross Sea, are used in combination with chemical data (from 1997) to study the interannual variability of this area which plays a key role in the formation of the High Salinity Shelf Water (HSSW), the densest water mass of the Southern Ocean which is a crucial component with the Circumpolar Deep Water (CDW) in the formation of the Antarctic Bottom Water. The short residence time of the HSSW in the Ross Sea represents a rapid conduit to transfer Antarctic atmospheric (climatic) anomalies to the rest of global ocean making this area a crucial region to improve understanding of climate change and variability, biogeochemical cycles and the coupling between climate and marine ecosystems in polar environments. Results reveal an interannual variability of the thermohaline stratification and a clear freshening of the deep layers from 1995 up today probably as consequence of a decrease of sea ice production and/or different mixing processes with the CDW. As far as O_2 and nutrients are concerned, the 1997 samples were characterized by a higher nutrients content than the samples collected in the following years, while the O_2 was slightly lower, even if this difference was not statistically significant. From pH and total alkalinity data, we obtained the saturation state of the sea water with respect to $CaCO_3$. The dissolution of solid $CaCO_3$ in deep waters is very important in transferring CO_2 from surface to deep waters. The samples resulted oversaturated with respect to the calcite, but near corrosive levels of aragonite saturation state were found. Aragonite undersaturation is of particular concern for the zooplankton species comprising Pteropods, which form aragonite shells. Our data agree with the occurrence of initial dissolution of the aragonitic shells of the pteropod Limacina helicina found in TNB polynya area.

P09PS.02

P09PS - Ocean Observations and Climate Change

Poster

Climate change impact on water and soil characteristics of Kavaratti Atoll - Lakshadweep Islands

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Lakshadweep islands are volcanic islands with corals, of Holocene age. It consists 36 Islands and 10 are inhabited. Total area of the Island is 32 sq. km and that of inhabited area (10 islands) is 26.2 sq. km. It is scattered in the Lakshadweep Sea of 80 and 12031'North latitude and 70° and 74° East latitude. These Islands are small islands and the biggest Island is 4.8 sq. km (Androth) and the smallest island is Bitra (0.1 sq. km). Surface of this Islands are flat and the maximum height from MSL is less than 5 M. Kavaratti Island is located in Lat N 10° and E Long. 72° . It is made up of weathered coralline rocks. Water is available within a depth of 2M in Kavaratti Island. Water samples are collected from fixed observation wells during monsoon, pre monsoon and post monsoon seasons. Sixty five Observation Wells are fixed for the study. Observation Wells (OW) are fixed on the lagoon side (western side), central region and beach side (eastern side). Water samples were analyzed for various parameters viz. turbidity, pH, salinity, alkalinity, nitrite, phosphate, ammonia, fluoride, silicate, calcium, calcium hardness, total hardness and magnesium hardness. Available data on above parameters for a period of ten years collected from Kavaratti Island Water testing Laboratory are also utilized for the study. The pH of water sample is more alkaline towards the southern side of the Island (8.24) and is slightly alkaline in northwest (7.23) region. The pH values are high in the wells located in lagoon side. It is reported that the pH values of soil ranges from 5.9 to 6.7. Maximum salinity is towards the southern side of the atoll (1.95 PSU) and minimum is (0.28 PSU) towards the middle of the island. Present study also present the impact of climate change on water quality parameters of Kavaratti Island

P09PS.03

P09PS - Ocean Observations and Climate Change

Poster

Lakshadweep Islands and climate change - Formation and sustenance

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Lakshadweep Islands are situated in Southern Arabian Sea (Latitude 8° and 13° N and Longitudes 71° and 74° E). They are volcanic origin, young and of late territory period. For the last two centuries, there are many attempts to elucidate the formation of these Islands. All these efforts are in confirmatory to the hypothesis of Darwin that the coral reefs can grow so as to sustain in shallow water, even though there is subsidence of the base. There are also studies that the coral can grow more than 360 mm/yr so as to combat with the accelerated sea level rise. Present study is an attempt to examine the various hypotheses on the formation of Lakshadweep atolls and the impact of accelerated sea level rise on Island ecosystem To examine the inundation of shoreline and coastal regions of Lakshadweep Islands, the height of Kavaratti Island from Mean Sea Level (MSL) was surveyed during the year 2012 with DGPS. This is the first attempt in this region to estimate the height with modern techniques. It is estimated that the maximum height of this Island is more than 19 M. A detailed study is convened to understand the hydrological scenario with the height of the Island. Coastal erosion and accretion is surveyed with DGPS for monsoon, pre monsoon and post monsoon seasons. Vulnerable regions were identified for this Island. Possible adaptation and mitigation measures to combat impact of climate change on island ecosystem are discussed in the present study.

P09PS.04

P09PS - Ocean Observations and Climate Change

Poster

The climatic control on variability of thermocline depth and thickness in the West Sumatra and South Java Waters

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Thermocline depth in the Eastern Indian Ocean base on profile data from the World Ocean Database (1899 to 2009) is conducted. The areas far from shore have a stable vertical temperature profile (envelope) thermocline and seasonal variations in thermocline depth and thickness are small. Areas that are far off the coast of West Sumatra has a variation of the depth of the thermocline +/- 10 m throughout the year. While in the offshore area south of Java has a variation of thermocline depth +/- 20 m throughout the year. Otherwise for area near the coast which have unstable envelope thermocline structure and large in seasonal variations in thermocline depth and thickness. Areas near the coast in West Sumatra and South Java have a variation of the depth of the thermocline were +/- 70 m and +/- 60 m respectively. ENSO and the IOD influence the depth and thickness of the thermocline in the waters of West of Sumatra and South of Java. In the El-Nino events and positive DM that occurred in 1997-1998 shows that the depth of the thermocline is very shallow (+/- 10 m) in both regions. Seasonal variation of the thermocline thickness in South Java Waters are more thicker than in West Sumatra Waters. The thermocline thickness has difference in the west season (145 m) and east season (140 m), while in the waters of West Sumatra has a thickness of 100 m on the west monsoon season and 110 m in the east. As for the depth of the thermocline is not seen significant differences in the two regions in both west and east monsoon season, which ranges between 50-60 m.

P09PS.05

P09PS - Ocean Observations and Climate Change

Poster

Hazardous wrecks and meteorological monitoring systems : Its impact on navigation and marine safety in West Africa

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The high rate of abandoned shipwrecks all over the country's coastal waters has become a major source of headache to both the government and Nigerians, especially regionally in Africa (West Africa). The attempt in this study is however to highlight and examine the role of hazardous wrecks and the meteorological monitoring systems along the coastline of West Africa, Nigeria in particular is discussed. Also considered has been given to the factors affecting developments in the maritime transports by ships, vessels etc by hazardous wrecks and its impacts on navigation and marine safety. The paper conclude by drawing the attention and stimulation of the private sector, urged the relevant stakeholders to expedite action on plans to remove the vessels, causing navigational hazards to other vessels entering the ports, just as it might trigger flooding of the nation's shorelines. Also developing the markets for viable maritime activities, obtaining the necessary finance for viable maritime technologies in the African continental coastlines.

P09PS.06

P09PS - Ocean Observations and Climate Change

Poster

Rainfall in the midstream of the Nile River as a source of river discharge

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In Sudan, mean annual rainfall observed at 11 rainfall observation stations is less than 100 mm in the north and more than 700 mm in the south. The dry season: when monthly rainfall is less than 10 mm-spanned half year or more at all observation stations. This was longest in the North, where the dry season extended for 9 - 10 months. The seasonality of rainfall time series at the stations was evaluated by the precipitation concentration index (PCI) and seasonality index (SI). The 11 rainfall stations were classified by PCI into 2 categories: 'seasonal- (Kadugli, Malakal), and 'highly seasonal- (other 9 stations). By SI, the stations were classified as: 'markedly seasonal- (Kadugli, Malakal, with a long drier season), 'extreme seasonal- (Atbara, Khartoum- 2 stations), and 'most rain in 3months or less- (other 7 stations). All stations were classified into 4 zones on the basis of annual rainfall. Cross-correlations of the rainfall time series in the each region were more than 0.6. Cross-correlations between the monthly rainfall time series of the 4 zones and discharge of the Nile River indicated high values. Contribution of rainfall in the basin to the discharge of the Nile River was obviously shown. Frequencies of the annual rainfall time series in the 4 regions were extracted by the power spectrum analysis. For all of the 4 regions, periods corresponding to obtained frequencies were similar to those of the sun spot number and SOI. Using obtained frequencies, fit of the Fourier series with the rainfall time series was performed. To optimize combination of the frequencies, the Akaike Information Criterion was used. Cross-correlations of rainfall time series of July and August, the rainy season in Sudan with sea surface temperature all over the world were calculated. Significant correlations were found at sea off western Africa, southern India, and South Africa at 3-6 months lag.

P09S1.01

P09S1 - Ocean Observations and Climate Change

Oral

Tropical Moored Buoy Arrays, ocean-atmosphere interactions, and climate change

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This presentation will highlight successes in observing system development for tropics over the past 30 years, with emphasis on the Global Tropical Moored Buoy Array. We will illustrate how this network of buoys, in conjunction with other in situ observing system components and Earth-observing satellites, has enabled advances in our understanding of El Niño and the Southern Oscillation (ENSO), the Indian Ocean Dipole, and other climate phenomena that have significant socio-economic consequences. Modern instrumental records are long enough now to detect decadal changes in the character of some modes of tropical climate variability, like ENSO. We will discuss whether these changes can be attributed to climate change or natural variability based on various threads of scientific evidence.

P09S1.02

P09S1 - Ocean Observations and Climate Change

Oral

Trends in the mixed layer at Ocean Station Papa and along Line-P in the Gulf of Alaska

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This paper presents a re-analysis of trends in water properties around the Gulf of Alaska. The data sets used are time series observations at coastal lighthouses and the Station-P and Line-P time series augmented with data from the Argo global float array. Early in the history of Station Papa the site was occupied by Canadian Weatherships. In 1981 the Weathership program was abandoned but the time series was maintained, with lower frequency sampling, using research vessels. Steadily the number of surveys per year declined to the current level of three per year. Thus we have a high density of observations early in the time series declining to a low density of ship borne observations late in the time series. This paper will show how Argo observations can be used to restore high frequency sampling as it was done in the 1960s and 70s. It is shown that though trends have changed, the essential story that was told 15 years ago has not changed in any meaningful way. Sea-surface temperatures are rising over a large part of the Gulf of Alaska and sea-surface salinities are declining. Both of these lead to a decrease in surface density. We show that the temperature change extends deep in the Gulf of Alaska, and the freshening trend extends to a depth of about 100 decibars. Potential energy in the water column is decreasing and the result of the decreasing potential energy and the increasing stratification implies a decrease in mid-winter mixed layer depths.

P09S1.03

P09S1 - Ocean Observations and Climate Change

Oral

Biases in Expendable BathyThermograph data: correcting historical data and planning for the future.

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As they comprise 56% of ocean temperature profile data between 1967 and 2001, quantifying biases in eXpendable BathyThermograph (XBT) data is fundamental to our understanding of the evolution of the planetary energy and sea level budgets over recent decades. The nature and time history of these biases remains in dispute and dominates differences in analyses of the history of ocean warming. We assembled a database of over 4,100 side-by-side deployments of XBTs and Conductivity-Temperature-Depth (CTD) data and use this unique resource to characterize and separate out the pure temperature bias from depth error in a way not previously possible.

We find that there is a pure temperature bias in Sippican probes of ~0.05°C, independent of depth. The temperature bias has a time dependency, being larger (~0.1°C) in the earlier analog acquisition era and likely due to changes in recorder type. We find that year-to-year variations in fall rate have a bigger effect on corrections to the global XBT database than any small effects of ocean temperature on fall rate. This study has large implications for the future development of better schemes to correct the global historical XBT archive and requirements for future XBT data collection.

P09S1.04

P09S1 - Ocean Observations and Climate Change

Oral

Indo-Pacific Ocean in a changing climate

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Over recent decades, the Indian Ocean has been warming at a relatively rapid rate compared with the oceans in other basins, and the South Pacific Gyre has intensified causing the East Australian Current to extend further southwards. On interannual time scales, El Niño – Southern Oscillation (ENSO) and the Indian Ocean Dipole dominate the climates of Indo-Pacific Ocean Rim countries and islands. Most dominant, however, ENSO-related temporal and distribution changes are observed throughout the Indo-Pacific Ocean, including changes to ocean temperatures, Australian coastal sea level and regional tropical cyclones, rainfall, and Indo-Pacific net primary productivity. While recent observations suggest there has been a shift in ENSO-type characteristics over the past few decades, Pacific decadal variability itself has a modulating effect on ENSO. This paper synthesizes the team's recent research findings associated with Indo-Pacific Ocean interannual to multi-decadal variability and trends in temperature, heat content, sea level and chlorophyll based on remote sensed and in situ observations, ocean reanalysis data, and dynamic ocean and climate model simulations. Specifically, the paper combines the statistical analysis of observations with the mechanistic understanding provided by deterministic models to explain the contribution from large-scale climate drivers on the ocean climate changes and dynamic linkages observed across the Indo-Pacific Ocean in recent times.

P09S1.05

P09S1 - Ocean Observations and Climate Change

Oral

Cananeia, Brazil - Lat 25, extreme and long term sea level values, compared to Hawaiian and PSMSL global series

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Fifty years of sea level data from Cananeia (Lat 25 1'.0 ; 47 55.5' Long) Brazil, were analyzed. Variability of the maxima and minima of met/ocean extremes were compared to series of San Francisco, Honolulu, Atlantic City, Balboa and Vigo, provided by the University of Hawaii Sea Level Center.The great majority of the sea level distributions have Gumble, Fréchet and Weibull tails. Fisher test identified Fourier decadal and intradecadal periods in all of them. Trend analyses of PSMSL series show that all Brazilian ports have positive trends. Plots of trends versus correlation bins of all ports, showed small standard deviations close to zero bin, up to the bin and greater absolute values of negative trends, than the positive ones in other bins. The highest negative and positive trend values occur geographically close to each other. Trends of all series seem to be well distributed along the Latitudes and along the Longitudes. The mean distance of the discrete sea level data points, to the regression line, previously calculated, was taken as a measure of proximity of each series. An F function, exhibiting the product of these coefficients was defined, which had a distribution tail to the left. Global values of F, series of Cananeia included, in a plot against the trends, exhibited a Christmas Tree aspect and, as the length in years of the series increased, in different plots, started to show two stems, one in the negative and the other in the positive side of the plot. For the longest series with more than 60 to100 years, the positive stem showed a straight line, pointing to 18 cm/cty, while the negative stem, along a curved like line, pointed to -58 cm/cty. Further analyses on these odd aspects are underway.

P09S2.01

P09S2 - Ocean Observations and Climate Change

Oral

Satellite observations for ocean and climate research

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With their relatively uniform spatio-temporal sampling and (often) global coverage, satellite observations in the past two to three decades have revolutionized ocean and climate research. Sustaining and enhancing satellite observations to produce consistent, climate-quality time series of essential ocean and climate variables and synthesis of these observations with in-situ measurements and state-of-the-art numerical models are critical to further improvement of our ability to monitor, understand, and predict ocean and climate variability and changes. This presentation highlights accomplishments of satellite observations, especially in terms of sea surface temperature, height, salinity, and wind as well gravity measurements. Synergistic use of satellite observations with in-situ data and models through ocean synthesis efforts under the Climate Variability and Predictability (CLIVAR) Program is described. State of the satellite observing systems is summarized. Future challenges in satellite observing systems and synthesis of satellite observations are discussed, including technical hurdles, resources, advocacy, international coordination, and cross-community interaction.

P09S2.02

P09S2 - Ocean Observations and Climate Change

Oral

Global ocean chlorophyll in a changing climate

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Oceans are the principle sink for atmospheric CO_2. While the impact of individual El Niños on ocean productivity have been investigated, how the ocean biology responds to recent changes in climate across a range of time scales has not been previously characterised. A doubling in the intensity of El Niños in the central equatorial Pacific in the past 30 years should have affected ocean productivity and thereby the sink of CO_2. In this paper, and based on the analysis of satellite remote-sensed estimates of surface ocean chlorophyll (Chl-a) we demonstrate that the dominant non-seasonal mode of Chl-a since the late 1990s is coupled with the central Pacific (CP) El Niño (in contrast to current understanding), and includes a decadal-scale, or longer-term, trend. Whether this trend is natural or otherwise (e.g., anthropogenic), the limited record length makes it difficult to conclude. However, back-reconstruction of the dominant mode time series to 1870 supports CP El Niño as being the key driver of Chl-a changes since the late 1990s, while the decadal-scale coupling has increased the global net amplitude. We estimate that CP El Niño has induced near-global ±0.5-0.6 $Pg.C.yr^{-1}$ changes in ocean net primary productivity (NPP) in the period 1998-2010, while the canonical El Niño is probably responsible for about two-thirds of this amount. We also find that CP El Niño acts to increase ocean NPP, contrary to our current understanding of El Niño effects. This highlights the important distinction between El Niño flavours on the global system. Finally, we estimate an equivalent offset at the rate of ~10% of current anthropogenic CO_2 emissions during peak CP El Niño events, due to the increase in NPP.

P09S2.03

P09S2 - Ocean Observations and Climate Change

Oral

Sea Surface Height Variability in the Gulf of Thailand and South China Sea using altimetry data: A preliminary study

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Sea Surface Height (SSH) study is used to determine sea level trend and dynamics which has been affected by global climate change, but only a few studies have been conducted regarding local SSH in the Gulf of Thailand (GOT) and South China Sea (SCS). We extract satellite data from Radar Altimeter Database System (RADS) by using TOPEX/POSEIDON, ERS-2, ENVISAT, JASON-1 and JASON-2 data from 1993-2010 using crossover residual minimization method, calculate and combine monthly mean sea level anomaly from five satellites. Distribution of SSH anomaly shows two modes : (1) Low water level remains in the central part with high water level near coasts of Asian continent, Borneo and Gulf of Thailand when northeast monsoon prevails (November to January). (2) High water level remains in the central part with low water level near coasts of Asian continent, Borneo and Gulf of Thailand when southwest monsoon prevails (May to August). Analysis of satellite altimetry data also yields the average rising rate between 4 – 5 mm/yr in GOT and higher rate is also found in SCS.

P09S2.04

P09S4 - Ocean Observations and Climate Change

Oral

Comparison of sea-level measurement from radar gauge with satellite altimeter in eastern Arabian Sea

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An Integrated Coastal Observation Network (ICON) has been established along the Indian coast and Islands (http://inet.nio.org) by CSIR-National Institute of Oceanography (NIO), India. It provides graphical presentation of sea-level information such as observed sea-level, predicted tide and residual sea-level. The availability of two stations Karwar (Lat: 14.48 deg. N, Lon: 73.06 deg. E) and Kavaratti (Lat:10.34 deg. N, Lon: 72.48 deg. E) along the Jason-181 track provides a more opportune use to compare the satellite altimeter data (corrected for instrumental noise, orbit determination error and geophysical errors, including the ocean and loading tide and the inverse barometer effect) in the Arabian Sea.

In this paper, we present the results of the comparative studies carried out between the sea level measurements for the year 2009 to 2010 using downward looking aerial microwave radar gauge with the data obtained from the nearest point on track (No-181) of JASON altimeter. The SLA available at the nearest point of Jason track-181 from Karwar (~35 Km) and the daily-mean sea level estimated using radar gauge are with a range of ~ ± 25 cm. The variance of SLA, daily-mean sea level and residuals are ~78 cm2, 106.8 cm2 and 46.2 cm2 respectively. The root-mean square difference (RMSD) between daily-mean sea level (residual) and the SLA is ~9.1 (10) cm. However, when the sea level (residual) are averaged using a convolution filter with hanning window (1440 points), implying a running average of 10 day period, the RSMD with SLA reduces to 8.2 (8.6) cm. Similar, study at Kavaratti Island between measurements from radar gauge data and the SLA from the nearest point (~ 7 Km) along JASON-181 track indicates that the RMSD between SLA and daily-mean sea level (10 minute residual) is ~7.1 (10.6) cm. The RSMD between 10-day running averaged sea level (residual) with the SLA improves to ~5.7 (8.6) cm due to the open ocean conditions.

P09S2.05

P09S2 - Ocean Observations and Climate Change

Oral

Decadal changes in dissolved inorganic carbon

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Since the ocean acts as a major sink for anthropogenic CO_2, the estimates of CO_2 changes in the ocean have been carried out in many previous studies. To evaluate the estimates, it is important to compare them based on various methods. First, we estimate anthropogenic and natural carbon changes in recent decades using the method based on measured total carbon differences on isopycnal surfaces between high-quality twice observations conducted under WOCE and WOCE revisit projects.

Since the comparison on the isopycnal surfaces is not strongly affected isopycnal surface heaving, small changes can be detected in deeper layers, which show the deeper transport of anthropogenic carbon. From the analysis, we obtained total anthropogenic carbon increases of 5-8 PgC / 10yr in the Atlantic, Pacific, and Indian Oceans.

Although the method can detect the exact changes on the isopycnal surfaces, the method can be applied only along the sections occupied twice, and the spatial representativity and the uncertainty of changes in the basins are unclear. Thus, we examine to make the gridded data from the CARINA and PACIFICA data, which are synthesized to keep the data consistency between chemical observations. Since relationships among temperature, salinity, and measured dissolved values are used in making the gridded data, observations of dissolved values as well as temperature and salinity can improve the estimates.

P09S3.01

P09S3 - Ocean Observations and Climate Change

Oral

Deep water warming in the world oceans

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Deep water warming has been found in the world oceans by comparing results from ship-based basin-scale repeat hydrographic surveys mainly conducted in the 2000s in CLIVAR/IOCCP and previous surveys conducted in World Ocean Circulation Experiment. In the Pacific Ocean, deep water warming was observed along the pathway of the Circumpolar Deep Water, which suggests a change in overturn circulation in the Pacific Ocean. In order to know the mechanism and time scale of such deep water warming, an improved ocean state estimation, in which the deep water warming is successfully reproduced, has been developed by using a four dimensional variation data assimilation technique. An adjoint sensitivity analysis reveals that an increase in the heat input into the sea surface off the Adélie Coast results in deep water warming in the subarctic North Pacific basin within four decades through a change in the configuration of the isopycnal surfaces (caused by a reduction in deep water formation rate) propagating as oceanic internal waves. Results from hydrographic observations which were conducted by R/V Mirai in 2013 in the Southern Oceans indicate a remarkable freshening and hints of reduction of bottom water. Change in water properties in deep layers affects sea level rise. Recent studies estimate a contribution to global sea level rise due to thermal expansion below 3,000m is about 0.1 mm / year, however, contribution of salinity change has to be more discussed for a precise estimation of deep layer contribution to global sea level rise. The recent studies on these topics and the most recent results from observations in the Southern Oceans will be introduced in the presentation.

P09S3.02

P09S3 - Ocean Observations and Climate Change

Oral

Salinity changes in intermediate water masses around the world

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A prominent feature of the subtropical North Pacific Ocean is the salinity minimum lying in a narrow density range of 26.7 to 26.9 (sigma-theta),this is known as the North Pacific Intermediate Water (NPIW). NPIW is formed by deep convection originating in the Sea of Okhotsk, but substantially modified in the Oyashio/Kuroshio mixing region.

A similar water mass is formed off the southern coast of Chile, this is the Antarctic Intermediate Water mass (AAIW) which spreads through the Drake Passage occupying the Atlantic Ocean at least as far north as the equator, the Indian Ocean and finally back into the Pacific. For both the NPIW and AAIW bulk properties of the water mass are determined by its near surface origin and this was used by Wong in 1999 (Nature). Wong showed that over a period of about 20 years, ending with the observations of the World Ocean Circulation Experiment, that the intermediate waters of the North and South Pacific, and the south Indian Ocean had freshened. A change she attributed to an increase in precipitation minus evaporation at high latitudes.

In this paper I reconstruct the WOCE Hydrographic Program stations using realisations from the Argo array. It will be shown that in the 20 years since WOCE the changes have become considerably less clear than were described by Wong even though a comparison between WHP and Argo involves considerably more high-quality data than was available to Wong. It will be shown that the NPIW has become significantly saltier since WOCE. The AAIW in the south Atlantic has become saltier, but this was an example not explored by Wong. The AAIW in the Pacific remains essentially unchanged but may have become slightly saltier in the south Indian Ocean. In all cases there are temperature changes correlated with the changes in salinity that are, roughly, density compensating. Thus there are no significant changes in the density of intermediate waters.

These results are very different from those reported by Wong and suggest a much more complex relationship between P-E changes at high latitudes and changes in intermediate water masses.

P09S3.03

P09S3 - Ocean Observations and Climate Change

Oral

Linked interdecadal Indo-Pacific subsurface temperature modes

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Comprehensive studies and analysis of the decadal-to-multidecadal ocean subsurface temperature variability are fundamental to improving our understanding of low frequency climate signals. Reanalysis products can provide very useful state estimates for investigating interdecadal climate changes. In the present study, we take advantage of the Simple Ocean Data Assimilation (SODA 2.2.4) data for the period 1950 – 2007 to identify the important decadal modes of variability that characterise the Indo-Pacific Ocean thermocline. An Empirical Orthogonal Function (EOF) analysis of the 10-yr low-pass filtered temperature applied across four depths (5 m, 97 m, 266 m and 468 m) shows that the dominant mode is characterised by a long-term temperature trend, with decadal scale fluctuations. A further EOF analysis of the 10-yr filtered detrended temperature data identifies the Interdecadal Pacific Oscillation as EOF1, the North Pacific Gyre Oscillation as EOF2, and the decadal component of El Niño Modoki as EOF3 (respectively modes 2, 3 and 4 of the non-detrended data). We show that decadal temperature variability has a pronounced vertical extension through the upper ocean. The upper thermocline levels (97 m and 266 m) account for most of the variance in the analysis. The «trend» mode connects the tropical western Pacific and the southern Indian Ocean via the Indonesian through-flow, and appears to be consistent with advection of salinity by water mass transformation. This study highlights the importance of examining the subsurface ocean – where investigations of sea surface temperature alone have not previously been able to show these dynamic connections between the Pacific and Indian Oceans.

P09S3.04

P09S3 - Ocean Observations and Climate Change

Oral

Evidence of halosteric driven sea level rise in the Antarctic coastal sea

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The Antarctic shelf seas (AASS) are a region of great climatic importance due to the vigorous interactions between the multiple components of the climate system that they host. Investigation of these interactions and their consequences is confounded by the difficulty in observing the AASS in the presence of sea ice, which covers the region over much of the year. It is possible to circumvent this problem however by analyzing satellite-derived measurements of sea surface height (SSH) during the largely sea ice-free summer months to determine the evolution of sea level in the region over the last two decades (1992 - 2010). We show that Antarctic coastal SSH has exhibited a pronounced circumpolar positive trend of ~1 mm yr-1 above the global-mean rate of sea level rise, peaking in the Ross Sea and in the eastern Indian sector. An assessment of the possible causes of the observed change in the AASS volume budget leads us to conclude that the rapid coastal sea level rise is likely to result primarily from a halosteric response to freshening, with decadal variations in wind forcing also contributing a significant (around one fifth) fraction of the signal.

P09S3.05

P09S3 - Ocean Observations and Climate Change

Oral

An investigation of the thermohaline variability of AAIW in the southeast Atlantic sector of the Southern Ocean through the development of a Gravest Empirical Mode and analysis of subsequent results

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The southeast Atlantic sector of the Southern Ocean connects the Atlantic with the Indian Ocean and the Antarctic Circumpolar Current, thereby playing a major role in global ocean circulation. Thermohaline transports in this area could have a critical influence on global climate. However, the magnitudes of heat and salt fluxes in this region are poorly understood as hydrographic observations are limited. A Gravest Empirical Mode (GEM) is set up for the area of the Southern Ocean south of Africa using 20 years of hydrographic measurements obtained from cruises, combined with 10 years of Argo data. By combining the GEM with altimetry sea surface height data (from 1992 to 2012), a Satellite GEM (satGEM) is created. Using the satGEM, a 20 year time series of weekly temperature and salinity fields are produced for the area. The results from the satGEM allow for a specific examination of Antarctic Intermediate Water (AAIW). This water mass was chosen as it is found within a depth range of the GEM where the residuals are at a minimum, and as it has been recently ventilated and thus fluctuations can be linked to changes in climate. Trends in heat and salt are produced with a detailed investigation into the particular changes in AAIW within each frontal zone. The influence of eddies acting as a concertina on AAIW is a specific focus of the study, causing a respective depression or shoaling of the AAIW isopycnal limits for positive or negative sea level anomalies. Cold core anomalies are found to produce a doming in AAIW where the water mass appears to come into contact with the surface mixed layer, thereby allowing for atmospheric exchanges at lower latitudes than was previously thought to occur. Obtaining an improved image of magnitudes and variability of AAIW thermohaline circulation in the Atlantic sector of the Southern Ocean greatly improves our understanding of this vital part of the global ocean and the role it plays in Earth's climate system.

P09S4.01

P09S4 - Ocean Observations and Climate Change

Oral

Local and remote impacts of freshwater input into the Bay of Bengal

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Monsoons create an assymmetry between the western and eastern parts of the North Indian Ocean. While the western part is cooler, more saline and highly productive, the eastern part is warmer, fresher and less productive. The large amount of freshwater that the Bay of Bengal receives is crucial in maintaining this hydrographic balance of the north Indian Ocean. Climate models project an amplification of the hydrological cycle in a warming regime though the available data sets suggest a decreasing supply of river runoff into the oceans. Therefore, it is imperative that the impact of freshwater on the dynamics and thermodynamics be clearly understood and quantified.

Recent observational experiments in the Bay of Bengal carried out under Indian Climate Research Programme (ICRP) have captured events of upper layer freshening and the ensuing alteration to the upper ocean stratification and air-sea heat exchange. Ship-board observations in the southern Bay of Bengal during the CTCZ (Continental Tropical Convergenge Programme) – within the core of the Summer Monsoon Current – have unravelled processes that maintain the salt balance of the Bay of Bengal. Ocean General Circulation Models have limited capability in reproducing the salinity variations observed by moored buoys in the Bay of Bengal, owing to the unavailability of accurate data on freshwater input into the ocean, insufficient resolutions (both horizontal and vertical) and inadequacies in parameterization of mixing. Neverthless, numerical experiments using models elucidate that the freshwater fluxes have significant influence on the sea surface temperature at both seasonal and intraseasonal time-scales. Implication of these impacts to ocean biogeochemistry and monsoon rainfall are challenging problems that need to be addressed by focussed obserational programs and modeling efforts.

P09S4.02

P09S4 - Ocean Observations and Climate Change

Oral

Warming of Indian Ocean and the general circulation models

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The long term trends in Sea surface Temperature(SST) estimated from three independent data sets indicated that, the SST over the Indian Ocean (IO) (north of 32 °S) increased at rates varying from 0.006 to 0.012 °C yr–1 (1950-2010). The SST and Heat Content anomalies was higher during El Nino and lower during La Nina. The warming trend was also seen in the heat content in the upper 300 and 700 m water columns. However, the warming of SST as well as the warming of upper layer does not seem to be due to the increased heat flux from the atmosphere. Rather, the trend in the atmospheric flux estimated using various data sets showed net decreases in atmospheric flux. The atmospheric flux decreased at a rate of 0.84 W m–2 yr–1 equivalent to a cooling of 0.01°C yr–1.

Five Ocean general circulation model's (OGCM) and a set of twentieth - century climate simulations from 13 coupled models were used to examine the trends in oceanic transport through the boundaries of IO. All models well reproduced the increasing trends in SST as well as the heat content in the upper 300 m water column. However, the net transport of oceanic heat estimated based on the transports across the boundaries did not indicate heat accumulation in the IO to account for the increase in SST or heat content in the water column. Our conclusion is that the heating of IO must have occurred due to the accumulation of heat due to the oceanic transport, but the models failed to bring out this fact due to their inability in simulating the velocity field.

P09S4.03

P09S4 - Ocean Observations and Climate Change

Oral

Variability and trends in Southern Ocean surface waters and implications for global climate

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Significant trends in surface hydrographic properties have been observed over the past 50 years. For the most part Subantarctic Surface Waters have cooled and freshened while waters to the north of the ACC have warmed and increased in salinity. It remains unclear (1) to what extent this is due to increasing greenhouse gases vs. stratospheric ozone depletion, (2) what the respective role of surface buoyancy fluxes is compared to internal ocean dynamics, (3) how much of the T-S trends have been mitigated by ocean eddy fluxes, and (4) what the implications are for interior water masses, carbon uptake, and the global ocean thermohaline circulation. In this talk I will discuss the role of the Southern Annular Mode in the observed trends in surface hydrographic properties of the Southern Ocean. Implications for interior water mass properties, ocean carbon uptake, and possible teleconnections to tropical climate modes will also be examined.

P09S4.04

P09S4 - Ocean Observations and Climate Change

Oral

Ocean surface carbon dioxide fugacity and its relation with drivers observed from sThe ocean as the source and sink of carbopace

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The ocean as the source and sink of carbon dioxide is important to global warming and ecology, but its quantitative contribution to the change of atmospheric carbon storage is insufficiently known. The exchange depends on the difference in fugacity (partial pressure) of carbon dioxide between sea and air, and a transfer velocity. The transfer velocity has traditionally been parameterized in terms of wind speed, which has been measured by a number of spacebased sensors. The fugacity in air is believed to change much less than fugacity in sea. Fugacity in sea is measured largely on ships; they are not sufficient to characterize spatial and temporal variability. Attempts have been made in the past to relate the fugacity in sea to parameters (drivers) that could be measured from space. These relations are found to be valid only in limited regions and in specific seasons. We have developed a statistical model to estimate the fugacity over global ocean for all seasons from NASA space measurements using the state-of-art statistical techniques. The input data are sea surface temperature, productivity, and salinity over global oceans. We are examining the role of these drivers in different location and seasons. The dependence of the fugacity on sea surface temperature in the tropics is replaced by dependence on productivity at higher latitudes. The change of fugacity is highly correlated to salinity around the Amazon River discharges and in the tropical instability waves in the Pacific. We are evaluating the accuracy of the fugacity in sea and its improvement on carbon cycle. We will explore proper remedies of any deficiency.

P09S4.05

P09S4 - Ocean Observations and Climate Change

Oral

Ocean Acidification (OA) and pollution load in the Bay of Bengal: Impact on marine ecosystem

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The study focused on ocean acidification and heavy metal concentration on sea water, sea sediment and seashells, oyster along the east coast of the Bay of Bengal. The study has collected thirty sea water samples upto 36 nm (about 67km) of continental shelf of mixed surface layer (upper 40 m), eight marine sediment samples and twenty eight sea shells and oysters with the help of Bangladesh NAVY (Roebuck Class Hydrographic Survey vessel). In this study AAS (Atomic Absorption Spectroscopy), Atomic Spectrophotometer and different lab experiments are performed.

The present study reveals that the average pH value was found to be 7.75. The pH in the bay is dropped by less than 0.2 units in eighteen years compared to pH level in 1994 (at least 7.95) (Royal Society, 2005). Therefore, the average reduction rate of the pH value is 0.0083 units per year.

The study shows the heavy metal concentrations hierarchy in the following manner; Fe>Mg>Pb>Cu>Zn>Cr; Fe>Zn>Ni>Cr>Cu>Pb>Cd and Fe>Pb>Cu>Cd in zooplankton, sediment and sea water, respectively. The average value of heavy metals in sea water was higher than the standard value. The highest concentration of heavy metal in sediment such as lead was 22.54 µg g-1; Cu had a high loading (34.90 µg g-1); Cd concentration was very high (5.98 µg g-1) that exceeded ERL value (1.2 µg g-1). The higher concentration of Ni exceeded ERL (20.9 µg g-1) and ERM value (51.6 µg g-1) and Zn (178.705 µg g-1) also exceeded ERL value (150 µg g-1). Enrichment of organic carbon (OC) and pollution load index (PLI) of marine sediment reveals minor to moderately severe enrichment of Zn and Ni along the coast.

Regarding sea shells and oysters, the average calcium carbonate was found to be 80% whereas normal shells are composed of 95-97%. It observed 0.03527% concentration of heavy metals in their shells. The lower pH (7.75) and toxic effect of Pb and Zn appear to be reduced their growth and made them fragile which may great threat to marine ecosystem.

P10PS.01

P10PS - The North Atlantic and climate change

Poster

Freshwater and salinity variability in the North Atlantic

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The sea surface salinity (SSS) distribution in the North Atlantic is affected by changes in the circulation and changes in freshwater fluxes. Changes in SSS are introduced into the ocean's interior by vertical processes like subduction or convection, and transported along circulation pathways. At a given location and depth, salinity could vary by water mass changes due to changes in the freshwater flux, or by vertical migration of density surfaces caused either by wind-driven changes of ocean ventilation or by thermodynamic processes, like poleward migration of isopycnals as a result of surface warming. A marked influence on upper ocean salinity in the subpolar North Atlantic have changes in the wind driven circulation associated with a shift of the subpolar front, separating the saline subtropical gyre from the fresher subpolar one.

Due to the lack of temporal and spatial resolution of salinity observations, salinity anomalies could up to now only be studied by averaging over 5 years. Thanks to the Argo program, the temporal and spatial resolution of salinity and temperature profiles since 2006 have significantly improved, allowing to calculate seasonal or even monthly means.

P10PS.02

P10PS - The North Atlantic and climate change

Poster

Influence of atmospheric pressure on geostrophic surface currents in the North Atlantic from satellite measurements

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Geostrophic currents are by definition steady in time and space, and are currents in balance between the Coriolis force and pressure gradient. But the mean sea level atmospheric pressure differences and corresponding geostrophic winds varies over the years, which affect the pressure gradient in the ocean and the wind stress, and thereby the geostrophic currents. It is therefore interesting to examine how the currents are affected by the changing atmospheric pressure and winds, both in strength and location.

Geostrophic surface currents can be calculated from satellite altimetry. This is done in the North Atlantic with data along three satellite tracks from the TOPEX/Poseidon, Jason-1 and -2 satellites spanning the 20 years period Jan 1993 to Jan 2013. When the currents are calculated, they are compared to drifter data in same period for validation.

Afterwards the currents are compared to the atmospheric surface pressure, to determine any correlation between the two. This result is then compared to a similar work by Flatau et al. (2003).

Finally the correlations will be basis for establishing an empirical model between the surface pressure and the currents. The efficiency of this model will be tested using independent data and the model will be used to improve the prediction of the surface currents from the pressure.

P10PS.03

P10PS - The North Atlantic and climate change

Poster

Changes of the Atlantic circulation in MPI-ESM CMIP5 climate projections

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We examine potential changes of the Atlantic meridional overturning circulation (AMOC) and of its seasonal cycle. We use climate change projections of the Max Planck Earth system model (MPI-ESM) performed within the suite of experiments for CMIP5. In particular, we analyse different RCP scenarios between 2006 and 2300. To be able to compare the model simulations against present day observations, we focus on the AMOC at 26°N. The AMOC is projected to weaken in the next centuries in the analyzed scenarios. The strongest weakening occurs in RCP85 from a time mean AMOC of 19.1 Sv (1850-2000) to 8.7 Sv (2150-2300). In all scenarios, the weakening results from the geostrophic transport which decreases from the beginning of the 21st century. Only in RCP26, the AMOC almost recovers its original strength (18.1 Sv) of the 20th century. The reduction in strength of the AMOC is accompanied by a change in the seasonal cycle. For the simulation of the past century (1850-2000), the simulated AMOC in MPI-ESM shows a pronounced minimum in April, a stronger AMOC towards summer and maximum in fall, similar to the observed mean seasonal cycle from the 8 years of measurements from the 26°N RAPID-array. In climate change projections, we find no significant change in the seasonal cycle in the RCP26 scenario, whereas we find a shift in the seasonal cycle in the RCP85 scenario. In the RCP85 scenario, the minimum in spring, as well as the strengthening of the AMOC in summer decrease after 2100. This shift in the seasonal cycle almost exclusively results from a shift in the seasonal cycle of the Ekman transport which initially has a maximum in summer (1850-2000) shifting to a minimum in summer (2100-2300). We also find that after 2100, the AMOC seasonal cycle is modified by a small decrease on both the spring minimum and the winter maximum of the geostrophic transport.

P10PS.04

P10PS - The North Atlantic and climate change

Poster

Towards understanding the role of circulation in the North Atlantic carbon budget

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Here we present results from a full Atlantic inversion of WOCE-era observations with a focus on the transport of dissolved inorganic carbon (DIC) and anthropogenic carbon (Cant) across the 25°N line. The DIC field and Cant estimates from a variety of sources are combined with the observed velocity field to produce estimates of meridional transport. The DIC and Cant transport estimates are then decomposed in much the same way that heat transports have been in the past. We look at the importance of the western boundary current (WBC), the deep western boundary current (DWBC), the interior return flow, barotropic versus baroclinic, and east versus west. The comparison is done for mass and DIC as well as for each of the different Cant estimates. Preliminary Cant transport results indicate 1) an agreement that the net transport is northward; 2) a range in estimates of net transport (0.03 ±0.06 to 0.13 ±0.02 $PgCa^{-1}$) that exceeds the predicted uncertainties; 3) that Cant estimated with similar techniques can still produce significantly different net transport estimates; 4) that having similar net transports does not necessarily indicate a similar underlying balance of components. In particular, there are differences in balances between WBC and DWBC, as well as east versus west.

P10PS.05

P10PS - The North Atlantic and climate change

Poster

Large-scale circulation in the northern North Atlantic: A mean state in the 2000s

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A mean state of the full-depth summer circulation in the Atlantic Ocean in the region in between Cape Farewell (Greenland), Scotland and the Greenland-Scotland Ridge (GSR) is assessed by combining 2002–2008 yearly hydrographic measurements at 59.5°N, mean dynamic topography, satellite altimetry data and available estimates of the Atlantic–Nordic Seas exchange. The mean absolute transports by the upper-ocean, mid-depth and deep currents and the Meridional Overturning Circulation ($MOC\sigma$=16.5 ±2.2 Sv, at σ_0=27.55) at 59.5°N are quantified in the density space. Inter-basin and diapycnal volume fluxes in between the 59.5°N section and the GSR are then estimated from a box model. The dominant components of the meridional exchange across 59.5°N are the North Atlantic Current (NAC, 15.5 ±0.8 Sv, σ_0<27.55) east of the Reykjanes Ridge, the northward Irminger Current (IC, 12.0 ±3.0 Sv) and southward Western Boundary Current (WBC, 32.1 ±5.9 Sv) in the Irminger Sea and the deep water export from the northern Iceland Basin (3.7 ±0.8 Sv, σ_0>27.80). About 60% (12.7 ±1.4 Sv) of waters carried in the $MOC\sigma$ upper limb (σ_0<27.55) by the NAC/IC across 59.5°N (21.1 ±1.0 Sv) recirculates westwards south of the GSR and feeds the WBC. 80% (10.2 ±1.7 Sv) of the recirculating NAC/IC-derived upper-ocean waters gains density of σ_0>27.55 and contributes to the $MOC\sigma$ lower limb. Accordingly, the contribution of light-to-dense water conversion south of the GSR (~10 Sv) to the $MOC\sigma$ lower limb at 59.5°N is one and a half times larger than the contribution of dense water production in the Nordic Seas (~6 Sv).

P10PS.06

P10PS - The North Atlantic and climate change

Poster

Transport variability of Labrador Sea Water through the Flemish Pass in relation to changes at 53°N

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The Labrador Sea is characterized by a cyclonic boundary current surrounding one of the most active areas of water mass transformation in the Atlantic. Labrador Sea Water (LSW), formed in the Labrador Sea from deep convection events, is exported to the subtropical gyre at the western boundary, namely through Flemish Pass or by the Deep Western Boundary Current (DWBC) around Flemish Cap. In this study, data is used from a MITgcm model integration having a horizontal resolution of 1/12° (~7.5km) and including variable atmospheric forcing from the NCEP/NCAR reanalysis. The model is a coupled ocean-seaice model and the configuration covers the whole Atlantic north from 33°S and the Arctic Ocean.

The data used in the study consists of monthly-averaged values extracted for the study region (35°-56°N and 67°-24°W) and for the time period January 1958 to December 2009. The modeling results were validated against observational data of the Flemish Pass area and model biases were assessed. The model LSW transport variability agrees well with available observations.

The focus of this study is to analyze the seasonal and inter-annual variability of the upper and deep LSW transports through and around (via the DWBC) Flemish Pass and to relate the variability 1) to upstream fluctuations at 53°N and 2) to atmospheric forcing conditions.

At seasonal time scales the maximum southward transport of the upper LSW at 53°N leads by one month the maximum southward transport at 47°N in the DWBC, while the maximum southward transport at Flemish Pass occurs 8 months after the maximum at 47°N in the DWBC. The mechanism responsible for the time lag between the Flemish Pass flow and the DWBC is demonstrated to be an anticyclonic circulation around Flemish Cap.

P10PS.07

P10PS - The North Atlantic and climate change

Poster

Links between thermohaline anomalies in Northwest Atlantic, Nordic Seas and climate changes

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Oceanography of Northwest Atlantic and Nordic Seas is formed by similar large-scale processes. In both regions these processes are developed in some opposition driven by atmospheric variability. Central areas of Labrador and Greenland Seas are a major source of convective renewal and production of North Atlantic Deep Water as a return branch of Atlantic Meridianal Overturning Circulation.

Oceanographic data from Northwest Atlantic and Nordic Seas were taken from the database collected at the Arctic and Antarctic Institute and the Bedford Institute. In order to analyze variability and relations between anomalies in two regions under consideration, time series of thermohaline anomalies were constructed. Time series indicate that convection in Labrador Sea became deeper beginning from mid-1960s till early 1990s. On the other hand, deep water of Greenland Sea became warmer and saltier in comparison with the early 70s.

Two fresh water flows from the Arctic are considered: (1) Fram Strait, West-Greenland and East-Greenland currents, (2) from Canadian Arctic Archipelago through Davis Strait. Content of fresh water in the upper layers were used to trace the pathways of positive FWC anomalies in 1950-60s. One path is from Fram Strait with East-Greenland and West-Greenland currents. In 1970s these anomalies appeared in Labrador Sea. Fresh water from Baffin Bay spread from Davis Strait with North Atlantic current and appeared in Norwegian Sea in the end of 1960s. The main reason of this freshening is the summer warming in the Arctic during the period of 1950-60. In 1990-2000s summer warming is followed by increasing freshwater in Labrador Sea and Baffin Bay as well. Correlation between thermohaline and atmosphere anomalies over these regions allows estimating the mutual impact of atmosphere and ocean with defining time lag. The results of this analysis are used to compare spatial-temporal variability of thermohaline anomalies with climate change in the regions.

P10PS.08

P10PS - The North Atlantic and climate change

Poster

A 20th-century reanalysis forced ocean model to recover North Atlantic multi-decadal climate variability from 1871-2010

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We examine the North Atlantic mean climate and multi-decadal variability (MDV) of the Max Planck Institute ocean model (MPIOM) forced with an ensemble of the atmospheric 20th century reanalysis (20CR) governing the period 1871-2010. In line with well-established mechanism and observations for the Arctic and Atlantic, the model exhibits a pronounced MDV involving sea water properties within the Labrador Sea, sub-polar gyre (SPG) circulation and Arctic in- and outflow. During the 1920s and 1930s, the North Atlantic shows a marked transition from cold and fresh to warm and saline water mass properties in concert with a recovery of key circulation modes such as the SPG.

Prior the transition, the North Atlantic is pre-conditioned by strong freshwater export from the Arctic and a weak SPG. The weak SPG is associated with negative NAO-like sea level pressure (SLP) anomalies and weak winds over the North Atlantic. The anomalous pressure appears larger in the 20CR compared to observations suggesting a strong damping of the modelled SPG. During the 1900s and 1910s the Arctic freshwater export is reduced and the SPG strengthened (the latter a result of the increased SLP gradient over the North Atlantic) thereby redistributing sub-tropical warm and saline water into the North Atlantic and increasing convection in the Labrador Sea and meridional overturning strength. The strengthened SPG further controls heat and freshwater transport in to the Arctic Region, and precedes the observed strong temperature trends by ~ 1 decade. Subsequently, convection within the Greenland Sea and overflow is increased.

The modelled MDV is in accordance with selected observations and reconstructions, but also resemble mechanism proposed by inherent modelling studies. This suggests, that the forced MPIOM provides a link for describing the ocean climate variability prior 1950, for which observations are sparse.

P10PS.09

P10PS - The North Atlantic and climate change

Poster

The study of Marine climate in Trondheim Fjord analyzed by hydrographical data collected during 1963-2005

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This research deals with the hydrography of Trondheim Fjord, a significant player in the local surrounding climate. Long-time hydrographical data (1963-2005) for three stations in the fjord were obtained from Trondhjem Biological Station, Norway. Moreover, data for the Coastal and Atlantic Currents at the Svinøy section, located at around 62°N in the southern Norwegian Sea were provided by the Institute of Marine Research in Bergen. Both data sets cover the whole column of water at different stations. At the Svinøy section, Atlantic inflow was defined as having salinity ≥34.5 and a corresponding temperature of ≥3 °C. To understand the sensitivity of the hydrographical data salinity records ≥35 were discussed. The research focuses mainly on information that can be extracted from the hydrographical data set of the Trondheim Fjord. The analysis of the data revealed that the fraction of Atlantic Water in Trondheim Fjord makes up approximately 65-70% of the total water volume at St. 15, 15-20% at St. 6 and nothing at St.1. On average, the fraction of Atlantic water is presumably 27-30 % of the total fjord volume and the remaining water volume is made up of coastal water somehow diluted with freshwater. Hydrography showed that the fjord is mainly influenced by warm and saline Atlantic Water. The data in this study have not been published earlier, except that Wendelbo (1970) treated the 1963-65 data in his research in Norwegian. However, this has not been done for the data sets after 1966. The results obtained here could help researchers to know the hydrographic pattern of the fjord and the extent of Atlantic Water inflow. Keywords: Hydrography, Atlantic Water, Norwegian Coastal Current and Trondheim Fjord

P10S1.01

P10S1 - The North Atlantic and climate change

Oral

North Atlantic climate variability: The role of the North Atlantic oscillation

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Three interrelated climate phenomena are at the center of research on Atlantic climate variability and predictability: Tropical Atlantic Variability (TAV), the North Atlantic Oscillation (NAO), and the Atlantic Meridional Overturning Circulation (AMOC). These phenomena produce a myriad of impacts on society and the environment on seasonal, interannual, and longer time scales through variability manifest as coherent fluctuations in ocean and land temperature, rainfall, and extreme events. Improved understanding of this variability is essential for assessing the likely range of future climate fluctuations and the extent to which they may be predictable, as well as understanding the potential impact of human-induced climate change. In this presentation the focus will be on atmospheric variability over the Atlantic and the processes and mechanisms that drive it. Particular emphasis will be on the NAO as the leading pattern of weather and climate variability over much of the Northern Hemisphere. A better understanding of how the NAO responds to external forcing, including sea surface temperature changes, stratospheric influences, and increasing greenhouse gas concentrations, is crucial in order to develop the knowledge required by society to address global environmental change and identify and implement solutions for a transition to global sustainability.

P10S1.02

P10S1 - The North Atlantic and climate change

Oral

The impact of polar mesoscale weather on the North Atlantic Ocean

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A smörgåsbord of mesoscale weather systems occur over the subpolar seas of the North Atlantic Ocean: polar lows, barrier winds, tip jets, gap jets and Arctic fronts. Here I will review progress in our understanding of these mesoscale (5-500 km scale) weather systems with a focus on the recent discoveries coming from International Polar Year projects, such as the Greenland Flow Distortion Experiment and the Norwegian IPY-Thorpex Experiment. The high winds associated with many of these weather systems induce elevated air-sea fluxes, potentially significant in forcing the ocean. However due to their relatively small scales, mesoscale systems can be missing or poorly represented in climate and ocean models or reanalyses products. This resolution problem will be discussed and some ocean modelling experiments where these systems are deliberately added will be highlighted.

P10S1.03

P10S1 - The North Atlantic and climate change

Oral

North Atlantic impacts on the Atlantic-European cyclone activity

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Midlatitude cyclones are known to be generated and intensified over the areas of high sea-air surface fluxes due to diabatic heating from below resulting in the enhancement of the low-level baroclinicity. In turn, cyclones contribute to the development of extreme turbulent fluxes providing locally high winds and air-sea temperature gradients. This makes it difficult to directly associate cyclone activity and surface flux anomalies on long-term scales and to handle the chicken/egg problem. We attempt to link cyclone activity in the Atlantic-European Sector with the anomalies of surface turbulent heat fluxes by considering extreme surface fluxes and characteristics of the cyclone life cycle. Surface flux statistics were derived from the fluxes recomputed for the reanalysis state variables for 1979 onwards using probability density distributions of surface turbulent fluxes. Characteristics of the cyclone life cycle were derived for the same period from modern era reanalyses using state of the art numerical tracking algorithm. The main questions addressed in this study are (i) in how way mean and extreme surface fluxes influence cyclone activity and on which time scales? (ii) which parameters of the cyclone lifecycle are most sensitive to the surface flux signals? and (iii) whether the response of cyclone characteristics to surface fluxes is local (as e.g. in WBCE regions such as Gulf Stream) or non-local and which mechanisms are responsible for each of the responses? To answer these questions, we analyse responses seen in cyclone deepening rates, propagation velocities, life time over the North Atlantic, Arctic and Europe to the extreme surface fluxes. Of a special interest are the responses in the frequency of cyclone clustering in the series, associated with the anomalous water vapor transport from the Atlantic to Europe.

P10S1.04

P10S1 - The North Atlantic and climate change

Oral

Simulated atmospheric response to inter-annual SST variations in the Gulf Stream region

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While recent studies show the importance of the Gulf Stream SST front for the climatological state of the atmosphere, a comprehensive understanding of the impact of SST variability in this region is still lacking. The work we present here deals with the atmospheric response to low-frequency SST variations in a relative high resolution (T106) version of the ECHAM 5 atmospheric general circulation model. Our focus lies on timescales >5 years, when ocean dymnamics start to control SST. A better understanding of the mechanisms linking SST and atmosphere might help to improve the predictability of the climate in the North Atlantic sector on decadal time scales.

First, we analyze a transient 5-member ensemble run forced by observed, monthly varying SST. Results indicate that in summer (winter) up to 70% (50%) of the low-frequency variability of convective precipitation over the SST front is linked to the boundary forcing. The locally box-averaged time series of SST and convective precipitation are highly correlated by 0.73 (0.55) in summer (winter). Composite analysis shows that anomalous strong local convective precipitation goes along with anomalous warm local SST.

To investigate whether the correlation in the latter experiment can be explained by local ocean-atmosphere interaction, we performed another experiment consisting of a climatologically forced control run and a sensitivity experiment, where we changed the SST pattern exclusively in the North Atlantic by adding the composite-derived anomaly. In both seasons the AGCM responds with a significantly enhanced convective precipitation. In summer we get a deep response, connecting an enhanced local SLP minimum, concentrated low level convergence and deep upward wind. In winter the response is only shallow. Anomalous local evaporation seems to play a dominant role for the convective precipitation signal and we show the importance of atmospheric fronts for producing the precipitation, particularly in winter.

P10S1.06

P10S1 - The North Atlantic and climate change

Oral

AMO and NAO: which is the controlling factor?

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Atlantic Multidecadal oscillation (AMO) is the index of surface temperature of North Atlantic (NA) which seems to exhibit multidecadal variability with a period of 60-70 years. The index, usually believed to be a proxy of Atlantic overturning circulation correlates with multiple climate phenomena in many different regions around the Atlantic. North Atlantic Oscillation (NAO) is an index of atmospheric westerly circulation in the NA sector controlling most of the wintertime climate variability in the basin vicinity. It shows autocorrelation on decadal scales. It also exhibits significant cross-correlation with AMO with AMO lagging NAO by 10-15 years (and significant anticorrelation with NAO lagging AMO by 10-20 years). Correlation does not imply causation but its existence as well as the well studied mechanisms of wind shear forcing influence on deep water forming (especially in the Labrador Sea) seem to show that AMO is being controlled by NAO. Recently even the connection of AMO index with overturning circulation changes has been questioned making AMO an artifact of North Hemisphere anthropogenic aerosol production history. On the other hand decadal scale climate memory implies a strong ocean component. Atlantic ocean circulation shows large scale coherent changes, with temperature and salinity anticorrelating both horizontally and vertically in time scales compatible with the AMO while hemispherical average temperatures anticorrelate in similar time scales. Improving NA SST representation in climate models makes them predict NAO better suggesting ocean temperatures (AMO) influence westerly circulation (NAO). So which controls which? This talk argues both are part of a large scale ocean-atmosphere multidecadal system which memory lies in the ocean circulation changing atmospheric westerly circulation in a way that forces deep water production changes in a 60-70 year cycle. If that is true, AMO and NAO decadal changes are manifestation of the same climate cycle.

P10S2.01

P10S2 - The North Atlantic and climate change

Oral

Is the oceanic heat transport with Atlantic water towards the Arctic changing?

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The flow of Atlantic water (Atlantic inflow) across the Greenland-Scotland Ridge (GSR) is critical for conditions in the Nordic Seas and Arctic Ocean by importing heat and salt. All three branches crossing the GSR have been monitored since the mid-1990ies and the transports of water and heat have been estimated. The Atlantic inflow, that forms the surface part of the thermohaline circulation in the North Atlantic, is affected by wind forcing and freshwater input but the most important driving appears to be the cooling of the ocean by the atmosphere in the subarctic seas and increasing of salinity in the Arctic Ocean through freezing of seawater. This results in the sinking of the surface waters that subsequently flow out of the area close to the bottom over the GSR. This removal of water from the Arctic region by the overflow generates sea level slopes that drive a northward transport of water and heat. With global climate change, the Arctic atmosphere is expected to warm and freshwater input to the Arctic to increase, both of which may act to slow the mechanism that drives these flows, and climate models predict a weakening of the North Atlantic thermohaline circulation. This presentation addresses the question, whether the weakening has already been initiated and what regions may have been affected. Based on observations and model results, we conclude that the volume transport of the Atlantic inflow has not weakened consistently whereas the temperature has increased.

P10S2.02

P10S2 - The North Atlantic and climate change

Oral

Arctic Freshwater Export: Status and Prospects

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Large freshwater anomalies clearly exist in the Arctic Ocean. They are due to enhanced melting of sea ice, increased runoff, and changes in atmospheric circulation that lead to surface convergence of freshwater. For example, freshwater has accumulated in the Beaufort Sea over the last 30 years, with an extra ~5000 km^3---about 25%---being stored. It is likely that this extra freshwater will be released from the Arctic via the Fram Strait and/or the Canadian Archipelago, perhaps as another ``Great Salinity Anomaly''. The freshwater discharge will likely have impacts on subpolar Atlantic circulation and ecosystems for several years. An unprecedented opportunity exists to anticipate and observe this discharge process. We review the state of knowledge about Arctic freshwater anomalies and outline potential scenarios for future Arctic freshwater export. Key uncertainties in estimating the timing, rates, and pathways of freshwater export are be identified. Challenges for observing systems to monitor the progress of anomalous freshwater are also be discussed.

P10S2.03

P10S2 - The North Atlantic and climate change

Oral

Observed trends of carbon sink, acidification and alkalinity in the North Atlantic

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Over the last decade, the oceanic uptake rate of atmospheric CO2 in the subpolar North Atlantic (NA) region has rapidly weakened while the meridional overturning circulation (MOC) has decreased. We analysed using novel field data the fundamental differences in the physical mechanisms governing the CO2 budget between the subtropical and subpolar North Atlantic regions. We found that the air-sea uptake of anthropogenic CO2 in the North Atlantic occurs almost exclusively in the subtropical gyre, whereas the subpolar gyre uptakes predominantly natural CO2. Here we show that the decrease in air-sea heat loss linked to the North Atlantic Oscillation-driven reduction in the MOC is the major factor explaining the decline in natural CO2 uptake in the subpolar gyre during the last decade. The spatiotemporal sparseness of in situ measurements has made difficult assessing the rates of ocean acidification. Here we show a time series of pH records in the North Atlantic that provides direct, quantifiable evidence for the development of acidification rates in upper and intermediate North Atlantic waters since 1981. The highest acidification rates are associated to Subpolar Mode Water (-0.0019 ±0.0003 y-1). The upper Labrador Seawater shows an acidification rate of -0.0012 ±0.00015 pH y-1. The deep convection of well-ventilated waters in the subpolar gyre transports surface waters, loaded with anthropogenic CO2, into intermediate waters faster than via downward diffusion and mixing alone. Also recent biogeochemical models have shown that this acidification is likely to impact calcification rates of pelagic organisms and predict trends of increase in total alkalinity (AT). The recent biannual occupations of the Greenland-Portugal OVIDE section offer a unique opportunity to verify this prediction. The data set shows a positive trend in AT for subsurface North Atlantic waters of 0.27 ±0.11 ìmol•kg-1•y-1 between 1981 and 2012.

P10S2.04

P10S2 - The North Atlantic and climate change

Oral

The influence of Arctic freshwater export on the North Atlantic circulation

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Arctic freshwater has the potential to influence the North Atlantic circulation through its impact on stratification and hence deep covection. Freshwater export is accomplished through two major gateways, the Canadian Arctic Archipelago (CAA) and Fram Strait. In this modelling study we show that the realism of the representation of the CAA in sea ice-ocean models does have a substantial influence on the North Atlantic circulation. More specifically, we use the Finite Element Sea Ice-Ocean Model (FESOM) with (5km) and without (25km) regional refinement in the CAA. It turns out that increasing resolution in the CAA to 5km increases the freswater export through the CAA leading to enhanced Labrador Sea convection and an associated strengthening of the MOC by about 10%. The physical mechanisms behind this sensitivity will be described in detail.

P10S2.05

P10S1 - The North Atlantic and climate change

Oral

The impact of polar mesoscale storms on Northeast Atlantic ocean circulation

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The atmosphere plays a key role in forcing the large-scale ocean circulation by moderating the formation of deep-water in the subpolar North Atlantic. Every year thousands of mesoscale storms – polar lows - cross this climatically sensitive region of ocean that are either too small, or short-lived, to be captured in meteorological reanalyses or numerical models. Here we show that by parameterizing polar lows we are able to reproduce their high wind speeds and heat fluxes, as well as their integrated effects, in remarkable agreement with observations. In an ocean circulation model our realistic atmospheric forcing increases the depth, frequency and area of deep convection in the Nordic Seas. This results in an increase in the northward transport of heat into the region and the southward transport of deep-water through Denmark Strait. We conclude that polar lows play an important role in driving the large-scale ocean circulation and so should be accounted for in short-term climate predictions. Recent studies predict a decrease in the number of polar lows over the Northeast Atlantic in the 21st Century which, based on our work, implies a reduction in deep convection and a potential weakening of the Atlantic Meridional Overturning Circulation.

P10S2.05

P10S2 - The North Atlantic and climate change

Oral

Observations of water mass interaction and mixing in the Faroe Bank Channel overflow

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The deep and narrow Faroe Bank Channel (FBC) is an important pathway for cold, dense waters from the Nordic Seas to flow across the Iceland-Scotland ridge and enter the North Atlantic. The swift and energetic turbulent overflow in the FBC is associated with strong vertical mixing. The variability of temperature and velocity in the overflow is dominated by oscillations of 2-3 days period, associated with a train of eddies passing along the slope. A research cruise was undertaken in May-June 2012 to measure the mixing and entrainment of the overflow at time scales resolving the mesoscale oscillations. Hydrography, currents and microstructure were sampled at several repeat sections and time series stations. In addition, two Slocum electric gliders, one equipped with turbulence sensors, were deployed during the cruise. Hydrographic profiles from the gliders and the shipboard survey show varying degrees of influence of a relatively fresh, intermediate water mass with low oxygen concentration between the upper waters of Atlantic origin and the dense overflow water. The presence and strength of the temperature, salinity and oxygen anomaly associated with this water mass vary strongly in time and space. In the channel proper, the low-salinity signal is smeared out by intense mixing. Further west (downstream) discernible salinity and oxygen minima are found. This is counterintuitive since the intermediate water is expected to arrive in this region after passing through the FBC. The varying water column structure revealed by the new observations are interpreted with respect to the circulation around the Faroes as well as to the mixing and entrainment associated with the overflow plume.

P10S3.01

P10S3 - The North Atlantic and climate change

Oral

Air-sea fluxes in the Gulf Stream region

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Mesoscale eddies and fronts in the Gulf Stream region modulate the marine meteorological boundary and have strong impact on air-sea exchanges of heat, moisture, and momentum during episodic high flux event associated with winter cold air outbreaks. Recent studies suggest that the Gulf Stream could affect the storm tracks as well as the storm intensities through the large turbulent heat fluxes. Meanwhile, evidence indicates that the increased storm frequency in past decades might have caused an increased number of high flux days that elevated the wintertime mean of turbulent heat fluxes and altered average wintertime temperature conditions in the region. However, air-sea fluxes from atmospheric reanalyses are not totally reliable for accurate characterization, because the actual impact of the large transfers of heat and momentum at the air-sea interface is still misrepresented by reanalysis models, owing to inaccurate boundary layer physics and poor observation inputs. There is a need to reexamine the relationship between the Gulf Stream, air-sea heat and momentum fluxes, and storms using better quality air-sea flux estimates that have a resolution sufficient to resolve the modulation of the ocean's mesoscale features on synoptic weather events. A satellite-based high-resolution analysis of air-sea heat fluxes and wind stress has been recently developed by the Objectively Analyzed air-sea Fluxes (OAFlux) project. The development has benefited from recent availability of high-resolution near-surface air temperature and humidity derivables from satellites and a suite of fine-resolution products from the Group for High Resolution Sea Surface Temperature. Here we present some fresh observational evidence on the relationship between SST, air-sea fluxes, and clouds on synoptic and seasonal timescales, and on the long-term change of average latent and sensible heat fluxes in wintertime and their relationship to synoptic weather events and basin-scale conditions.

P10S3.02

P10S3 - The North Atlantic and climate change

Oral

The North Atlantic cold bias in climate models

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A cold bias in the North Atlantic is a common feature of coupled climate models. We note that the bias is intimately related to the path taken in models by the Gulf Stream and the North Atlantic Current, discuss the origin of this model error and its impact on the model climate and variability.

P10S3.03

P10S3 - The North Atlantic and climate change

Oral

Widespread cooling of the subtropical North Atlantic driven by a reduction in the meridional overturning circulation, in 2009-10

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Beginning in 2010 the subtropical North Atlantic cooled from the surface to at least 2 km depth. The decrease in ocean heat content (OHC) associated with this cooling is abrupt, large and vertically coherent. Here we diagnose the causes of this cooling by examining the changes in energy fluxes to the subtropical gyre.

For the surface mixed layer, both atmospheric forcing (during the extreme negative NAO winter of 2009/10) and ocean heat fluxes are important in the reduction in OHC, suggesting an active role for the ocean in the generation of upper ocean OHC anomalies on seasonal timescales comparable to those from atmospheric forcing. The deep OHC anomalies are primarily driven by a 30% reduction in the Atlantic Meridional Overturning Circulation and the associated heat flux from 2009 as measured by the purposeful RAPID-MOCHA array at 26.5°N.

P10S3.04

P10S3 - The North Atlantic and climate change

Oral

A decline of AMOC is causing the warming hole above the North Atlantic in observed and modelled warming patterns

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The pattern of Global Mean Temperature (GMT) change is calculated by regressing local Surface Air Temperature (SAT) to GMT for an ensemble of CMIP5 models and for observations over the last 132 years. Calculations are based on the historical period and climate change scenarios. As in the observations the warming-pattern contains a warming hole over the subpolar North Atlantic. Using a bivariate regression of SAT to GMT and an index of the Atlantic meridional overturning circulation (AMOC), the warming-pattern is decomposed in a radiatively forced part and an AMOC fingerprint. The North Atlantic warming hole is associated with a decline of the AMOC. The AMOC fingerprint resembles Atlantic Multidecadal Variability (AMV), but details of the pattern change when the AMOC decline increases, underscoring the non-linearity in the response. The warming hole is situated south of deep convection sites, indicating that it involves an adjustment of the gyre circulation, although it should be noted that some models feature deep convection in the middle of the subpolar gyre. The warming hole is already prominent in historical runs, where the response of the AMOC to GMT is weak, which suggests that it is involved in an ocean adjustment that precedes the AMOC decline. In the more strongly forced scenario runs, the warming hole over the subpolar gyre becomes weaker, while cooling over the Nordic Seas increases, consistent with previous findings that deep convection in the Labrador and Irminger Seas is more vulnerable to changes in external forcing than convection in the Nordic Seas, which only reacts after a threshold is passed.

P10S3.05

P10S3 - The North Atlantic and climate change

Oral

Impact of a 6 Sv reduction in the Atlantic Meridional Overturning Circulation on the distribution of temperature and salinity

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The Rapid programme has been monitoring the Atlantic Meridional Overturning Circulation (AMOC) at 26°N since 2004. For the first 5 years, the yearly averaged AMOC varied only between 17.3 Sv and 19.3 Sv with a mean of 18.1 Sv. During 2009-10, there was an event in which the AMOC decreased by nearly 6 Sv to 12.2 Sv on a year-long basis. We examine the processes involved in this reduction in the AMOC and conclude that most of the change is due to increased southward flow in the mid-ocean thermocline and reduced southward flow in the Lower North Atlantic Deep Water below 3000 m depth.

The AMOC transports substantial amounts of heat and salt northward through the Atlantic. We present time series of northward heat and salinity transport across 26°N since 2004 using Rapid boundary time series and mid-ocean Argo profiles. The 2009-10 event is evident in reduced northward heat and salt transport. We examine the impact of this event on temperature and salinity distributions both north and south of 26°N. The reduction in overturning circulation, heat and salinity transports affects upper ocean heat and salinity content particularly north of 26°N where colder upper ocean temperatures coincide with cold sea surface temperatures in December 2010. These cold temperatures possibly affected the North Atlantic Oscillation and hence European wintertime conditions in late 2010 and early 2011.

P10S3.06

P10S3 - The North Atlantic and climate change

Oral

A new index for the Atlantic Meridional Overturning Circulation at 26°N

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The Atlantic Meridional Overturning Circulation (AMOC) has received considerable attention, motivated by its major role in the global climate system. Observations of AMOC strength at 26°N made by the RAPID-MOCHA array, provide our best current estimate of the state of the AMOC. The period 2004-2011 when RAPID data is available is too short to assess the decadal variability of the AMOC. Here, we define a new AMOC index at 26°N that combines the Florida Strait transport and the southward geostrophic wind-driven transport. This index is expected to reflect variations in the AMOC at interannual to decadal timescales. This estimate of the surface branch of the AMOC can be constructed as long as reliable measurements are available for the Gulf Stream and wind stress. To test the reliability of the index on interannual and longer timescales two different NEMO simulations are used: a forced and a coupled simulation. In these simulations the index captures a substantial fraction of the AMOC variability and is in good agreement with the AMOC transport at 26N both on interannual and decadal timescales. No significant decadal trend is found in any of these two simulations. These results indicate that it might be possible to extend the observation-based RAPID AMOC index at 26°N back to the 1980s.

P10S4.01

P10S4 - The North Atlantic and climate change

Oral

Spreading of Labrador Sea Water in the subpolar North Atlantic and its relation to the location of the Sub-Arctic Front

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Several studies have identified spatial shifts in the location of the Sub-Arctic Front in the subpolar North Atlantic. These shifts point towards a shrinking or growing of the subpolar gyre which seems to be linked to variability induced by the North Atlantic Oscillation. Based on hydrographic data derived from ship surveys and Argo profiles, changes in the properties of Labrador Sea Water (LSW), one of the dominant water masses contributing to the cold branch of the Meridional Overturning Circulation, are quantified as LSW crosses the Mid-Atlantic Ridge (MAR) in the subpolar North Atlantic and enters the eastern basin. At the MAR the least diluted LSW is often found at the same latitude where the Sub-Arctic Front separates the fresh subpolar waters from the saline waters imported by the North Atlantic Current. Changes in LSW properties observed next to the MAR and in the eastern basin are therefore investigated in the light of the changing formation history of LSW as well as spatial shifts in the location of the frontal system. Furthermore, the importance of the different fractures zone, cut into the MAR between 48°N and 52.5°N, for funneling the LSW into the eastern basin is discussed.

P10S4.02

P10S4 - The North Atlantic and climate change

Oral

Freshwater exchange from the Labrador Current into the sub-polar North Atlantic

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The Labrador Current carries freshwater from the Arctic, Greenland and Canadian north south along the western margin of the sub-polar gyre. Given the proximity of the region of deep water formation in the Labrador Sea to this fresh boundary current, many have speculated on the role high-latitude freshwater may have on the formation of Labrador Sea Water and the meridional overturning circulation. However, other studies have suggested that there is little offshore exchange along the Labrador margin, with most freshwater being mixed offshore in the region of Flemish Cap and the Grand Banks. Therefore we here focus on the question of how does this freshwater leave the boundary current system and where is it taken up into the Atlantic Ocean. We examine these questions using several eddy-permitting regional configurations of the NEMO coupled ocean/sea-ice numerical model ranging from 1/4 to 1/12 degree. As well as examining hydrographic properties and fluxes, we use the lagrangian float tool Ariane to examine the freshwater pathways and their variability. We find little offshore exchange from the Labrador Current north of the Grand Banks and most of the freshwater exchanged offshore only enters the interior of the Labrador Sea after circulating around the sub-polar gyre via the North Atlantic Current and the West Greenland Current.

P10S4.03

P10S4 - The North Atlantic and climate change

Oral

On the modifications of the Denmark Strait overflow plume during its descent into the North Atlantic

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The Denmark Strait overflow provides about half of the total dense water overflow from the Nordic Seas into the North Atlantic Ocean, thus contributing significantly to the formation of North Atlantic Deep Water. The velocity and hydrography of the overflow has been monitored at the sill of Denmark Strait with moored instrumentation since 1996, and at a downstream mooring array near Ammassalik since 1986. Overflow transports were found to exhibit variations on a wide range of time scales: eddy variability dominates the high frequency variations, while strong interannual variability masks any possible long term trends. The seasonal cycle was found to be of no importance for the properties measured at the sill, but its significance increased with downstream distance.

Since 2007 data from moored temperature, conductivity and pressure recorders have been available at both locations, monitoring the hydrographic modifications of the overflow plume due to its descent from the sill to approx. 2000 m depth. Despite a difference of 1.5°C between the mean temperatures at both arrays, variations in temperature at Ammassalik showed a good correlation with the temperatures at the sill. Temperature signals were thus advected from the sill downstream. In contrast, salinity variations were found to be uncorrelated. Entrainment of ambient waters apparently strongly modified the salinity of the plume, inducing either low salinity phases due to entrainment of East Greenland Current waters via the East Greenland Spill Jet or high salinity phases due to increased contribution of Atlantic waters. Results from a 2-month mooring experiment located in the entrainment regime between the Denmark Strait sill region and Ammassalik show the hydrographic properties and currents to be dominated by variability with time scales of 1.5–2 days, associated with mesoscale eddies.

P10S4.04

P10S4 - The North Atlantic and climate change

Oral

Variability of Labrador Sea Water exported through Flemish Pass

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Labrador Sea Water (LSW) is formed at times of deep convection events in the North Atlantic Labrador Sea. Its main export pathway is southward as part of the Deep Western Boundary Current (DWBC) which constitutes the cold return flow of the climate relevant Atlantic Meridional Overturning Circulation (AMOC). Changes in the AMOC strength modulate climate variability; such changes are thought to be linked to variations in LSW formation.

At the southern exit of the Labrador Sea the underwater plateau Flemish Cap is a topographic obstacle which splits the DWBC into a branch carrying LSW through the 1200m deep Flemish Pass between the Grand Banks of Newfoundland and Flemish Cap, and a second branch carrying all DWBC components along the continental slope around Flemish Cap. Up to now, transports of LSW through Flemish Pass and their contribution to the AMOC are still uncertain, the importance of the pass for the export of LSW and its associated variability is yet unknown.

This study focuses on the magnitude of LSW transports and its associated variability through Flemish Pass as well as the processes which drive the variability. Ship-based measurements of hydrography and current velocity were investigated for LSW transports and property changes in the Flemish Pass. Based on a 20 year long time series we monitored a warming and salinification of the LSW with a significant warming trend of 0.03°C/year and increasing salinities of 0.003/year since 1992. Similar signals were found by other studies in the LSW source region and at 53°N, which indicates that the long term variability of LSW properties in Flemish Pass is remotely influenced from upstream processes.

P10S4.05

P10S4 - The North Atlantic and climate change

Oral

A downwards heat and salt injection mechanism linking mid-latitudes and Polar regions in the North Atlantic

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The ocean is the main heat reservoir of the Earth's climate system. In the view of that, the increasing radiative forcing is expected to be reflected as a global ocean warming. However, in the last decade the upper ocean heat storage has decelerated, which has result in an active search for the missing heat in the deep ocean. The observed imbalance is still not closed, but even if it was, understanding the mechanisms able to transfer so efficiently the heat from the atmosphere to the deep ocean in contrast to past observations is urgent. Here, we use two oceanographic time-series running since the beginning of the 1990's in the Bay of Biscay (Eastern North Atlantic, ENA) and the Greenland Sea, and the set of Argo floats to describe an effective downwards mechanism of heat and salt injection to the deep ocean and the connection between changes at both locations in the North Atlantic.

The extremely cold winter of 2005 in south-western Europe, after many years of sustained warming, caused a profound transformation of the hydrographic structure at the mid-latitude ENA. Mediated by a strong winter mixing, the main outcome was, besides a transient subsurface cooling, the downwards injection of the heat and salt gained slowly but persistently in the upper levels. The contraction of the subpolar gyre in the last decade allows paths of warmer and saltier ENA and subtropical waters to the northern gyre and the Nordic Seas. The arrival of these saltier Atlantic waters has not been density-compensated in the Greenland Sea. As a result, the sustained cooling in winter 2008 in the Greenland Sea resulted in a strong mixing until 2000 m that similarly injected the heat and salt in the Atlantic layer directly to that depth. The ultimate cause of the strong winter mixing in 2005 was a blocking situation in the North Atlantic, whose current recurrence may secure the transferring of upper saltening/warming trends into deeper depths and seems to be related with Arctic sea-ice retreat.

P10S4.06

P10S4 - The North Atlantic and climate change

Oral

Near-cessation of subtropical mode water formation in the western North Atlantic in the warm winter of 2011-2012

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The winter of 2011-2012 was a particularly weak season for the formation of 'Eighteen Degree Water' (EDW), the subtropical mode water of the western North Atlantic, as demonstrated by Argo and repeat hydrography. Weak, late winter buoyancy forcing produced shallower than usual winter mixed layers throughout the subtropical gyre, failing to thoroughly ventilate the underlying mode water, and can likely be attributed to the coinciding high, positive phase of the North Atlantic Oscillation (NAO). The lack of EDW formation left the seasonal pycnocline nearly intact, precluding the entrainment of nutrient-rich waters into the euphotic zone and limiting air-sea CO_2 exchange. The present investigation evaluates 2011-2012 winter buoyancy content anomalies, surface buoyancy fluxes, and advection of buoyancy via the Gulf Stream, and compares these quantities with those of the past seven winters exhibiting more vigorous EDW formation. The 2011-2012 formation season was not unusual relative to climatological buoyancy content at the onset of winter forcing, nor was it unusual relative to geostrophic buoyancy transport, but experienced a shorter than usual, mild winter with anomalously small surface buoyancy loss very late in the season.

P10S5.01

P10S5 - The North Atlantic and climate change

Oral

Meridional transports in the Atlantic Ocean at 7.5N and 24.5N in 1992-1993 and 2010-2011

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An inverse model has been applied to two oceanographic cruises carried out in 2010 and 2011 at 7.5N and 24.5N, respectively. Results have been compared to a reanalysis of these same sections conducted in 1992 and 1993, in the frame of the WOCE program. The inverse model encompasses 17 equations and 196/226 unknowns for 1992/2011, corresponding to the velocities in the reference layer. Different constraints have been considered: transport of Antarctic Bottom Water and Deep Western Boundary Current at 7N, transport of the Florida Current, and transport of the Antilles Current and Deep Western Boundary Current at 24N. The analysis shows stronger thermocline and Antarctic Bottom Water transports during 1992-1993 than during 2010-2011.

P10S5.02

P10S5 - The North Atlantic and climate change

Oral

Meridional Overturning circulation at 26N and the North Atlantic heat Content (MONACO)

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The main goal of MONACO is to understand the links between the meridional overturning circulation (MOC) and the meridional heat transport (MHT) from the RAPID-WATCH observing system, and the subannual to interannual variability of oceanic heat content (OHC) inferred from Argo floats and sea surface temperatures (SSTs) in the North Atlantic.

We have calculated the OHC and OSC (Ocean salinity content) variability in the North Atlantic for the 1999 to 2012 period, and the MOC observations are available from April 2004 to April 2012.

An analysis of the trends and inter-annual variability of MOC and OHC will be presented. In particular the major MOC event of 2009-2010 will be discussed in the context of the change in OHC and its relationship to air-sea fluxes and SST over the N.Atlantic during this period.

P10S5.03

P10S5 - The North Atlantic and climate change

Oral

The seasonal cycle of the AMOC at 26°N - Eastern Boundary considerations

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The RAPID array at 26°N has provided continuous estimates of the strength of the Atlantic Meridional Overturning Circulation (AMOC) of 17.6 ±4.6 Sv 2004–2012. Much of the variability comes from a 7 Sv seasonal cycle. The major component of the seasonal cycle comes from the eastern boundary where seasonal variations of wind stress curl drive transport anomalies that are robust even in the face of the large dip in the AMOC observed in 2009/10. Much of the variability is explained by the transport anomaly generated from the projection of wind stress curl onto the first two baroclinic Rossby modes.

Two major results are discussed: firstly, the patterns of wind stress curl at the eastern boundary are complex due to the presence of the Canary islands. The implications of this complex pattern of wind stress curl are discussed in the context of whether a similar seasonal cycle may exist at other locations.

Secondly, not explained by the forced Rossby model is a seasonally reversing deep poleward undercurrent. Consisting of Antarctic Intermediate Water and Mediterranean water, this local current is not only a significant contributor to the strength of the overturning but contributes a large amount to the freshwater transport at this latitude.

P10S5.04

P10S5 - The North Atlantic and climate change

Oral

Oceanic dominance of interannual subtropical North Atlantic heat content variability

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Ocean heat content varies on a range of timescales. This variability can be driven either by oceanic or atmospheric heat transport for a local body of water. To diagnose the relative contributions and respective timescales, this study uses a box model forced with GCM output to investigate the heat content variability of the subtropical North Atlantic from 26°N to 36°N. The oceanic and air-sea heat flux data needed to force the box model is taken from a 19 year (1985 to 2006) simulation performed with the 1/12° version of OCCAM. The box model heat content is compared to the corresponding heat content in OCCAM for verification. The main goal of the study is to identifiy to what extent the interannual to sub annual ocean heat content variability is of atmospheric or of oceanic origin. To achieve this the box model is subjected to different scenarios where it is forced either with the full (detrended) ocean and air-sea fluxes or with their deseasoned counterparts. This revealed that in all cases, the seasonal variability was dominated by the sub annual component of the air-sea flux, which produced a seasonal range of ¡0.41°C. However, on longer timescales the interannual oceanic heat transport dominates, with changes of up to 0.16°C. The technique is subsequently applied to observational data. For the ocean heat fluxes, we use data from RAPID at 26°N, and at 36°N the heat transport is inferred using a linear regression model from the oceanic low-frequency transport in OCCAM. The air-sea flux from OCCAM is used for the years from 2004 to 2006 when the RAPID timeseries and the OCCAM simulation overlap whereas a climatology is used for the air-sea flux from 2006 onwards. The results confirm than on longer (> 2 years) timescales the ocean dominates the ocean heat content variability. This work illustrates the importance of observational timeseries, as well as underlining how useful model verification can be.

P10S5.05

P10S5 - The North Atlantic and climate change

Oral

On the spatial structure and temporal variability of poleward transport between Scotland and Greenland

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The flow north of warm subtropical water though the northeastern Atlantic is known to have many pathways that vary over time. However, quantifying these continues to be a challenge due to eddy variability that makes detection and study of the underlying mean field and its trends difficult. In this study we revisit an earlier 1999-2002 program of repeat and regular sampling of upper ocean currents between Scotland and Greenland to determine flow patterns in the northeastern North Atlantic. We combine this 4-year study with 18 years of altimetry to examine the region's temporal variability. The high-resolution scans of currents in the top 400 m were made with an ADCP on Nuka Arctica, an ice-reinforced container vessel in regular traffic between Greenland and Denmark. The measurements show that the Reykjanes Ridge (RR) serves as a very effective separator of flow towards the Nordic and Labrador Seas, respectively. Topography clearly plays a fundamental role in guiding these two branches, but whereas the Labrador Sea branch exhibits two mean flows to the north on the western slope of the RR, the eastern branch flows north in roughly equal amounts over the deep Maury trough and east of Hatton Bank (including the Slope Current). There is also a well-defined and stable flow south along the eastern slope of the RR. The satellite altimetric sea surface height data shows good overall agreement with geostrophically determined sea level difference from the repeat ADCP sections, but are unable to resolve the fine structure of the topographically defined mean circulation. Altimetry show that poleward flow west and east of the RR is strongly anticorrelated. The data reveal that the two eastern sub-branches are also strongly anti-correlated, but offset in time with respect to the Labrador Sea branch. Remarkably, all these variations cancel out for the entire Greenland-Scotland section leaving a gradual decrease in sea level difference from 0.64 to 0.56 m over the 1993-2011 period.

P10S5.06

P10S5 - The North Atlantic and climate change

Oral

Changes in open ocean - shelf exchange along the continental slope of NW Europe global during the 21st Century

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It has been speculated that the high biological productivity and carbon fixation on continental shelves plays a key role for both, the economic basis for industrial fishery and the oceanic uptake of atmospheric CO_2. We here employ the global ocean general circulation and biogeochemistry model MPIOM/HAMOCC with enhanced resolution over the NW European shelf (~10 km in the southern North Sea). Coupled to this is the regional atmosphere model REMO to downscale CMIP3 and CMIP 5 scenarios to study the climate warming impact on the North Sea and the adjacent NW European shelf. We find that already a moderate sea surface warming of 2.0 K and associated changes in circulation reduce biological production on the NW European shelf by ~35%. This reduction is twice as strong as the reduction in the open ocean caused by enhanced stratification. The underlying mechanism is a spatially well confined stratification feedback along the continental shelf break which reduces the winter nutrient supply from the deep Atlantic by up to 50% with subsequent reductions in biological activity. As a result the North Sea is nearly decoupled from the deep Atlantic the nutrient inventory drops by about 25%. Carbon uptake on the NW European shelf decreases by 1/3 at the end of the 21st century compared to the end of the 20th century implying a strong weakening of shelf carbon pumping. Much of the carbon taken up by the North Sea, is subject to air-sea gas exchange, when North Sea waters leave the North Sea via the Norwegian coastal current and joins the Norwegian current. Diagnostic tracer experiments indicate that only about 20 % of carbon absorbed by the North Sea reaches depth below the open ocean mixed layer.

P10S6.01

P10S6 - The North Atlantic and climate change

Oral

The surface-forced overturning of the North Atlantic : Estimates from modern era atmospheric reanalysis datasets

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Estimates of the recent mean and time varying water mass transformation rates associated with North Atlantic surface-forced overturning are presented. The estimates are derived from heat and freshwater surface fluxes and sea surface temperature fields from six atmospheric reanalyses (JRA, NCEP-1, NCEP-2, ERA-I, CFSR and MERRA) together with sea surface salinity fields from two globally gridded data sets (World Ocean Atlas and EN3). The resulting twelve estimates of the 1979-2007 mean surface-forced streamfunction all depict a sub-polar cell, with maxima north of 45 °N, near σ =27.5 kg m-3, and a sub-tropical cell between 20 °N and 40 °N, near σ =26.1 kg m-3. The mean magnitude of the sub-polar cell varies between 12-18 Sv, which is consistent with estimates of the overturning circulationbased on sub-surface observations. However, some of the estimates of the surface-forced overturning show anomalously strong sub-tropical cells and a counter circulation in the tropics. Analysis of the thermal and haline components of the surface density fluxes indicate that these large differences in the inferred low latitude circulation are largely due to the biases in reanalysis net heat flux fields, which range in the global ocean mean from -13 Wm-2 to 19 Wm-2. The different estimates of temporal variability in the sub-polar cell are well correlated with each other. This suggests the uncertainty associated with the choice of reanalysis product does not critically limit the ability of the method to infer surface forced variability in the sub-polar overturning circulation. In contrast, the different estimates of sub-tropical variability are poorly correlated with each other, and only a subset of theestimates are able to capture a significant fraction of the variability in independently estimated changes in Sub-Tropical Mode Water volume.

P10S6.03

P10S6 - The North Atlantic and climate change

Oral

On the relation of the potential predictability of the AMOC and the MHT

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The latitude-dependent potential predictability of the North Atlantic meridional overturning circulation (AMOC) cannot be directly transfered to that of the meridional heat transport (MHT; Tiedje et al., 2012). To facilitate a better understanding of the dynamical relation between both quantities we analyze hindcast ensembles based on an oceanic state estimate using two potential predictability measures, the anomaly correlation and the prognostic potential predictability. The subtraction of the Ekman (heat) transport shows the different influence of the wind on both quantities' potential predictability, and also suggests the important role of the MHT's gyre component on the potential predictability at the subpolar latitudes. Further, we find that only the geostrophic parts of the AMOC's and the MHT's potential predictability are related. The geostrophic parts of the AMOC and the MHT are estimated from the thermal wind transport based on boundary densities and the MHT's overturning component minus the Ekman variability, and show a similar potential predictability structure across the North Atlantic. Subsequently, transferring the potential predictability of the AMOC estimated from density and wind observations to the potential predictability of the MHT might only be possible at latitudes where the gyre component can be neglected.

P10S6.04

P10S6 - The North Atlantic and climate change

Oral

Millennial scale variability in high arctic oceanography and calving activity of the Svalbard-Barents Sea paleo-Ice Sheet (0-74 ka)

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The interplay between deep ocean currents, surface water conditions and the Svalbard-Barents Sea paleo-Ice Sheet is studied in centennial resolution for 74,000 years (74 ka) from mineralogical studies of three cores from the western Svalbard slope (1130-1880 m water depth, 76-78°N). The strength of the bottom currents flowing northwards into the Arctic Ocean is reconstructed from grain-size of “sortable silt” (10-63 µm) in one core. Sand grains in deep ocean sediments are essentially transported by ice and labeled Ice Rafted Detritus (IRD). IRD is studied for flux, composition and grain-size in three cores. One record is decomposed into an end-member model separating the IRD into Local / Distant and Coarse grained / Fine grained. The data displays a consistent 1-2 ka rhythm in pace with the well-known climatic Dansgaard/Oeschger events in both the bottom current strength and the IRD composition. The IRD composition shifts between Local mainly Coarse grained sand and Distant mainly Fine grained sand. Most of the IRD deposited during the warm Interstadials was Local and Coarse grained and presumably transported by local icebergs. Conversely, the Stadial IRD was mainly Distant and Fine grained and probably to a larger extent transported by sea ice. IRD from the last glacial maximum (LGM) was also mainly Distant and Fine Grained. The Interstadial/Stadial shift in the origin and grain-size of IRD is partly due to increased Interstadial iceberg calving from the Svalbard-Barents Sea paleo-Ice Sheet, and partly a result of ice melting faster in warmer water and thus distributing its full load of sand grains over shorter distances in warmer climatic conditions. Thus, the IRD records for the western Svalbard slope should be regarded as partly a proxy for the calving activity of the Svalbard-Barents Sea paleo-Ice Sheet and partly a temperature proxy for the surface water in the Nordic Seas.

P10S6.05

P10S6 - The North Atlantic and climate change

Oral

Decadal variability of the AMOC and the North Atlantic ventilation

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The North Atlantic has the highest vertically integrated inventories of anthropogenic CO2 and Chlorofluorocarbons (CFCs), and is the only basin where large inventories of anthropogenic CO2 are clearly present at mid to abyssal depths, due to the formation of the North Atlantic Deep Water (NADW) feeding the deep branch of the Atlantic Meridional Overturning Circulation (AMOC). There is however a lack of consensus on the relationship of the AMOC variations and uptake of the anthropogenic gases in the North Atlantic on decadal time scales, due to lack of long term observation and divergence of model simulations of the AMOC. Here this relationship will be investigated using a newly configured global Ocean Circulation Model (HYCOM) coupled with the GFDL 3-layer sea-ice model and a CFC uptake model following OCMIP2 protocol. The model is forced by 5 cycles of the interannual CORE forcing (1948-2009) with the first 4 cycles as spin-up. Unlike other ocean models forced by realistic reanalysis forcing, our newly configured HYCOM does not require surface salinity relaxation, which has been known to be one of the factors affecting AMOC variability in ocean model simulations. The model results show a vigorous AMOC with large decadal variation and the deep penetration (1200-5000m) of CFC into the subtropical North Atlantic along the Deep Western Boundary Current. The modeled AMOC decadal variation and tracer concentration in the North Atlantic will be compared to available historical hydrographic data and available CFC measurements.

P10S6.06

P10S6 - The North Atlantic and climate change

Oral

Oceanic fluxes and storage of heat and freshwater in the North Atlantic

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A North Atlantic temperature and salinity field is generated every 10 days from the early 2000's. These fields are generated using Argo data that have been optimally interpolated on density surfaces. Temperature and salinity anomalies from the Hydrobase climatology are interpolated without making the widely used assumption that the anomalies have a zero mean. In addition to the temperature and salinity fields, uncertainty estimates in each field are quantified. The mapping uncertainty on density levels is about half the uncertainty calculated when mapping is on pressure levels.

We use the optimally interpolated Argo fields in conjunction with full-depth coast-to-coast hydrography and information from the RAPID-MOCHA monitoring array at 26°N in the Atlantic to quantify the variability in the oceanic freshwater flux at this latitude. Including the information (from hydrography and Argo) from the interior of the subtropical gyre reduces the southward freshwater flux at 26°N by 0.1Sv to 0.3Sv southward (1 Sv = 10^6 m^3 s^{-1}), compared with using end-point estimates alone. Quantifying the temporal variability of this interior component is only possible using Argo data. The mapped Argo data are further used to quantify the heat and salt storage of a region north of 26°N. A loss of heat and salt is observed following the 2009/10 slowdown of the Meridional Overturning. The magnitude of these shortfalls corresponds closely to the deficit of heat and salt supply by the slowed MOC, and is equivalent to an upwards heave of isopycnal surfaces of 20 metres.

P10S7.01

P10S7 - The North Atlantic and climate change

Oral

Uptake and storage of anthropogenic carbon by North Atlantic Deep Water

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The North Atlantic shows the highest column inventories of anthropogenic carbon among all ocean basins. The main reason is the presence of recently ventilated North Atlantic Deep Water (NADW), which is rich in anthropogenic carbon (Cant). An almost 20 year long time series of CFC data from the subpolar North Atlantic is used to calculate the concentrations and inventories of Cant by means of the TTD method. The longterm trend over the last 20 years in Cant storage remained almost constant, despite of the incraesing atmospheric CO_2 content. The interannual variability of the Cant uptake by NADW reaches up to 0.2 Pg carbon, i.e. about 10 % of the global oceanic Cant uptake rate. These variations are directly linked to the convection activity in the Labrador Sea, whereas changes of the Cant inventory in the overflow water masses are less important.

P10S7.02

P10S7 - The North Atlantic and climate change

Oral

Interannual variability and trends in oxygen in the mode and intermediate waters of the subpolar North Atlantic

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A recent study based on 50 years of oxygen observations in the North Atlantic has revealed a strong decrease in the oxygen concentration in the Mode Water (MW) and Intermediate Water (IW). These changes were partly determined by decreases in circulation and ventilation, and partly by warming, which decreases the solubility. Superimposed on these long-term trends was a substantial amount of interannual to decadal variability that makes the calculation of the trends often statistically not significant. The large number of repeat cruises undertaken along the A2 (43°- 47°N, 1993 - 2002) and the 47°N lines (2003 - 2011) provide us with the opportunity to investigate interannual variability of oxygen with nearly annual resolution and to understand its main drivers. Our results show that the oxygen concentration in the Subpolar MW and IW varied primarily in response to changes in the circulation associated with the contraction of the subpolar gyre observed after 1994, which caused a reduction of the oxygen concentration within these water masses. In light of the observed negative trends over the last five decades in the MW and IW, the circulation changes associated with either contraction or expansion of the subpolar gyre can either accelerate or damp the oxygen decrease due to reduction in ventilation and warming.

P10S7.03

P10S7 - The North Atlantic and climate change

Oral

Declining nutrient levels in the Rockall Trough as a result of a weakening Subpolar Gyre

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Between 1996 and 2011 the upper waters (200-700 m) of the Rockall Trough have become warmer (+0.48 °C), saltier (+0.088) and depleted in nitrate and phosphate (-2.19 µM and -0.14 µM respectively). These changes, all out with calculated errors, can be explained by the varying influence of southern versus subpolar water masses in the basin as the Subpolar Gyre weakened. When the Subpolar Gyre is strong the upper waters of the Rockall Trough are composed of ~50 % southern (low nutrient) waters and ~ 50 % subpolar (high nutrient) waters. In contrast when the gyre weakens and contracts north-westward the upper layers are dominated (> 90 %) by water masses originating from south of the Rockall Trough in the Bay of Biscay intergyre region. Temperature, salinity, and nitrate and phosphate concentrations within the upper waters of the Rockall Trough strongly correlate with a measure of the strength of the Subpolar Gyre (the first principal component of sea surface height over the subpolar North Atlantic) until a threshold. As the gyre weakens the upper layers of the trough become warmer (r-0.85), more saline (r-0.86) and depleted in nitrate and phosphate (r+0.81 and r+0.87 respectively). However, below the threshold, when the Subpolar Gyre is particularly weak as has been observed since the mid-2000s, salinity remains high and near constant (35.410 ± 0.005) whilst temperatures decrease slightly (-0.21 °C). This is thought to be a response to the maximum percentage contribution of the southern water masses within the Rockall Trough having been reached. Hence, unless the source properties of the southern water masses change it is supposed that the upper waters of the Rockall Trough will remain relatively unaffected even if the Subpolar Gyre continues to weaken.

P11PS.01

P11PS - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Poster

Assessing the impact of late Pleistocene megafaunal extinctions on global vegetation and climate

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The end of the Pleistocene marked a turning point for the Earth system as the climate gradually emerged from millennia of severe glaciation in the Northern Hemisphere. It is widely known that the deglacial climate change was accompanied by an unprecedented decline in many species of large terrestrial mammals, featuring among others the near-total eradication of the woolly mammoth. Due to an herbivorous diet that involved the grazing of a large number of trees, their extinction is thought to have contributed to the rapid and well-documented expansion of dwarf deciduous trees in Siberia and Beringia, which in turn could have affected the surface albedo of Northern Continents, and contributed to the changing climate of the period.

In this study, we use the University of Victoria Earth System Climate Model (UVic ESCM) to simulate the possible effects of megafaunal extinctions on Pleistocene climate change. We have introduced various hypothetical scenarios of megafaunal extinctions ranging from catastrophic to more realistic cases, in order to quantify their potential impact on climate via the associated biogeophysical effects of expanding vegetation on regional and global temperature. In particular, we focus our attention on a Maximum Impact Scenario (MIS), which represents the greatest possible post-extinction reforestation in the model. The more realistic experiments include sensitivity tests based on the timing of extinction, the amount of tree clearance associated with mammoth diets, and the size of mammoth habitats.

P11PS.02

P11PS - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Poster

Sensitivity of SST to wintertime rainfall around Japan

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The impact of high resolution sea surface temperature (SST) data on the winter time climate around Japan is investigated using a WRF model with a horizontal resolution of 20 km. The OISST (0.25 deg) and the smoothed SST are used as the lower boundary condition in the experiments. Generally, the OISST is warmer in the south of the Polar Front over the Japan Sea, the Kuroshio/Oyashio extension, and the coastal regions around Japan comparing with the JRA25 SST because the OISST resolves the small scale features in the SST related to ocean currents. In comparison, the magnitude of surface winds simulated with the OISST is weaker (stronger) on the (colder) warmer SST regions. The difference affects the convergence fields of surface winds, further causing the difference in precipitation. The results suggest a potential impact of small scale features in SST on atmosphere.

P11PS.03

P11PS - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Poster

Reanalyzing temperature and salinity on decadal time scales using a 3D ocean circulation model of the Baltic Sea

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A data assimilation system based on the Ensemble Optimal Interpolation approach is presented. The system uses anomalies from an ensemble of model states to estimate the Background Error Covariances (BECs). Samples from a static ensemble are chosen from the same season as the analysis time to deal with the strong seasonal variability in coastal regions. Furthermore, it is also discussed how to use observational information with different time windows in one assimilation process. A single observation experiment shows that the ensemble based BECs are multivariate, inhomogeneous and anisotropic. To evaluate the performance of the analysis system in the Baltic Sea, a set of reanalysis experiments spanning the period January 1970 to December 1999 has been carried out by assimilating temperature and salinity profiles into the Rossby Centre Ocean model. Experiments with and without data assimilation have been performed. The root mean square deviations between reanalysis results and observations at all levels show that temperature and salinity have been improved significantly, compared to the simulation without data assimilation, by 31.1% and 38.8% respectively. The vertical structure of the reanalyzed fields is also adjusted. Comparing the reanalysis fields and forecasting fields with independent CTD data, we found significantly improved temperatures in middle and upper layers and for salinity even in deeper layers.Especially, the temporal variations of the deep water salinity caused by saltwater inflows are improved. Moreover, the reanalysis has improved the depth of the halocline and thermocline (compared to observations) which are overestimated in the run without data assimilation.

P11PS.04

P11PS - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Poster

Annual and seasonal monitoring of meteorological and agricultural drought in Morocco using open satellite short time series

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This paper focuses on annual and seasonal comparison and monitoring of remotely sensed meteorological and agricultural drought indices over rainfed agriculture and vegetation cover zones of Morocco. The research was based on a set of open data composed from a short time series of monthly TRMM-precipitations images covering 15 years from 1998 to 2012, Worldclim global precipitation representing the period of 1950- 2000, time series of Normalized Difference Vegetation Index (NDVI) and time series of Normalized Difference Water Index (NDWI) extracted from SPOTVGT and covering the same period, in addition to Global land cover map (2000). In this regard, time series of TRMM-precipitations were compared to Worldclim global precipitation, and then used for the calculation of the Standardized Precipitation Index (SPI). This index was calculated for each hydrological year and also for each of the three key seasons in Morocco in term of precipitation and vegetation growing cycle (autumn, winter and spring), during the studied period. Likewise, NDVI time series were acquired, processed and used for the calculation of Standardised Vegetation Index (SVI) as a commonly used index for Agricultural drought assessment. This paper introduces a new index, Standardized Water Index, derived from NDWI time series. It is known to be sensitive to vegetation water content, since it is calculated from Shortwave Infrared (SWIR) and Near-Infrared. 320 cross-tables, proportions of concordance and Cohen's kappa coefficients were established for different combinations. The spatiotemporal comparison of the three indices was then carried out in addition to the assessment of their agreement for each hydrological year and for each season, at level of rainfed agriculture and vegetation cover. The results showed that the concordance between SVI and SWI is relatively higher and more significant than the concordance of others combinations for hydrological years and for the three seasons.

P11PS.05

P11PS - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Poster

Multi – pronged approach to exploring climate and range land management

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Issues surrounding Rangeland use affects climate, and how climate change affects Rangeland use, require examination of societal and environmental systems across space at multiple scales, from the global climate to regional vegetative dynamics to local decision making by farmers and herders. It also requires an analysis of causal linkages and feedback loops between systems. This survey discusses a methodological framework to quantify the two-way interactions between Rangeland use and arid and semi- arid land climate systems. Arid and semi- arid lands are facing rapid land use change, where changes in climate would have serious impact on livelihoods and livelihood systems, and requiring new coping and land use strategies. This survey explores linkages between vital areas of global change research, these include, land use management and climate change. These linkages are examined through modeling agricultural systems, land use driving forces and patterns, the physical properties of land cover, and the regional climate. Both qualitative and quantitative methods are being used to illustrate a diverse pluralism.

Keywords: Multi – pronged approach to exploring climate and range land management

P11PS.06

P11PS - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Poster

Study of a class of problems of optimal ship routing based on risk theory

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Modern navigation is a complex process of vessel control, whose main purpose is to provide a safe and economical movement. Route and conditions optimization is the simultaneous consideration of many factors that affect the speed and safety of the vessel, as well as to ensure environmental safety. Passage in the route can be done in many ways and certainly not the shortest route may be the best. Implementation of sailing courses should include the formation of the route leading to the destination in the shortest time and with the mean of navigational hazards. In order to find the optimum it is necessary to solve the problem of finding the smallest values of special functionals, including the value of functional of the deviation of the vehicle from the prescribed route, and different kind of «risk».
In the report an algorithm for the numerical calculation of the optimum ship route will be proposed. The method for the numerical calculation of the optimum ship route is based on the route cost functional, which describes the total costs the route between the two points may be burdened with. We will consider some kinds of possible critical situations with the ship. Having described the situations possibilities characteristics and the loss of consequences we will propose the algorithm for numerical estimation of the risk. There will be considered also the variational equations for the minimization problem and the solvability problem will be examined. The problem studied in the report will be solved numerically for some particular cases.

P11S1.01

P11S1 - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Oral

Can an influence of changing aerosol emissions be detected in the pattern of surface temperature change between 1970 and 2000?

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Since the 1970's, there has been a rapid change in the magnitude and spatial distribution of anthropogenic aerosol particle and precursor emissions in the world with a significant decrease over e.g. Europe and North America and a substantial increase over large parts of Asia. During the same time period, there has been a significant increase in global greenhouse gas concentrations. In the present study, CMIP5 model output are used together with the global climate model CAM-Oslo to examine if the shift in aerosol emissions between 1970 and present day results in a clear fingerprint in the modeled atmospheric circulation, precipitation and temperature change patterns. In particular, we analyze the response in Arctic regions to changes in tropical and mid-latitude aerosol forcing. To evaluate the simulations, we make use of observations and re-analysis data of surface temperature, precipitation and 300 hPa geopotential.

P11S1.02

P11S1 - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Oral

Isolating mesoscale coupled ocean-atmosphere interactions in the Kuroshio Extension region

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The Kuroshio Extension region is characterized by energetic oceanic mesoscale and frontal variability that alters the air-sea fluxes that can influence large-scale climate variability in the North Pacific. We investigate this mesoscale air-sea coupling using a regional eddy-resolving coupled ocean-atmosphere (OA) model that downscales the observed large-scale climate variability from 2001-2007. The model simulates many aspects of the observed seasonal cycle of OA coupling strength for both momentum and turbulent heat fluxes. We introduce a new modeling approach to study the scale-dependence of two well-known mechanisms for the surface wind response to mesoscale sea surface temperatures (SST), namely, the «vertical mixing mechanism» (VMM) and the «pressure adjustment mechanism» (PAM). We compare the fully coupled model to the same model with an online, 2-D spatial smoother applied to remove the mesoscale SST field felt by the atmosphere. Both VMM and PAM are found to be active during the strong wintertime peak seen in the coupling strength in both the model and observations. The atmospheric response to the oceanic mesoscale SST is also studied by comparing the fully coupled run to an uncoupled atmospheric model forced with smoothed SST prescribed from the coupled run. Precipitation anomalies are found to be forced by surface wind convergence patterns that are driven by mesoscale SST gradients, indicating the importance of the ocean forcing the atmosphere at this scale.

P11S1.03

P11S1 - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Oral

Projected Tasman Sea climate change and extremes in the 21st century

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The western Tasman Sea is warming at almost four times the global average rate. Observational and modelling studies suggest that the increased sea surface temperature (SST) is largely due to a spin-up of the South Pacific Gyre over recent decades. The extending EAC does not represent a simple change in the mean flow, but rather complex pulse and eddy changes, and is likely to affect higher order statistics such as the frequency of warming or cooling events. Extreme temperature events in particular can have catastrophic impacts on fragile coastal ecosystems. We investigate how the ocean climate in the Tasman Sea is projected to change during the 21st century. Here, we discuss results from a high-resolution (~10 km) ocean circulation model, forced by output from a large-scale climate model simulation, for the Tasman Sea region through the 2060s. We present the projected future ocean climate in terms of changes in the central statistics (mean SST, SST variance, eddy kinetic energy, etc) and occurrence of extreme temperature events. The ocean model provides accurate estimates of the large-scale general circulation and central statistics. As is common in climate model predictions, the extreme events are not properly represented. Model biases are account for by using a hierarchical Bayesian model and extreme value theory. By mapping changes in ocean climate statistics and extremes, we identify specific regions where the change in climate is expected to be particularly strong. The results show that both mean SST and SST variance are predicted to change significantly in the Tasman Sea. Also, the estimated change in SST extremes between the 2060s and 1990s is due to a combination of changes of the mean SST and changes in higher order statistics, primarily SST variance. Finally, the eddy kinetic energy in the entire Tasman Sea is predicted to increase considerably which may have a significant impact on vertical mixing and thus nutrient levels and biological productivity.

P11S1.04

P11S1 - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Oral

Observationally-constrained estimates of global fine-mode AOD

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Small aerosols are mostly anthropogenic, and fine-mode aerosol optical depth (fAOD) can be used to infer anthropogenic aerosol amounts. We estimate AOD and fAOD globally on a monthly time scale from 2001 to 2010 by integrating monthly satellite-based (MODIS and MISR) and ground-based (AERONET) observations.For fAOD, three integration methods are developed to utilize global coverage by satellite data and maximize the influence of AERONET data. We evaluate each method by applying the method without a few randomly-chosenAERONET data and comparing its output with the few AERONET data. The best performing method matches AERONET FMF (fine-mode fraction) very well (correlation = 0.9), while a simple use of MISR FMF gives the correlation of 0.5. This best method is based on integrating the Ågström exponent (AE) data from MODIS, MISR and AERONET.

Using our integrated data, we find that the global 2001-2010 average of 500 nm AOD and fAOD is 0.171 and 0.093, respectively. fAOD over eastern Chinais several times as large as the global average. The linear trend from 2001 to 2010 is found to be slightly negative in global AOD or global fAOD. This decreasing trend is particularly pronounced over the west (Western Europe and US/Canada combined) where a fAODreduction isabout -20%. On the contrary, fAODinIndia and eastern China combined increased. These results quantify the overall anthropogenic aerosol emission reduction in the west, and stagnatingconditions in Asia. Moreover, our results in the west are consistent with the so-called surface brightening phenomenon in the recent decades.

P11S2.01

P11S2 - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Oral

Radiative forcing and climate impacts of constrained emissions of absorbing aerosols over Southeast Asia

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Recent work has used an inverse modeling technique to produce the first global average estimate and uncertainty of annual BC emissions. This result produced an optimized range for BC emissions ranging from 200% to 300% the emissions currently used by the IPCC, AEROCOM, and Bond et al. When run forwards through a coupled aerosol and climate modeling framework, the annual average results match well.

However, there are still significant underestimates in a few geographic regions: specifically those that are impacted by large-scale fire sources. Therefore, to better address this, recent work used a decadal time series of satellite measurements, and a new analysis technique, to identify and constrain these has been performed at high spatial and temporal resolution, specifically for two of these critical areas, both based in Southeast Asia.

These new emissions a-priori locations, strengths, and ratios of BC to OC are used in connection with associated error bounds, and the MIT-CAM-AERO-URBAN modeling system, to describe the impact that they have on the regional scale environment. This includes quantifying both the radiative forcing and its uncertainty, as well as using a slab ocean approximation to compute an equilibrium climate state. These results will be presented, and demonstrate that improvements to the annual amount, the regional amount, and the temporal variations each lead to significant changes to the radiative forcing and equilibrium climate response.

It is hoped that these results can point the way forward in terms of further improvements that can be made, through approaches such as idealized simulations to better understand the dynamical consequences, and fully coupled air, ocean, and aerosol studies to better understand the climate response.

P11S2.02

P11S2 - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Oral

Eddy properties in the Mozambique Channel: a comparison between observations and 2 numerical ocean circulation models

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Analysis of satellite altimetry observations, transports estimates from a mooring array, as well as output from 2 different numerical ocean circulation models (ROMS and HYCOM), have been used to investigate the mesoscale eddy properties and transport variability in the Mozambique Channel. The power spectral density of the model transports at 17S indicates the models ability to represent the transport variability at mesoscale frequencies (range between 3 and 10 per-year). The models have shown an exaggerated representation of the lower frequencies (below 3 per-year), while underestimating the higher frequency signals (above 10 per-year). The overestimation of the seasonal cycle appears in our case not to be related to a misrepresentation of the mesoscale variability. The eddies were identified using an automatic eddy tracking scheme. Both anticyclonic and cyclonic eddies appeared to have a preferred site of formation within the channel. The density distribution have shown that the anticyclones exhibited a bi-modal distribution: the first mode was associated with the typical scale for the oceanic mesoscale turbulence, while the second mode was related to the passage of large rings at a frequency of about 4 - 7 per year. On the other hand cyclonic eddies had a single mode distribution that follows the first baroclinic Rossby radius of deformation, which is a typical scale for the oceanic mesoscale surface eddy variability, suggesting that their formation is associated with baroclinic instability. Eddy mean amplitudes per class of radius (for radius below 100 km), increase linearly with increasing radius, while no linear relationship exist for the rings. Different from the rings, the increase on the amplitude of the eddies was consistent with the increase of their life expectancy and travelling distances.

P11S2.03

P11S2 - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Oral

Applying downscaled data to develop IDF curves at ungauged sites: essential drainage design curves for urban planning

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Lack of sufficiently long rainfall records is common in Southeast Asia countries. This leads to improper drainage design. Optimal drainage designs rely very much on the rainfall Intensity-Duration-Frequency (IDF) curves; essential drainage design curves for urban planning. As climate has shown significant changes in rainfall characteristics, the adequacy of existing IDF curves is called for particularly when the rainfall is much more intense. For ungauged sites, developing IDF curves for future climate is even challenging. Liew et al. (2012) presented a novel approach in which rainfall data were extracted from a high spatial resolution Regional Climate Model driven by Reanalysis data. A novel (3-step) Downscaling-Comparison-Derivation (DCD) approach to derive IDF curves for present climate using extracted Dynamically Downscaled data was demonstrated at ungauged sites in Indonesia. This paper extended the application of the approach to other ungauged sites in Southeast Asia (e.g. Malaysia and Vietnam). The study is performed by first identifying the nearest meteorological stations where IDF curves exist. Biases resulting from these meteorological sites are captured and serve as very useful information in derivation of present day IDF curves for ungauged sites. For anticipated changes in rainfall intensities due to climate change, this study also demonstrated the development of future IDF curves for ungauged sites. The derivation of future IDF curves was done by applying the «simple delta» (Δi) method on high resolution dynamical downscaling outputs from GCM CCSM3.0; emission scenarios A1FI, A2 and A1B. Results from different emission scenarios are able to give a comprehensive assessment to policy maker on which scenario to adopt in future. It provides information on the adequacy of storm drainage design at gauged and ungauged sites to cope the impacts of climate change. This creates effective adaptation measures to address climate change impacts.

P11S2.04

P11S2 - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Oral

Is anthropogenic aerosol forcing during the Monsoon season unimportant?

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Radiative forcing by anthropogenic aerosols after monsoon onset is often considered unimportant compared to that in the pre-monsoonal period, due to precipitation scavenging of these aerosols. We have examined this assumption for the South Asian monsoon using three model runs with forcing prescribed only during the pre-monsoonal period (April-May), only during the monsoon period (June-September), and during both periods. Monthly climatological forcing values were prescribed over South Asia every year to the Community Earth System Model (CESM 1.0.4) with all model components from atmosphere, ocean, land, to sea and land ice active, and integrated over 200 years under year 2000 conditions. We propose that aerosol forcing after monsoon onset, though relatively weak, still exhibits a clear impact locally on the rainfall, particularly over central India where transport or longevity of aerosols is not required to achieve such an effect.

P11S2.05

P11S2 - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Oral

Climatic variability in the Sub – Saharan region

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Background: Climatic variability in the Sub – Saharan region has been monitored, using both systematic rainfall records and proxy information concerning lakes and rivers and the occurrence of famine and drought.
Methods: Proxy data have been used to produce a semi-quantitative data set spanning most of the continent and having an annual time resolution. Various issues related to the causes of this variability are also considered: atmospheric and oceanic processes, desertification, mineral dust and hydrological feedbacks.
Results: The most significant climatic change that has occurred has been a long-term reduction in rainfall in the semi-arid regions. The Sub – Saharan region has been affected by increased aridity. Few changes in temperature have been demonstrated. These have occurred on a much smaller scale and are of considerably lower magnitude than those over the continents. Dry episode have prevailed and conditions more typical of the 'normal' for the current century again prevailed. Thus, another period of dry conditions evidenced in the Sub – Saharan region are not in themselves evidence of irreversible global change. On the other hand, the processes controlling rainfall over most of the continent are now reasonably well understood. One of the most important factors, particularly in the Sub – Saharan region, is sea-surface temperatures. It has been hypothesized that anthropogenic changes in the land surface, particularly land use change and desertification, have contributed significantly to the decline in rainfall. Current evidence suggests that if changes in the land surface (e.g., vegetation cover, soil moisture) significantly impact climate, they are much more strongly controlled by natural climate variations, such as the recent decline in rainfall, than by human-induced land-use change or degradation.
Conclusion: There is no any accurate large-scale assessment of the extent, nature and degree of such changes. The dreaded 'desertification' process appears

P11S2.06

P11S2 - Integrated Environmental Modeling: Regional Climate and Ocean Modeling

Oral

Dynamics of coastal upwelling off the southwest coast of India: Observations and simulations

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Hydrographic data collected from the southeastern Arabian Sea (SEAS) during 2007-2008 and the Princeton Ocean Model was utilized to study the dynamics of upwelling off the southwest coast of India. Prime mechanism for upwelling in this region was the steady northwesterly winds from March, while the winds and the southerly West India Coastal Current (WICC) sustained it. As the Kelvin Wave generated at the equator terminated at the head Bay in March, it has no role in the upwelling dynamics. Observations and simulation showed upsloping of isotherms at the subsurface from March and its surfacing in May. The divergence of WICC at the southern tip of India in May, as evident from the simulation, might have triggered the surfacing of isotherms. Below WICC, undercurrent was evident from March, with its source from Bay of Bengal during March-April and from equator during the monsoon season. Simulation showed weak influence of remote winds from equatorial and eastern Bay in the upwelling off the west coast of India, whereas the western bay winds have profound in the localization of upwelling to south of 10oN and its weak alongshore and offshore extension.

PS1PS.01

PS1PS - Extreme waves

Poster

Strongly nonlinear wave transformation and interaction in shalow water

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The strongly nonlinear wave propagation and interaction in shallow water is studied with use of numerical solutions of shallow-water system written in divergent form by the finite volume method. New effect of reflected wave formation from the shock wave of negative polarity is investigated. It is shown that the nonlinear generation of the reflected wave in the process of the shock wave formation strongly influences the interaction of two unidirectional waves. This process is more manifested for the waves of negative polarity (troughs), adding an further dissipation mechanism. Under the same conditions (same amplitude and wavelength) wave crests are more presistent than wave troughs and live longer time. Application of obtained results to the extreme (rogue) wave appearance is discussed.

PS1PS.02

PS1PS - Extreme waves

Poster

Spectral wave climate of extreme wind waves

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The advent of data reanalysis, development of hydrodynamic numerical wave models, and the application of high-performance computing results in the availability of hindcasted wave fields of long duration (40 or more years). As a result new unique statistics are obtained. Among others are extreme climatic two-dimensional wave spectra for different wave making conditions.

Key parameters of any two-dimensional spectra are at least wave heights H, periods T, direction d, peakedness g and angular parameter s.

The main steps of spectral wave climate investigations include:

Hindcasting of wave spectra by spectral hydrodynamic model.

Classification of spectra for different classes (as rule 5 classes, namely: wind waves, swell, wind waves & young swell, matured swell & wind waves, complicated wind fields).

Estimation of parameters for each class of spectra.

Calculation of joint distributions of wave spectra parameters, including the extremes of return periods up to 100 years. As a result climatic wave spectra of rare probability are estimated.

Results of hindcasting by spectral models do not display any suspicion to freak wave, as this is specific single wave. Freak (rogue) wave have some principal difference from extreme waves, mainly due to their form and asymmetry. Physical hypotheses of freak wave generation allow their arising in any place of an Ocean. Classical statistical analysis of time series do not allows estimating the probabilities of freak wave occurrence and associated weather conditions. The approach regarded freak wave as multidimensional random event is proposed. Contaminated distribution may be used for probability density approximation of joint extreme and freak wave.

Presented approach is realized in the new generation of wind and wave handbooks published by Russian Maritime Register of Shipping, starting from 2006. The details of approach and results for different seas will be presented.

PS1PS.03

PS1PS - Extreme waves

Poster

Implication for people's safety in extreme situations

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Usually there is uncertainty about characteristics of the rogue waves (wave height, approached time). This limits the ability of people to adjust their behavior to the stressful situations. Possible reactions of people on some scenario of rogue wave appearance are discussed in presentation.

PS1PS.04

PS1PS - Extreme waves

Poster

Surfactant dynamics under the action of strongly nonlinear waves

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As it is known, the sea surface is covered by the surface-active films of natural and antropogenic origin. Its concentration is described by the 2D advection-diffusion equation, and advection is related with near-surface velocities induced by the large-amplitude waves. The two kinds of sea large-scale waves in the coastal zone are considered: edge waves and trapped waves. The approximated solutions of the advection-diffusion equation are obtained for weakly nonlinear waves. Numerical simulations are performed for strongly nonlinear waves with use of computer code WaveSurfactant. Spatial patterns of the surface manifestation of large-scale waves of large amplitudes are demonstrated.

PS1PS.05

PS1PS - Extreme waves

Poster

Dispersive focusing and modulation instability as mechanisms of the rogue phenomena in the sea waves of different nature

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The mechanisms of the rogue wave formation are well described for the surface gravity waves (Kurkin and Pelinovsky, 2004; Kharif et al, 2009). The similar mechanisms can “work” for sea waves of different physical nature: Stokes edge waves, Rossby waves, internal waves. The features of the manifestation of the two mechanisms (dispersive focusing and modulational instability) in different kinds of sea waves are discussed.

PS1PS.06

PS1PS - Extreme waves

Poster

Dynamical effects in the near-bottom field induced by the large-amplitude sea waves

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Extreme sea waves propagated in shallow waters can influence on the fine sediment transport due to large variations of the near-bottom velocity field. The various kinds of the large-amplitude sea waves are considered: unidirectional surface waves, topographically trapped waves, edge and unidirectional internal waves. The characteristics of the near-bottom currents induced by such waves are analyzed and compared. They are used to calculate numerically and analytically the variations of the sediment thickness using the simple 1D sediment transport model. The numerical code called WAS (Wave Action on Sediments) is described.

PS1PS.07

PS1PS - Extreme waves

Poster

Extreme internal waves in the horizontally inhomogeneous ocean and its action on the bottom sediment transport

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The huge internal waves can induce large near-bottom currents influenced on the sediment transport. The characteristics of the prognostic internal waves in different areas of the World Ocean are computed using data of the NOAA and GDEM hydrological atlases. The near-bottom particle velocities are calculated within the extended Korteweg-de Vries model solving the eigenvalue problem with nonlinear correction. The applied sediment transport model is based on the Shields parameter computed through local values of the near-bottom velocities. Analytical approximated solutions for the variation of the sediment thickness under action of nonlinear internal waves are obtained. Special numerical software IWAST (internal wave action on sediment transport) is created and tested on analytical solutions for idealized situation when the internal solitary wave is propagated in the basin of constant depth.

PS1PS.08

PS1PS - Extreme waves

Poster

Multi-soliton dynamics in shallow water

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The dynamics of soliton field in the framework of Korteweg-de Vries (KdV) equation is considered. Firstly, the elementary act of soliton interaction (two-soliton interactions) is studied in details. It is shown that such interaction (especially interaction of solitons with amplitude ratio close to the critical value, which separates exchange and overtake regimes) leads to the decrease of the 3rd and 4th moments (skewness and kurtosis) of the nonlinear wave field while the 1st and the 2nd moments (mean and variance) remain unchanged due to the conservation of the mass and momentum. Secondly, numerical study of the statistical characteristics of multi-soliton fields which are generated from the initially isolated solitons with random phases and amplitudes is made. The effect of the nonlinear interaction between solitons and dispersive trains is considered. It is confirmed that first two moments being the invariants of the Korteweg – de Vries equation remain to be constant. The skewness and kurtosis vary in time in each realization but tends to the constants in the average.

PS1S1.01

PS1S1 - Extreme waves

Oral

Fully two-dimensional rogue wave dynamics

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The theory for the nonlinear dynamics of rogue waves in 1+1 dimensions has long been associated with the nonlinear Schroedinger equation in one spatial dimension. In the present talk I extend the theory to 2+1 dimensions in which fully directional wave trains are given concrete meaning. I also develop a spectral theory for rogue waves for which the associated Riemann spectrum is a two by two matrix. The nonlinear interactions are treated as off-diagonal terms of a particular type. I show how to simulate a fully 2+1 wave field using the approach and I point the direction to fully nonlinear wave trains described by the Euler equations in a similar manor. Three goals of the theory are discussed: (1) the physics of rogue waves in directional seas, (2) the nonlinear Fourier analysis of wave data and (3) the hyperfast simulation of directional wave fields. Some details of the method are given, although a new book will give most of the details: Rogue Waves and Holes in the Sea, by Alfred R. Osborne [2013].

PS1S1.02

PS1S1 - Extreme waves

Oral

Manifestation of wave coherence in rogue events

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Different situations are shown and discussed, when wave coherence due to the nonlinear wave interaction becomes evident.

The envelope soliton solution of the nonlinear Schrodinger equation is examined by means of fully nonlinear simulations of the Euler equations and also in laboratory experiments in the situation of strong nonlinearity. It is shown that strongly nonlinear effects do not destroy the solitary wave group even when the steepness is high.

The attempt to map the weakly nonlinear analytic description of modulated nonlinear waves (due to the Inverse Scattering Technique) to the case of strong nonlinearity is undertaken. Qualitative comprehension of the strongly nonlinear wave dynamics and qualitative description of it would provide elements of the deterministic short-term forecasting for rogue waves. The accessibility of this goal is discussed.

PS1S1.03

PS1S1 - Extreme waves

Oral

Extreme events in numerical simulations of sea states

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An approach to extensive studying rogue wave occurrence in numerical simulations is presented. As a result of numerical simulations of the unidirectional wave evolution, spatio-temporal fields of wave data of the size 20 min x 10 km are obtained with high resolution in time and space and are used for statistical analysis with the focus on extreme waves. Having the exhaustive information on the wave evolution enables us to capture the detailed picture of individual rogue waves; to detect intermittent rogue wave events, which last for significantly longer time, and hence, to draw the image of a rogue wave. Due to the benefit of owing full wave data, the question of relation between extreme wave kinematics and extremely high waves is discussed in the statistical sense.

PS1S1.04

PS1S1 - Extreme waves

Oral

Dynamical criteria for rogue Waves in nonlinear Schrodinger models

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In this talk rogue waves in deep water in the framework of the nonlinear Schrödinger (NLS) and Dysthe equations will be investigated. Amongst the homoclinic orbits of unstable NLS Stokes waves, we seek good candidates to model actual rogue waves. We propose two selection criteria:stability under perturbations of initial data, and persistence under perturbations of the NLS model. We find that requiring stability selects homoclinic orbits of maximal dimension. Persistence under (a particular) perturbation selects a homoclinic orbit of maximal dimension all of whose spatial modes are coalesced. These results suggest that more realistic sea states, described by JONSWAP power spectra, may be analyzed in terms of proximity to NLS homoclinic data. In fact, using the NLS spectral theory,we find that rogue wave events in random oceanic sea states are well predicted by proximity to homoclinic data of the NLS equation.

PS1S1.05

PS1S1 - Extreme waves

Oral

An experimental study on the excitation of rogue waves in opposing currents

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Laboratory experiments in a wave flume and a narrow directional wave basin have been carried out to investigate the nonlinear dynamics of mechanically generated water-wave trains when propagating on adverse current gradients. Observations substantiate that the increase of wave steepness induced by the wave-current interaction excites nonlinear mechanisms such as modulational wave instability. This facilitates the formation of freak waves also under those circumstances when they are less likely. Experimental results support recent theoretical achievements based on a current-modified Nonlinear Schrodinger equation, which demonstrate that rogue waves are triggered by current with negative gradient of horizontal velocity

PS1S1.06

PS1S1 - Extreme waves

Oral

The rogue wave of 27 August 1969 at Dwarskersbos, South Africa: Field survey and simulation as a meteo-tsunami

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In the early hours of 27 August 1969, the village of Dwarskersbos, South Africa, was inundated by a wave which flooded houses and damaged small boats.

This small tsunami took place in the absence of any seismic source or extreme weather, and its origin remains mysterious.

In 2010, we conducted a field survey based on the interview of 9 elderly witnesses living in the village, using techniques developed earlier for the study of the 1946 Aleutian and 1956 Greek tsunamis. We measured 13 locations, with runup reaching 2.9 m for a maximum inundation of 260 m.

The most remarkable aspect of our dataset is the extreme concentration of the flooding along a 2-km stretch of coastline. In particular, the tsunami did not reach the opposite side of St. Helena's Bay, nor did it affect Elands Bay and Lamberts Bay, respectively 43 and 68 km to the North. To investigate the possible origin of the Dwarskersbos tsunami, we first simulated an underwater landslide taking place in a canyon 20 km Northwest of Shelley Point, using the MOST code. This predicts comparable amplitudes along most of the regional coastlines, and thus fails to explain the documented concentration at Dwarskersbos.

By contrast, we explore a meteorological origin for the event by simulating the coupling between a possible squall (modeled as a steep pressure front) propagating over St. Helena's Bay and the oceanic column, using Proudman's [1953] original model, as applied by Platzman [1958] to the case of the 1954 Chicago rogue wave. We find that a front moving at 15 m/s in the azimuth N100E can resonate exclusively with the shallow bathymetry off Dwarskersbos, and thus explain most of the features revealed by our survey. This interpretation would be in contrast to the case of the tsunami of 21 August 2008, for which a comprehensive series of maregraphs along a 900-km stretch of coastline supports the model of distant source possibly involving slope failure of the continental margin along the Chamais Slump.

PS1S1.07

PS1S1 - Extreme waves

Oral

Design for Ship Safety in Extreme Seas - EXTREME SEAS

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The EC project EXTREME SEAS (Design for Ship Safety in Extreme Seas) and its results are presented. Particular focus is given to contribution to the progress beyond the state of the art. The project started in 2009 and will be finished in 2013. The strategic objective of EXTREME SEAS is to improve design of ship structures that are exposed to rough climate, by providing technology and methodology that need to be a part of design for ship safety in extreme seas. The second main objective is to develop warning criteria for marine structures against extreme sea states and rogue waves. The project is studying physical and statistical properties of extreme and rogue waves, and is developing advanced numerical and physical simulation models for wave-structure interaction. Numerical simulations of waves and ship behavior in waves are validated by model tests carried out in recognized model basins. The developed methodology and tools will be generally applicable to different ship types. The case studies considered in EXTREME SEAS are devoted to container vessels, to passenger ships, to LNG carriers and to product and chemical tankers.

PS1S2.01

PS1S2 - Extreme waves

Oral

Extreme wave events and regional cycle's influences: The Cadiz coast study case

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Climatic change-related impacts on coastal areas became an important issue in past decades and nowadays threat many human settlements and activities. Occurrence and distribution of extreme waves and storms are important issues in the incidence of coastal erosion, deterioration and/or complete disappearance of ecosystems. This work presents the characterization of coastal storms in Cadiz (SW Spain) and the determination of their recurrence intervals and relationships with several regional cycles. Storm characterization was carried out using the Storm Power Index (Dolan and Davis, 1992) and five classes were obtained, from class I (weak events) to V (extreme events). Storm occurrence probability was 96% for class I (i.e. almost one event per year) to 3% for class V. The return period for class V was 25 years and ranged from 6 to 8 years for classes III and IV storms, e.g. significant and severe events. Classes I and II showed a period of recurrence ranging from 1 to 3 years. Approximately 40% of the change in monthly wave data and storminess indices was related to several teleconnection patterns, being the Arctic Oscillation (AO), with 21.45%, and the North Atlantic Oscillation (NAO), with 19.65%, the most important drivers of change. It is interesting to note that a great number of storms, larger storm duration and higher values of Storm Power Index were only observed when neutral to strong negative NAO and AO phases occurred at the same time (89 storms and 3355 h) and/or when there was an abrupt change of NAO and AO phases, i.e. they moved from a positive to negative phase without passing through a neutral phase. The results obtained in this work have wider applications for ocean and coastal management. It is suggested that methodology used can be easily applied in different areas where wave buoy data are available.

PS1S2.02

PS1S2 - Extreme waves

Oral

Extremes of wave-induced water level setup in the urban area of City of Tallinn, Estonia

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Short-term variations in the water level and accompanying coastal flooding in the microtidal Baltic Sea are mostly driven by the atmospheric forcing. Extreme water levels have reached a reasonable value of 1.57 m above the long-term mean in Tallinn. However, in coastal segments that are open to high waves the water level may be considerably higher owing to wave-induced set-up. The existing inundation maps, operational water level forecasts and warning systems often ignore this phenomenon that usually becomes evident in selected coastal sections depending on the wave approach direction.

We systematically analyse the potential for the wave-induced water level setup at the waterfront of Tallinn. Wave properties are modelled using a triple nested version of the WAM model, with a resolution of the innermost grid down about 470 m, and forced by one-point high-quality wind data from Kalbadagrund for 1981–2008. About 50% of the coastal sections of Tallinn can be substantially affected by substantial wave setup during certain storms. The levels of extreme setup (on top of the storm surge) often reach 0.7–0.8 m and thus considerable contribute to the threat of inundation. While the overall highest waves along the entire coastline of Tallinn (digitised into about 100 sections) are created by only four storms in 1981–2008, the number of storms responsible for the highest setup in different coastal sections is more than 40. The conjecture that the highest setup not necessarily occurs during the strongest storms has major implications to the evaluation of marine-driven risks in certain coastal areas.

PS1S2.03

PS1S2 - Extreme waves

Oral

Statistical distributions of wave heights of depth-limited storm waves

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The distribution of wave heights often significantly differs from the well-know Rayleigh distribution. In order to address this, different statistical distributions have already been proposed, e.g. by Forristall (1978). In addition to that especially the distribution of extreme waves changes in depth-limited waters of the shelf seas. This effect of depth limitation is e.g. considered by Battjes and Groenendijk (2000) by introducing a composite Rayleigh-Weibull distribution. Since the extreme wave height and its probability is very relevant for the design of offshore structures, like wind farms, there is still a need for further analysis of wave height distributions. The basis of our study on wave height distributions is a continuous, high resolution data set of water level elevation measured at two sites (particularly research platform “FINO I“) in the North Sea operated for at least 5 years. The measurements were carried out with radar gauges (Barjenbruch and Wilhelmi, 2008) and cross-checked with buoy data. On an hourly basis the distributions of wave heights and periods were derived. For the test of published distributions of wave heights a set of extreme wave events (with maximum wave heights larger than 40 % of the water depth) was selected. The general applicability of published distributions as well as their parameterization were tested. Adaptations to the parameterizations of all distributions to North Sea conditions are given as well as the quality of fit. The spatial variability of the parameterization is tested for the measuring site at FINO I by operating four identical radar gauges at different measuring positions allowing a contemporaneous comparison of distributions.

PS1S2.04

PS1S2 - Extreme waves

Oral

Wave crest distribution of random directional wave fields

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Abnormal waves, often called freak or rogue waves have been subjected to much attention in the last decade. Owing to many research efforts, the occurrence of rogue waves, their mechanism, and detailed dynamic properties are now becoming clear. The predictions made by theoretical and numerical models compare well with experimental results. Although statistical properties of rogue waves have been studied by many researchers limited investigations have been dedicated to statistical distribution of wave crest accounting satisfactory for presence of rogue waves. Several studies have shown that modulation instability has strong impact on the crest distribution which, in particularly for the long-crested waves, is deviating significantly from the second order based Tayfun (1980) and Forristall (2000) wave crest distributions. It has also been shown that the effect of modulational instability is substantially reduced in more realistic directional wave fields. Laboratory data of random directional wave fields have been used to investigate the combined effect of higher order nonlinearity and directional spreading on the wave crest distribution. Different sea states with a variety of combination of steepness and directional spreading have been considered, ranging from long to short crested wave fields. The study is also supported by numerical simulations carried out by solving the equations with the Higher Order Spectral Method proposed by West et al. (1987). A 2-parameter Weibull distribution has been fitted to the experimental data and the related parameters have been parameterized as a function of wave steepness and directional spreading as well as a general version of the Benjamin-Feir Index for directional sea states given by Mori et al. (2011). The proposed distribution is compared with field data and discussed in view of the existing theoretical second and higher order crest distributions.

PS1S2.05

PS1S2 - Extreme waves

Oral

An experimental investigation of regular harmonic waves in Marintek Ocean Wave Basin

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We report an experimental investigation of the propagation of interacting harmonic waves in the 50x70m Marintek Ocean Basin. Sensors were positioned in different groups along the central axis of the basin in the direction of wave propagation. The first row was placed at distance of 4.8 m from the wave generators and enabled detection of the initial wave shape and its evolution in time. These were followed by single sensors and sensor groups positioned at 5 m intervals, which allowed monitoring of the changing wave shape with the passage of time, distance, and inter-wave interactions. Waves were investigated within the frequency range 0.4 - 2.5 Hz, for amplitudes 0.068 ¨C 0.2 m. The signal recording time at one measurement set was typically 300 s, corresponding to approximately 200-500 wave crests. The first set of tests involved a study of quasi-one-dimensional harmonic waves, propagating perpendicular to the line of paddles. These waves were affected by the added noise generated by the paddles. The directional wave generator in the Marintek basin consists of number of paddles, spaced by 0.4 m. The gap between paddles of several centimetres is covered by waterproof elastic material. This non-uniformity produced a flux of water into and out of the basin through the «between-paddle gaps» resulting in waves of short wavelength, in our case with λ ~ 5-10 cm. They represent a form of added noise. They propagate relatively slowly through the basin at phase velocity $v_{Ph}=g/\omega=\sqrt{(g/k)}$. When the surface elevation measurements are analysed, this noise manifests as a sharp increase in the standard deviation of the wave amplitude and as the appearance harmonics in the Fourier spectrum of the signal. We will discuss the Fourier spectrum of the initial harmonic waves and its evolution with time and distance, the interactions of two and three co-linear harmonic waves, and the influence of the noise on these interactions in the quasi-one-dimensional case.

PS1S2.06

PS1S2 - Extreme waves

Oral

Marine storminess (1880-2012) from VOS: Climate variability in wind wave extremes and geometry

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We present the assessment of the observed climate variability in marine storminess over global oceans during the last 130 years from the Voluntary observing ship (VOS) data. Importantly, VOS data provide the best sampling in many coastal areas that allows for reliable estimates of extreme wave statistics. Three streams of data provide different sets of wave statistics used for the analysis of linear trends and interannual variability. During the last 130 years our analysis identified upward changes in the mean wave height over North Pacific (up to 7 cm/decade) and the absence of significant linear trends in the North Atlantic. After 1950 waves are growing up over Northern Hemisphere mid latitudes showing the strongest increase in the North Atlantic of 12 cm/decade. For the last 5-6 decades in the Pacific changes in extreme SWH are clearly coordinated with the increase of extreme seas, while in the North Atlantic changes in extreme SWH do not show correlation with extreme wind seas, but rather with swells. For the period after 1970 we also demonstrate secular increase of wind sea periods in both Northern and Southern Hemispheres which is not proportional to the changes in wind sea heights, implying statistically significant trend in the wind sea steepness. Furthermore, extreme waves become steeper for most areas. Detailed analysis for some coastal regions in the North Atlantic and North Pacific identified several distinct discrepancies with the open ocean patterns of variability. Thus, along European and West American coasts the trends in extreme waves as well as changes in steepness characteristics are stronger than for the open ocean. Our analysis allowed for discrimination between the effect of better near-coastal sampling and regional mechanisms associated with locally higher extreme winds.

PS1S3.01

PS1S3 - Extreme waves

Oral

Discussion on possibility of rogue wave formation in a basin of intermediate depth due to the modulational instability

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Properties of rogue waves in the basin of intermediate depth are discussed in comparison with known properties of rogue waves in deep waters. Based on observations of rogue waves in the ocean of intermediate depth we demonstrate that the modulational instability can still play a significant role in their formation for basins of 20 m and larger depth. For basins of smaller depth, the influence of modulational instability is less probable. By using the rational solutions of the nonlinear Schrödinger equation (breathers), it is shown that the rogue wave packet becomes wider and contains more individual waves in intermediate rather than in deep waters, which is also confirmed by observations.

PS1S3.02

PS1S3 - Extreme waves

Oral

The role of modulation instability in the appearance of large-amplitude internal waves

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The modulation instability of long internal waves can occur in various areas of the World oceans for certain conditions on the density stratification. It leads to appearance of internal breather-like waves which appear and disappear very quickly. In nonlinear theory of long internal waves based on the Gardner equation these conditions satisfy to the positiveness of the coefficient of cubic nonlinearity term. Our calculations show that the cubic nonlinear term is positive for the conditions of many regions in the Ocean, for example in the South China Sea in January and the Baltic Sea in July. Parameters of internal wave groups which are optimal for modulation instability are discussed. The numerical simulation of modulation instability development and the appearance of internal waves of huge amplitudes is performed in the framework of the Gardner equation and full nonlinear Euler equations.

PS1S3.03

PS1S3 - Extreme waves

Oral

Parametric excitation of internal waves and convective instability of a fluid layer heated from above

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The criterion of the parametric instability of a fluid layer heated from above is obtained. The parametric instability is caused by a weak temporal modulation with an amplitude ε and a period τ of the acceleration of gravity. The amplitude and the period lie in the region of the ground demultiplicative resonance, $1 \gg \varepsilon > \tau/T_d$, where T_d is the characteristic time scale of dissipative processes whose spatial scale is determined by the excited wave length. Such a mechanism allows to generate parallel internal wave fronts since the mechanism of excitation of the wave amplitudes is not connected to the introduction of additional anisotropy into the system. The possibility of the oceanic and upper atmospheric internal waves with the two-day period is studied. Such mechanism of internal waves generation may be also realized in the earthquakes.

PS1S3.04

PS1S3 - Extreme waves

Oral

Important effects of large-amplitude internal waves in shelf environment: Observations and numerical modelling

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Internal waves in shelf zone of the oceans and seas, being in most part of cases nonlinear waves, propagate in very inhomogeneous media. This circumstance made internal wave dynamics on shelf very complex. We present review of our results on investigation of some important effects in intense internal waves on a shelf obtained during past several years. We carried out long-term field observations on shelf of the Sea of Japan, the Black Sea, and on Pacific Coast of Kamchatka, to reveal main effects in internal waves propagating there. After collecting the observational data we made numerical modelling for these effects. In the field observations besides traditional instruments we have also used ADCP for internal waves study. Numerical modelling of observed processes was made on the basis of solving full Navier-Stokes and diffusion equations. We concentrate our attention on study the effect of change of internal wave polarity which takes place when intense internal waves propagate from deep to shallow water and pass an overturning point evolving from internal depression waves to internal elevation waves. A case of an internal wave propagating from shallow water to deep water (with transformation of elevation waves to depression internal waves) was also considered. We investigated as well propagation of internal solitons through interthermocline lens on shelf and generation of internal waves by moving surface intrusion of freshened water. Results from numerical modelling were in a good agreement with observed data. The work was supported by CRDF and RFBR.

PS1S3.05

PS1S3 - Extreme waves

Oral

Resonance phenomena in the tsunami wave dynamics on the coast

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The resonance phenomena plays significant role in the amplification of the tsunami waves in coastal areas and leads to different physical phenomena: long duration of water oscillations, later arrival of wave with maximal amplitude comparing with leading waves, group structure of tsunami waves. Usually, such effects are related with a complicated two-dimensional bathymetry of bays and jagged coastal line. The aim of this report is to show that even for one dimensional long wave propagation, resonance effects may appear for waves with certain frequencies depended on bottom profile. In tsunami run-up theories for idealized topography (slope beach is matched with horizontal bottom), the typical incident wave is usually presented by the solitary pulse like soliton, or sign-variable impulse like N-wave. Although the periodic waves have been also discussed (from the pioneer work by Carrier-Greenspan, 1958), they never considered as benchmarks for testing numerical tsunami codes. Resonance effects in the case when the incident wave of an arbitrary shape approaches from far area to idealized beach geometry are very weak. They may be important for periodic waves if the wave is generated in the coastal area (Kajiura, 1977; Stefanakis et al, 2011). Here we present the results of experimental study of the resonance phenomena in the laboratory flume of Caen University, confirming theoretical predictions. Meanwhile, the resonance phenomena are possible for waves coming from far zone if the bottom profile contains two pieces with different slopes. In this case, the resonance is important for incident solitary waves also. The detailed analysis is given for single Gaussian and N-gaussian waves of various parameters which were chosen through empirical relations with an earthquake magnitude. It is shown that resonance phenomena are manifested sharply for weakest earthquakes and N- wave.

PS1S3.06

PS1S3 - Extreme waves

Oral

Regularized shallow-water equations as a model for a solitary wave generation

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Among wave motions in seas and oceans, the birth and behavior of large-amplitude solitary waves (called in the literature extreme, or giant, waves) are of great interest.

According to modern concepts and observational experience, in some cases, these waves can be generated by wind and act as a solitary wave or a group of solitons [1,2]. The mechanism of generation of wave–wind solitons has not been fully understood because this study in the real world is very difficult. Some aspects of this phenomenon was observed and investigated experimentally in a wind-water annular tunnel in, e.g. [3].

In this study, we show the results of direct numerical simulation of an isolated wind–wave soliton on the basis of the regularized shallow-water equations [4]. These equations can be regarded as a generalization of the classical Saint-Venant system, that is accomplished by strongly non-linear additional terms with a small parameter as a coefficient. The corresponding numerical solutions correctly reflect the main characteristics of the generation and behavior of solitary waves observed in the experiment [3]. The wind strength and friction forces are taken into account.

In the full presentation the form of regularized shallow-water equations will be shown together with the numerical algorithm and details of computational results.

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PS2PS.01

PS2PS - Hydroacoustics/T-waves

Poster

Characteristics of T-wave envelopes revealed from numerical simulation

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There have been several studies about empirical relation between seismic source parameters (e.g., focal mechanisms, depths, magnitudes, etc.) and T-wave observation. In order to delineate the relation, numerical and theoretical approaches to figure out T-wave excitation mechanism are required. In an attempt to investigate source radiation and wave scattering effects in the oceanic crust on T-wave envelopes, we perform three-dimensional numerical modeling to synthesize T-wave envelopes. We first calculate seismic P- and SV-wave energy on the seafloor using the Direct Simulation Monte Carlo based on the Radiative Transfer Theory, which enables us to take into account both realistic seismic source parameters and wave scattering in heterogeneous media. Then, we estimate excited T-wave energy by normal mode computation. The numerical simulation has been carried out considering the following different conditions: source types (strike and normal faults), source depths (shallow and deep), and wave propagation through homogeneous and heterogeneous Earth media. From the results of numerical modeling, we confirmed that T-wave envelopes would vary according to spatial seismic energy distributions on the seafloor for the various input parameters. Furthermore, the synthesized T-wave envelopes show directional patterns due to anisotropic source radiation, and the slope change of T-wave envelopes caused by focal depth. Seismic wave scattering in the oceanic crust is likely to control the shape of envelopes.

PS2PS.02

PS2PS - Hydroacoustics/T-waves

Poster

Automatic recognition of T and P waves in the continuous records of moored hydrophones

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A network of moored hydrophones is an effective way of monitoring the seismicity along the oceanic ridges. Due to high cost of the boat time, the moments of instruments' installation and recuperation are separated by time periods of significant duration, normally a year or even longer in some cases, which results in very large data sets. The preliminary but indispensable part of the analysis of the recuperated data consists in finding all acoustic signals of interest. This part is extremely time-consuming as it is done by a human operator who visually examines the entire database. To speed up the analysis, we propose to use a recent method by Sukhovich et al. (GRL, 2011), which was developed for an automatic recognition of teleseismic P waves by autonomous underwater floats. We have applied this method to locate the acoustic signals of two principal geophysical interests, T waves and teleseismic P waves, in the data collected by a moored hydrophone in the North Atlantic. We show that the method allows to efficiently resolve these two types of signals while keeping the number of wrong identifications to a minimum. The different parameters that influence the resolution power of the method are discussed. It is shown that the choice of these parameters should be based on the statistical properties of the spectral content as well as the signal-to-noise ratio (SNR) of the signals to resolve. Our results indicate that the method can be successfully applied to automatize the preliminary analysis of the databases obtained in the long hydroacoustic experiments.

PS2S1.01

PS2S1 - Hydroacoustics/T-waves

Oral

MERMAIDs: first observations of teleseismic P-waves with freely floating submarine robots

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Lack of seismic data collected at sea severely impedes progress of global seismic tomography. Present techniques use OBSs and moored hydrophones. However, installation and data recovery costs render them too expensive to fill in existing data gaps. Teleseismic P-waves arriving at the ocean bottom refract into water and propagate in the form of acoustic signals whose arrival times can be used to remove the data shortage. Simons et al. [JGR, 2009] designed and tested a prototype of underwater robot called MERMAID equipped with a hydrophone to record acoustic signals generated by P-waves. Following their experiments, we have constructed an operational MERMAID (see abstract by Hello et al.) Communication with the robot at surface is possible via Iridium satellite system. By varying its buoyancy, MERMAID can dive and remain at certain depth while continuously monitoring pressure variation. Upon detection of a P-wave by STA/LTA algorithm, the robot should immediately ascend for satellite transmission of its GPS coordinates and the recorded signal. However, many detectable signals of other origins exist (ships, airgun campaigns, T-waves). As each diving/surfacing depletes the battery, it is extremely important to ensure the ascents only in case of a teleseismic P-wave detection. Algorithm for automatic recognition of detected signals uses wavelet transform and information on statistical properties of signals of the same origin. In this talk we report first recordings of teleseismic P-waves by MERMAIDs. In 2011-2012 three tests were conducted in Mediterranean allowing to record nine teleseismic events. Our results indicate that no simple relation exists between event's magnitude and SNR of a generated acoustic signal. Factors such as fault orientation and meteorological conditions must play important role in detectability of seismic events. We also report latest results of first fully autonomous run of a final MERMAID design.

PS2S1.02

PS2S1 - Hydroacoustics/T-waves

Oral

Multichannel seismic/meteorological/zoological monitoring of the oceans

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We have built and tested a prototype «Mermaid» float as a seismological sensor using an Apex float from Teledyne Webb Research, a Rafos hydrophone, and electronics developed in collaboration with Osean. Two of these floats have been deployed in the Mediterranean sea between Nice and the island of Corsica late 2012, five others launched in Feb 2013 in the South Indian Ocean, a dozen more will follow near the Galapagos in the Pacific. A wavelet-based algorithm parameters discriminates P-waves from the continuous input signal (see abstract by Sukhovich et al.). Ten significant events can be stored in internal memory during an average «parking depth» drift of 10 days at a chosen depth of up to 2 km. At the end of the preprogrammed mission the float surface and transmit data (health logs and events) in Rudics mode by Iridium satellite network. A major event will force the float to ascent immediately to the surface and transmit the recorded data as well as its GPS position. A second, dual channel, prototype version using two dedicated hydrophones has been designed to enlarge the band pass for acoustic signals with much higher frequency than seismic. It continuously analyzes acoustic signals to detect both major seismic events and meteorological phenomena such rain, drizzle, open sea and ice, or whale migration. This extension to multi-purpose applications makes the Mermaid very attractive for the Argo program. In fact, Mermaids using passive low cost sensors form a very light and complementary solution that can be integrated with an Argo float if CTD data are observed during ascent and descent. Such multidisciplinary approach should allow seismologists to participate in international program such as Argo and obtain the dense ocean coverage needed to image the deep structure of the Earth.

PS2S1.03

PS2S1 - Hydroacoustics/T-waves

Oral

Advances in understanding seafloor tectonic processes from t-waves

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It has been over 60 years since T-waves were first identified as the water-bourn phase of a seafloor earthquake, and about 20 years since T-waves started being routinely monitored and processed in near real-time in the north-east Pacific using the U.S. Navy's SOund SUrveillance System (SOSUS) (Fox et al, 1993). Initially, T-wave studies were met with concern regarding the accuracy of locations as well as a lack of understanding about how T-waves found their way into the SOFAR channel. However, T-wave monitoring has now been shown to have a wealth of scientific applications and has shed light on deep-sea tectonic processes from mid-ocean ridges to subduction zones. The ability to detect earthquakes 1-2 orders of magnitude smaller than land networks has revealed a dynamic seafloor and in particular has identified and characterized numerous episodes of mid-ocean ridge volcanism. Recent results from around the global ocean will be presented and compared with what can be discovered from land stations and ocean bottom seismograph (OBS) recordings. Hydroacoustic monitoring has an important role to fill in bridging the gap between global seismic network monitoring capabilities and more detailed, but expensive and geographically limited, OBS experiments.

PS2S1.04

PS2S1 - Hydroacoustics/T-waves

Oral

The influence of bathymetry on the excitation of T-waves

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T-waves, sometimes also referred to as «T-phases,» are a ubiquitous component of the low frequency ocean acoustic wave field and can be excited by marine earthquakes, submarine volcanoes, and by conversion from seismo-genic elastic waves to acoustic waves at continental or island slopes, or rough surfaces, among other sources. T-waves are mostly not excited directly, as they comprise low order acoustic modes in the ocean, which generally have ray equivalent turning points at depths much shallower than the source depth of the actual earthquake. Heterogeneities of some sort are required for T-wave generation. If the Earth were a plane layered semi-infinite halfspace or a radially symmetric sphere, T-waves would not exist. We employ two independent elastic-acoustic propagation models, a two-way (forward and backward) coupled mode model and a one-way parabolic equation (PE) solution, to examine the efficiency of various bathymetric heterogeneities at exciting T-waves. We examine the downslope conversion and the rough surface scattering hypotheses for generating T-waves. Our rough surface model is a deterministic proxy for a true stochastic rough surface. Rippled seafloors are also considered in this context.

PS2S1.05

PS2S1 - Hydroacoustics/T-waves

Oral

Localization of T-wave energy on land revealed by a dense seismic network in Japan

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We have investigated the wave propagation characteristics of a seismic T wave on land in northeastern Japan using the seismograms recorded by a dense seismic network Hi-net. The analyzed T wave is a unique one that was generated by a large intermediate-depth earthquake beneath the network and back-propagated from the Emperor Seamount Chain in the northern Pacific. Spatiotemporal variation of an RMS envelope filtered with a passband of 1– 2 Hz demonstrates multiple arrivals of the T wave and inhomogeneous distribution of amplitude. Judging from the spatial pattern of first arrival times and the polarization characteristics, we regard the seismic T wave as a Rayleigh wave. A possible conversion area, estimated by a method similar to the source-scanning algorithm, is located to the northeast of Honshu Island and may have a dimension of ~100 km. The most prominent feature of the spatiotemporal variation of the RMS amplitude is the localization of T-wave energy in the northeastern part of Honshu Island. This localization can be attributed either to the close proximity of the conversion area to land or to the large extent of the area. However, these factors are supplementary because they cannot explain a sharp contrast in amplitude between the two areas with comparable distance but different azimuth from the conversion point. An essential factor in explaining the observation is the non-isotropic radiation from the conversion points. Since the conversion occurred on the continental slope, the maximum amplitude of converted energy is expected to appear either in the propagation direction of incoming acoustic waves or in the steepest direction of the local topography. These factors, in particular a convex shape of bathymetry, probably caused the focusing of converted energy into the northeastern part of Honshu Island. Acknowledgments: We thank the National Research Institute for Earth Science and Disaster Prevention (NIED) for providing waveform data from Hi-net.

PS2S1.06

PS2S1 - Hydroacoustics/T-waves

Oral

Seismicity and accretion processes along the Mid-Atlantic ridge around the Azores hot-spot using data from Autonomous Hydrophone

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The seismicity of the Mid-Atlantic Ridge (MAR) has been monitored for several years by two networks of 4 autonomous underwater hydrophones (AUH) moored within the SOFAR channel on the flanks of the ridge. The instruments were deployed north and south of the Azores Plateau between 40° to 50°N from June 2002 to September 2003 (SIRENA) and between 32° and 39°N from July 2005 to August 2008 (MARCHE). Due to the low attenuation properties of the SOFAR channel for the propagation of earthquake-generated T-waves, hydrophone arrays significantly reduce the detection threshold to a magnitude completeness level Mc of 2.1 along the MAR, compared to a Mc of ~4.3 from land-based seismic networks. Our hydrophone arrays detected and located 5600 events inside the MARCHE array and 1700 events inside the SIRENA array, providing new information on the spatio-temporal distribution of the MAR seismic activity. In hydrophone catalogues, earthquake sizes are measured by their acoustic magnitudes (Source Level, SL). The lowest source level above which our data set is complete is SLc=205 dB. Seismic swarms were analyzed using the SEISAN software package. Using three criteria - a minimum SL of 210, a radius of 30 km and a time window of 40 days -, 7 swarms with more than 15 events are identified between 32° et 39°N of latitude (~ 2,5/year) and 15 swarms between 40° to 50°N (~ 11/year). The maximum number of earthquakes in a swarm is 57 events. From the SL distribution as a function of time after the mainshock, swarms can be sorted between tectonic events with a «mainshock-aftershock» distribution, fitting a modified Omori law, and volcanic events showing more constant SL values. We further examine the setting of these sequences, using gravity, bathymetry, and available local geological data.

PS2S2.01

PS2S2 - Hydroacoustics/T-waves

Oral

Three-dimensional mapping of evolving internal waves using combined in-situ and remote sensing data

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Propagation of internal waves in shallow water waveguide plays an important role in intensity fluctuations of acoustic signals. Modeling acoustic field in these regions requires detailed knowledge of sound speed and its spatial and temporal variability resulting from various inhomogeneities in the ocean. Although satellite imagery can provide snapshots of the surface impressions of the internal waves, they provide limited images in each orbit. Hence, other techniques to obtain internal wave field data are desirable. In this paper, an example is shown where a time-varying, 3D internal wave fine structure is reconstructed using simultaneous measurement of temperature data using thermistor arrays and the surface impressions of a moving internal wave packet from a ship's radar during the Shallow Water 2006 experiment. Parameters of internal wave train, such as wave speed, propagation direction and amplitude of the wave fronts, are determined. Resulting temperature field induced by the internal waves is used to construct a 3D sound speed input for modeling acoustic wave propagation in shallow waters. Excellent agreement between acoustic data and model results encourages research into inverse problems of determining internal wave parameters using acoustic wave propagation.

PS2S2.02

PS2S2 - Hydroacoustics/T-waves

Oral

Long-term hydroacoustic monitoring in the Atlantic and Indian Oceans

Royer, J.Y. 1; Chateau, C. 1; D'Eu, J.F. 1; Guennou, C. 1; Jamet, G. 1; Perrot, J. 1; Sukhovich, A. 1; Tsang-Hin-Sun, E. 1; Guinet, C. 2; Samaran, F. 3

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Since 2002, our laboratory has been deploying long-term arrays of hydrophones to monitor the low-level seismicity associated with seafloor spreading in the Atlantic and Indian oceans. We are currently maintaining three hydroacoustic arrays: 5 sites since 2010 in the Southern Indian Ocean, encompassing three ridges with contrasting spreading rates; 5 hydrophones since 2011, around the MOMAR hydrothermal sites, south of Azores; and 5 hydrophones since 2013, around the St Paul FZ in the Equatorial Atlantic. Our objectives are to monitor the seismic and volcanic climate associated with seafloor spreading ridges (16 to 70 mm/yr), large offset fracture zones and intraplate deformation, and which is poorly recorded by remote land-based seismological networks. This long-term acoustic monitoring provides information on the spatial and temporal distribution of the low-level seismicity (30 to 50 times more active than shown by land-based catalogs) and allows deciphering the tectonic or volcanic origin of event-clusters. Our arrays also provide information on the presence and migration patterns of several species of large baleen whales, particularly in the remote Southern Indian Ocean. Other sounds of interest include icequakes from the Antarctic margin and drifting icebergs, and low-frequency noise related to the sea-state.

Our hydrophones are designed for a continuous recording at 240Hz with an autonomy of 18 months and a high-precision clock (10-8). There are positioned in the axis of the Sound Fixing and Ranging (SOFAR) Channel, whose acoustic properties allow earthquake and volcanic T-waves to propagate over large distances with little attenuation.

Through forward modeling with a finite element method (SPECFEM2D), we are also investigating the seismic to acoustic conversion processes, and the effects of long distance propagation of T-waves in the water column and SOFAR channel. Some results from these experiments and approaches will be presented.

PS2S2.03

PS2S2 - Hydroacoustics/T-waves

Oral

Modelling and measuring acoustic backscattering cross-section due to simultaneous contributions from swimbladder and fish flesh

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Recent computational improvements have enabled the superposition of swimbladder (gas-filled spheroid) and fish flesh (liquid-filled spheroid) contributions to compute fish target strength. Their corresponding backscattering cross-sections were coherently added. A prolate spheroidal scattering approach has been adopted to model scattering response by bladdered and bladder-less fish. The implemented model enables simulation of a great variety of scattering shapes in fresh water and oceans that are attainable by prolate spheroids. Moreover, the used curvilinear coordinate system leads to a separable solution for the scalar Helmholtz equation. Two different experimental conditions have been simulated with the implemented model. Measurements of acoustic backscattering target strength of Percichthys trucha at 38 kHz using encaged fish with a split-beam echo-sounder was conducted in an Argentinean lake. A Monte Carlo method was used to simulate target strength probability density functions taking into account fish behaviour through an experimental tilt-angle distribution analysis. The model was also applied for further analysis of reported maximum and average target strength dependence on fish length from gadoids and mackerel. For both experimental conditions, a very reasonable agreement was obtained when comparing measurements and simulations. Experimental evidence showed that slight tilt-angle variation can generate significant differences in backscattering target strength parameter. This feature could be simulated since fish flesh contribution was included in the total scattering response. Furthermore, incorporating the measured tilt-angle distribution improved agreement between experimental and simulated results.

PS2S2.04

PS2S2 - Hydroacoustics/T-waves

Oral

Underwater vector sensor measurements

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In addition to the overall sound pressure level, measurements of the underwater acoustic vector field establish a unique set of acoustic vector properties. The vector measurements, typically made by spatially separated hydrophones or particle-motion sensors (a tri-axial accelerometer or geophone), consist of the three components of particle motion and the acoustic pressure. Vector properties of the acoustic field, such as the balance between potential and kinetic energy or the path of acoustic particle motion, relate directly to the source location and the environmental properties of the propagating medium. We investigate here, how a vector interpretation of the the acoustic field can further our understanding of ocean sound-sources, in particular, for acoustic fields consisting of reflections from the sea-bed and/or sea-surface. For example, a vector property based on the ratio of the acoustic particle velocity to pressure magnitude is substantially larger in regions of destructive interference than in regions of constructive interference (where the ratio is nearly a constant). This vector property can pin-point the location of destructive nodes, which characterize the acoustic modes. Another vector property, the degree of circularity, describes the elliptical acoustic particle motion often observed in interference fields. We show, though a series of experimental measurements with a vector sensor, how the spatial and frequency dependence of the degree of circularity relates to source localization. Additionally, we demonstrate, with both experimental and modeled data, how the composition and layered structure of the sea-bed effects vector properties, which in turn can be used for geoacoustic inversion.

PS2S2.05

PS2S2 - Hydroacoustics/T-waves

Oral

New advanced discriminants for explosive hydroacoustic phases

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The enforcement of the Comprehensive Nuclear-Test Ban Treaty (CTBT) requires the monitoring of acoustic sources in the oceans in order to detect underwater explosions. We present new advanced criteria used to discriminate hydroacoustic phases between explosive events and earthquakes. These criteria can be applied on records from both hydrophones and «T-phase» seismic stations. In the time domain, and in addition to the classical amplitude/Duration discriminant, we use a catalogue of reference envelopes to which a signal can be directly compared by cross-correlation algorithms.

In the frequency domain, we use several methods including: the study of the decay of spectral amplitude with frequency (both in terms of a power law, and of smoothness), and the evolution of the duration of the signal when corrected using an empirical compensation of any frequency dispersion present in its Fourier spectrum. We show that a combination of these various methods allows the correct identification of the nature of all sources in a large dataset of more than 300 signals. We further discuss methods to improve the calculation of the period of a pulsating bubble on signals from «T-phase» seismic stations.

S101PS.01

S101PS - Seismological Observation and Interpretation

Poster

Locations and magnitudes in the ISC-GEM Global Instrumental Earthquake Catalogue (1900-2009)

Di Giacomo, D. 1; Bondár, I. 1; Engdahl, E.R. 2; Storchak, D.A. 1; Villaseñor, A. 3; Lee, W.H.K. 4; Bormann, P. 5

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The ISC-GEM Global Earthquake Catalogue represents the final product of a two-year project sponsored by the Global Earthquake Model Foundation (GEM). The catalogue is available at the ISC website (www.isc.ac.uk) and consists of some 19,000 instrumentally recorded, moderate to large, earthquakes that occurred during the 110-year period between 1900 and 2009. Because of limitations in resources, time and data availability, we processed earthquakes selected according to time-varying magnitude cut-offs. These are 1900-1917: $Ms \geq 7.5$ worldwide, as well as a selection of shallow events ($Ms \geq 6.5$) in stable continental areas; 1918-1959: $Ms \geq 6.25$; and 1960-2009: $Ms \geq 5.5$. Each hypocentre listed in the catalogue was relocated using uniform and rigorous location and depth determination procedures. Thanks to the ISC-GEM location procedures and the substantial increase in the volume of observational data used in the relocations, we show that the ISC-GEM catalogue provides an improved view of 110 years of global seismicity of the Earth. With respect to magnitude, each earthquake in the catalogue is characterized by either a direct (i.e., based on seismic moment computation) or a proxy value of Mw (i.e., based on empirical conversion relationship). Direct values of Mw were compiled either from the Global Centroid Moment Tensor catalogue (www.globalcmt.org, starting in 1976) or from publications with reliable computation of seismic moment (largely for earthquakes before 1976). For those earthquakes without direct values of Mw, instead, we recomputed surface and body wave magnitudes using original amplitude-period measurements, and obtained Mw proxies using newly derived non-linear regressions between Ms-Mw and mb-Mw. Finally, we discuss the improvements in the magnitude composition of the ISC-GEM catalogue when compared to previous catalogues.

S101PS.02

S101PS - Seismological Observation and Interpretation

Poster

Data collection from early instrumental seismological bulletins for the ISC-GEM Global Instrumental Earthquake Catalogue

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This contribution outlines the data digitized from an unprecedented amount of historical paper-based seismological bulletins with fundamental parametric data for relocating and reassessing the magnitude of earthquakes that occurred between 1904 and 1970. This effort was necessary in order to produce the ISC-GEM Global Instrumental Catalogue covering the last 100+ years of large earthquakes. The parametric data obtained and processed during this work fills a large gap in electronic bulletin data availability. This new dataset complements the data freely available from the International Seismological Centre (ISC) bulletin starting in 1964. To facilitate earthquake relocation, different sources have been used to retrieve body-wave arrival times. These were entered into the ISC database using optical character recognition methods (e.g., ISS bulletins, 1918-1959) or manually (e.g., BAAS bulletins, 1913-1917). In total, ~1,000,000 phase arrival times have been added to the ISC database between 1904 and 1970. With respect to the amplitude-period data necessary to re-compute magnitude, we considered the global collection of paper-based bulletins stored at the ISC and entered relevant station parametric data into the database. As a result, some ~110,000 valid body- and surface wave amplitude-period pairs for re-computing magnitudes Ms and mb were added to the ISC database. The original paper bulletins were then scanned and will be made available at the http://storing.ingv.it/bulletins/ website. These newly available digital instrumental data will be significant in any future study of earthquakes occurred in the early instrumental period.

S101PS.03

S101PS - Seismological Observation and Interpretation

Poster

EMSC Real Time activities. Performances and evolutions

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The EMSC provides several real time information services for earthquakes in the Euro-Med region and worldwide which will be presented in this poster.

The EMSC website (http://www.emsc-csem.org) is the second website for global earthquake information and attracts more than 1.5 millions visitors per month on average. More than 30,000 earthquakes are published each year and a website for mobile devices is also available (http://m.emsc.eu).

The Earthquake Notification Service operational 24/7 aims at quickly (within 20-25 minutes from the earthquake occurrence) disseminating information for potentially damaging earthquakes via email, sms or fax. This service has more than 11,000 users and is operated in coordination with the national institutes.

During those last years, efforts have been carried out to improve the quality of the information published. An authoritative location procedure has been implemented end of 2010 and shows satisfactory results. An authoritative location is available for more than 40% of the M4+ earthquakes in the Euro-Med region. A Data Selected Locations procedure will be explained in this poster and implemented in order further improve the accuracy of the locations published by the EMSC.

During those last years, the EMSC developed an original approach called “Citizen Seismology” to involve citizens in earthquake response by offering them the possibility to share, through the Internet, their own testimonies on the earthquake effects with other witnesses and with the scientists. These techniques encompass among others the detection of felt earthquakes via surges of web traffic on EMSC website which are published on Twitter (@LastQuake). An online questionnaire is available for eye-witnesses in 32 languages. Pictures of damage provided by the eye-witnesses are collected and published after manual validation. Being also present on the social networks (Facebook, google+) helps to enlarge our audience and touch other communities.

S101PS.04

S101PS - Seismological Observation and Interpretation

Poster

Towards a unique station inventory for Europe

Godey, S. 1; Frobert, L. 1; Mazet-Roux, G. 1; Clinton, J. 2; Kaestli, P. 2; Sleeman, R. 3; Galanis, O. 3; Zednik, J. 4; Semrad, J. 4; Guegen, P. 5

1 EMSC, France; 2 ETH, Switzerland; 3 ORFEUS, Netherlands; 4 GFU, Czech Republic; 5 ISTerre, France

Within Europe, seismological and engineering communities are engaged towards the development of station information databases for strong motion and broad band instruments. Within NERIES, protocols to provide accelerometric data via a dedicated portal were set up successfully. In NERA project, the working group on Strong Motion has the goal to provide access to real time and reviewed strong motion data. During the NERIES project, the first inventory of accelerometric stations in the Euro-Mediterranean region (3,700 stations from 40 countries) was performed. In parallel, ORFEUS runs a working group dedicated to the coordination of broadband data acquisition and data exchange. It maintains a station database of permanent and semi-permanent digital BB stations in the European-Mediterranean area. A specific database is under developments by GFU to serve the BB community. This database would host information from about 1,000 stations in the EIDA. As metadata necessary for broad band and accelerometric stations description are partly overlapping, the development of a unique European stationbook becomes necessaryl and the different working groups are joining their efforts. The available database will be extended to include new metadata, and provide online access with update capabilities. The new station book will be based on an extended EIDA database structure and existing EIDA stations will already be included. Additional information unavailable in EIDA will be imported in the database using a web interface. We present the architecture of this unique stationbook and describe the implementation plan. We also provide information on other projects and initiatives currently in progress which may benefit from the unique stationbook. The relation to the FDSN StationXML and SC3 inventoryXML will be discussed. Compatibilities with worldwide seismological initiatives will be presented such as the International Registry of Seismograph Stations of the ISC and NEIC.

S101PS.05

S101PS - Seismological Observation and Interpretation

Poster

A strategy for earthquake catalog relocations using a maximum likelihood method

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A strategy for relocating earthquakes in a catalog is presented. The strategy is based on the argument that the distribution of earthquakes in a catalog is reasonable a priori information for earthquake relocation in that region. This argument can be implemented using the method of maximum likelihood for arrival time data inversion, where the a priori probability distribution of the event locations is defined as the sum of the probability densities of all events in the catalog. This a priori distribution is then multiplied by the standard misfit criterion in earthquake location to form the posterior likelihood function, assuming the two are independent. The probability density of an event in the catalog is described by a Gaussian probability density. The a priori probability distribution is, therefore, defined as the normalized sum of the Gaussian probability densities of all events in the catalog, excluding the event being relocated. For a linear problem, the posterior likelihood function can be approximated by the joint probability density of the a priori distribution and the distribution of unconstrained locations due to misfit alone. After relocating the events according to the maximum of the posterior likelihood function, a modified distribution of events is generated. This distribution should be in general more densely clustered than before. The a priori distribution is updated and the process is iterated. Iteration violates the assumption that the priori and the likelyhood function are independent, however, their dependence is weak and grows slowly with iteration number. The strategy is applied to the aftershock sequence in southwest Iceland after a pair of earthquakes on 29th May 2008. The relocated events reveal the fault systems in that area. Synthetic data sets are used to test the general behaviour of the strategy.

S101PS.06

S101PS - Seismological Observation and Interpretation

Poster

Real-time moment tensor inversion of earthquakes in Portugal

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Mainland Portugal is currently covered by ~30 permanent broadband seismic stations that transmit data to *Instituto Portuguê;s do Mar e da Atmosfera (IPMA)* in real-time. This high-density and high-quality data coverage allows automatic retrieval of earthquake source parameters based on waveform modeling. In this work we present moment tensors of earthquakes that occurred between 2007 and 2012 in Portugal and offshore areas. Moment tensor inversion is performed using two distinct codes: ISOLA (Sokos and Zahradnik, 2008) and KIWI (Heimann, 2010). ISOLA implements a time-domain iterative deconvolution algorithm based on Kikuchi and Kanamori (1991), while KIWI implements a multi-step combined time and spectral domain algorithm. Both codes use estimates of earthquake epicenter, depth and magnitude as input, then refine epicenter and depth by grid-searching around the starting parameters. Both methods output earthquake depth and moment tensor. ISOLA must be handled manually, while KIWI can be configured to run automatically and in real-time. We have analyzed all earthquakes in our dataset using both methods which give comparable results when run manually. KIWI is currently under implementation at IPMA for the real-time analysis of earthquakes. Quality control is the major challenge for real-time waveform analysis. In order to increase the reliability of our automatic solutions, we exploit the following strategy: 1) determine in advance which are the most reliable stations and 2) perform multiple inversions with different input parameters. The results obtained are important for two main reasons: 1) they contribute to improving our understanding of the seismo-tectonic setting of Portugal and 2) provide the basis for automatic waveform monitoring at IPMA. This research is supported by European and Portuguese funding (FP7-PEOPLE-IRG-2008, PTDC/CTE-GIX/116819/2010, PTDC/GEO-FIQ/3522/2012).

S101PS.07

S101PS - Seismological Observation and Interpretation

Poster

Towards real-time double-difference earthquake location in Switzerland

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Detailed information on the spatio-temporal migration of seismic activity within earthquake sequences provides an important seismotectonic context for rapid hazard evaluation. For those applications, monitoring the migration of seismicity requires the precise location of hypocenters in real-time. The double-difference (DD) location method in combination with differential times measured from arrival-time picks and waveform cross-correlation (Waldhauser and Ellsworth 2000) provides high-resolution images of seismicity. The method was recently adopted for real-time application and it is operational in the Northern California Seismic Network (Waldhauser 2009). The concept of this approach is an algorithm locating a new event with respect to a background catalog using the DD-formulation. The background catalog is generated from past seismicity using the hypoDD algorithm and the catalog is frequently updated to account for new events.

In this paper we will present our strategy to implement the real-time DD approach in the Swiss National Network operated by the Swiss Seismological Service (SED). The SED recently migrated its entire seismic monitoring software to the SeisComP3 framework, which will feed the real-time DD algorithm with phase picks and initial locations. The background catalog is derived from inverting differential times of SED bulletin data (including >10,000 earthquakes and 1,800 identified quarry blasts) and cross-correlating the entire waveform archive starting in 1984. To assess the quality of the new background catalog, we compare it to previous relative locations of isolated earthquake sequences and ground-truth events in different parts of Switzerland. The resolution of first-order active fault zones like the northern Valais lineament is significantly improved by the new DD-background catalog. In addition, known quarry blasts events cluster more tightly in the background catalog, which can be used in future for identification of blasts.

S101PS.08

S101PS - Seismological Observation and Interpretation

Poster

New version 2013a of Seismic Analysis Program Seismic Handler

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The Seismic Handler package is a widely used software for seismological processing and observatory purposes. Unique features are sophisticated array processing methods, extensibility by attaching external programs and plug-ins and easy usage of continuous waveform data.

Expanding digital seismic networks offer new possibilities for scientific research and require more software features. In the last years Seismic Handler was further developed to meet the needs of the seismological community.

The new version of Seismic Handler includes a new fomula for Wood-Anderson magnitude estimation according to IASPEI recommendations. On our poster we'll discuss the notable differences in comparision to the classical method.

We also present the upcoming release of SHX – Seismic Handler eXtended. It was re-implemented using the python programming language. It includes all features of SH plus additional attributes for graphical user interface, power spectral density calculation, meta-data handling and more.

S101PS.09

S101PS - Seismological Observation and Interpretation

Poster

New data about seismicity of semipalatinsk test site territory

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According to the current maps of general seismic zoning of the Republic of Kazakhstan (2006) Semipalatinsk Test Site territory located in the east of Kazakhstan is related to aseismic region of Kazakhstan. However, the recent investigations and analysis of archived data showed the Test Site territory and its vicinity experienced earthquakes in the past and some seismicity is observed in present. Maximum magnitude of the recorded earthquakes is 5 – 5.9.
The following activities were undertaken to solve the issue on natural seismicity at the STS region:
- world seismological bulletins, and information on historical seismicity from literature were analyzed. Historical analogue earthquake seismograms beginning from 1950 were collected, earthquake parameters were precised.
- All modern instrumental seismic data from regional Kazakhstan network beginning from 1994 were processed.
- Temporary seismic stations networks were installed on the Test Site territory during 2005-2010 to record small seismic events at the sites where strong nuclear tests were conducted formerly.
- Deep faults dividing the earth crust blocks were revealed. The tectonic elements location was precised by decoding Landsat space images, and using materials of geological and topographical surveys. The map of the main tectonic structures of the STS territory and its vicinity was constructed.
A joint earthquake catalogue for the STS territory and its vicinity covering the period from 1783 till present was created, the most active seismic zones were revealed, earthquake focal mechanisms were constructed. The calculations show that the STS territory may still experience events with intensity 6 on MSK-64 scale.
Availability of industrial seismicity is of high probability. It appears as small seismic quakes at the region of Degelen site where nuclear tests were conducted earlier.

S101PS.10

S101PS - Seismological Observation and Interpretation

Poster

Standardized nomenclature for reporting seismic event types

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Many types of seismic events are recorded by modern seismic networks. Event types include natural earthquakes, induced events, and explosions as well as many less common types such as ice quakes and meteorite impacts. There is a need for researchers, especially in the area of seismic hazard, to know if an event was tectonic, natural but non-tectonic, or anthropomorphic. Currently, seismic networks use differing nomenclature for reporting event type. These differences arise from varying operational practice and non-standard definitions included in common seismic bulletin formats such as the ISF, IMS, GSE, Nordic, and QuakeML. Some of these formats make the problem worse by mixing event types with event effects. The current nomenclatures do not allow reporting of sufficiently descriptive event types which causes either a misuse of specific event types or withdrawal of information.

Three international data centres that work with large volumes of seismic bulletin data, the International Seismological Centre (ISC), the USGS National Earthquake Information Center (NEIC) and the European-Mediterranean Seismological Centre (EMSC), have jointly reviewed their current practice of reporting event types. We present a nomenclature that allows event type reporting in a general or a more specific way, depending on the level of precision desired. The nomenclature also removes the sometimes-reported mix of event type and event effects. We encourage adoption of the nomenclature in seismic bulletin exchange formats. The proposed nomenclature is yet to be included in the common existing formats, but the nomenclature is designed not to require a change in the basic structure of these formats.

S101PS.11

S101PS - Seismological Observation and Interpretation

Poster

An approach for industrial blasts and earthquakes discriminating on the territory of Kazakhstan

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Since 2007 the Institute of Geophysical Researches implements field trips for detailed investigating of industrial blasts sources on the territory of Kazakhstan. By present time, field investigations on detailed study of industrial blasts sources in Kazakhstan were conducted for the territory of the Semipalatinsk Test Site and a part of adjacent regions (2007), for Kostanay and Aktyubinsk regions (2008) in the north of Kazakhstan; for Zhambyl, south-Kazakhstan and Kyzyl-Orda regions (2009) in the south of Kazakhstan; for Karaganda region (2010) in Central Kazakhstan; for north-Kazakhstan, Akmola and Pavlodar regions (2011) in the east of Kazakhstan; for east-Kazakhstan region (2012). In total, in 2007 – 2012 the following industrial blasts objects were revealed on the investigated territories: 270 quarries, 11 underground mines, and 12 other objects (laying a gas pipeline, construction of industrial facilities, elimination of ice jams in rivers, military sites). The collected material allows to solve successfully the tasks on discriminating the nature of recorded events for its further division into industrial blasts and earthquakes. Search of ground-truth explosions is of special emphasis as for those accurate blasting parameters, relation to a distinct quarry and relevant records at the stations are available. Ground-truth explosions data are used to study velocity characteristics of medium, to enhance events location accuracy, and to test monitoring stations capabilities.

Integrated investigation of seismic records and quarries at which industrial blasts are conducted allows seismologists to identify seismic events more accurately, to develop identification techniques, to compile high-quality earthquake catalogues that will result in correct assessment of seismic hazard for Kazakhstan territory.

S101PS.12

S101PS - Seismological Observation and Interpretation

Poster

Establishment of Borehole Observation System and High Resolution Seismic Studies in the Western part of the main Marmara Fault in the frame of a EU-FP7 project titled as MARSITE

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The MARsite project proposes to identify the Marmara region as a ‘Supersite’ within European initiatives to aggregate on-shore, off-shore and space-based observations, comprehensive geophysical monitoring, improved hazard and risk assessments encompassed in an integrated set of activities to respond to all priorities identified in the ENV.2012.6.4-2 call. MARsite aims to harmonize geological, geophysical, geodetic and geochemical observations to provide a better view of the post-seismic deformation of the 1999 Izmit, loading of submarine and inland active fault segments and transient pre-earthquake signals, related to stress loading with different tectonic properties in and around Marmara Sea. These studies are planned to contribute to high-quality rapid source-mechanism solutions and slip models, early warning and rapid-response studies. The project outputs will also be adapted to improve various phases of the risk management cycle with the creation of a link between the scientific community and end users. The objectives of “Establishment of Borehole Observation System and High Resolution Seismic Studies in the Marmara Sea” in this project are; To design and build multiparameter borehole system consisting of very wide dynamic range and stable borehole (VBB) broad band seismic sensor, and incorporate 3-D strain and tilt meter, and temperature and local hydrostatic pressure measuring devices; Combining borehole and surface network data for earthquake location improvement; Determination of surface and near-surface effects masking the source information on seismic waves; Monitoring rupture nucleation and propagation using borehole and surface array data; To measure continuously the evolution of the state of stress of the fault zone surrounding the Main Marmara Fault and to detect any anomaly or change which may occur before earthquakes; To identify the presence of repeating earthquakes along the MMF; To understand the stress transfer mechanism from east to west.

S101PS.13

S101PS - Seismological Observation and Interpretation

Poster

Seismicity of potassium salts deposit in Belarus

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The results of the study for the epicentral zone of seismic events mine fields Starobin deposit of potassium salts in Belarus are presented. Period of observations here from the opening 01.01.1983 the first and only seismic station «Solegorsk» to 31.12.2006 is described. Station in the mine at a depth of 436 m is installed. Epicenters on the epicentral distance and azimuth to the epicenter are processed. Mines are at a small area and earthquakes mainly outside are located. The total number events equal N=1097, of them 845 was localized. The increase of the station «Soligorsk» from V=3000 in 1983 to V=35000 in 2006 changed. So periods and areas confident logging of different magnitudes are investigated, which made it possible to construct a normalized magnitude-frequency relation with slope b=0.72. Also a comparison of the cumulative magnitude-frequency relation graph of seismic events Starobin potassium salt with similar graph, which for other potash deposits in Russia, Canada and Germany was produced. According to the A.A. Malovichko for all potash deposits, two groups of events stand out: the numerous weaknesses shocks in the areas of rocks collapse and isolated induced earthquakes (bursting). And in this case there is the stable correlation between Mmax of first and second groups M2-M1=3.5. Time delay induced bursting several years and even decades years can reach. For example, in Solikamsk (in the Urals in Russia) extraction in 1980-1988 was produced. A strong earthquake with M=4.3 occurred in 1995, i.e. 15 years after of the commencement of extraction and 7 years - after its completion. In Germany, at mine Teutschenthal, extraction in 1969-1971 was produced. Large induced bursting in 1996 occurred, i.e. just over 25 years. In Belarus, the process of development of field continues, while there is a weak earthquakes of the first group, but the second phase has not yet been.

S101PS.14

S101PS - Seismological Observation and Interpretation

Poster

Seismological monitoring of oil and gas deposits in Kazakhstan as a basis for induced earthquake prediction

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Every year the worldwide practice of oil and gas deposit development provides new examples of technogenic earthquakes occurrence.

The problem is not confined only to the natural and induced earthquakes. Development of oil and gas fields often causes surface lowering processes, creation of surface faults, moving of layers, etc.

Seismological monitoring of oil and gas deposits mounts a complex of measures providing after their fulfillment the technical, economical and seismic safety of population, territories, structures and facilities in oil production areas due to seismic risk mitigation, damage reduction, structures preparedness to strong technogenic earthquakes and reduction of expenses on aftermath elimination. Kazakhstan has considerable explored resources of oil and gas. Amount of production and transportation of hydrocarbon raw material to markets constantly increases. This fact forces us to be in earnest about probability of technogenic catastrophe occurrence.

Thus during the last years activization of seismic processes is observed in the territory of Western Kazakhstan in large deposits as Karachaganak, Kenkiyak and Zhanazhol, where no earthquakes occurred before the beginning of industrial production of hydrocarbon material. Hydrocarbon material production not only causes the local technogenic earthquakes but also can provoke strong earthquakes of tectonic nature. Such earthquakes are referred to the induced ones. The 2008 Shalkar Earthquake occurred near the Karachaganak deposit is an example of the induced earthquake. During the Shalkar Earthquake two settlements were destroyed. Such strong seismic processes also take place in the other deposits including both hydrocarbon fields and mineral deposits. In Kazakhstan wide experience on seismic process monitoring of deposits is accumulat

S101PS.16

S101PS - Seismological Observation and Interpretation

Poster

Static stress drop inferred from near-fault observations for the 1999 Chi-Chi, Taiwan earthquake

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In 2001, a special issue of the Bulletin of the Seismological Society of America (BSSA) featured seismological research for the 1999 Chi-Chi Taiwan earthquake. This study uses source parameters suggested by the first author in this special issue to estimate static stress drop associated with the Chi-Chi earthquake. The waveform simulation method was used to carefully examine these source parameters. The simulation results indicate that source parameters, inferred from near-fault observations, are well determined. According to the rupture area and slip, the static stress drops ($\Delta\sigma_s$) obtained were distributed between a small value of 47 bars near the epicentral region and a much larger value (>200 bars) to the north. Similar trends in dynamic stress drop ($\Delta\sigma_d$) were also recognized by the first author in his paper published in 2001 BSSA special issue. Comparing the $\Delta\sigma_s$ with $\Delta\sigma_d$, satisfies the relation $\Delta\sigma_s / \Delta\sigma_d \fallingdotseq 1$. This relation suggests that fault motion is mostly spent releasing seismic wave energy during the rupture process of the Chi-Chi earthquake. The consistency between static and dynamic stress drops thus provides a measure of energy-moment (E_s/M_0) ratios, which range from 9×10^{-5} to 6.5×10^{-4}. The average E_s/M_0 ratio estimated for the northern portions of the fault is 3.4×10^{-4}, which is about 3 times that of the south. Such a high E_s/M_0 ratio can be interpreted as having low strength in the rupture for the northern portions of the fault, where the fault would release less energy per unit rupture surface to create the new rupture.

S101PS.17

S101PS - Seismological Observation and Interpretation

Poster

Dubai Seismic Network

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On April, 2006 Dubai Municipality (DM) established a broadband seismological network in Dubai Emirate, United Arab Emirates (UAE). This network was the first seismic network in UAE and consists of four remote seismic stations to observe local and regional seismic activity that may have an affect on Dubai city and its surrounding areas. Each station consists of a very broad-band seismometer (STS-2) and a force balance accelerometer (ES-T). The system exchanges real-time data with the National Center of Meteorology and Seismology in Abu Dhabi, the Earthquake Monitoring Center in Oman and few of GSN stations, which increases the aperture of the network.

On April, 2012 DM installed more five free field strong motion stations inside the urban area based on Dubai microzoning studies to estimate shake map. This shake maps are published on the website on real time and are accessible by the decision makers.

Although, the local seismic activity from June 2006 to October, 2012 reflects low seismic activity it indicate active tectonics in the relatively a seismic northern Oman Mountains region. Few inland clusters of micro to small earthquakes have been identified. A clear cluster of small to moderate earthquakes took place in the Eastern Part of UAE to the East of Masafi while two clusters of micro to small earthquakes took place at Wadi Nazwa and northern Huwaylat. Focal mechanisms of few well recorded earthquakes in this region indicate normal faulting generally trending NE in parallel to transition shear zone between the collision at Zagros and subduction at the Makran zones.

S101PS.18

S101PS - Seismological Observation and Interpretation

Poster

Fluid-induced earthquakes?: Earthquakes with a low stress drop beneath Tanzawa Mountains region in Japan

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The Tanzawa Mountains region in Japan is located in the Izu-Honshu collision zone, where the Izu Bonin arc on the Philippine Sea plate has been colliding to Honshu Island on Okhotsk and Amour plates. Several tectonic faults have been developed in the region and the seismicity is very high. Most earthquakes in the region have reverse-faulting focal mechanisms, which is consistent with the collision. An earthquake cluster activity took place beneath the Tanzawa Mountains region with a depth of 20 km in the end of January, 2012. Japan Meteorological Agency (JMA) determined hypocenters of 76 earthquakes with M > 2 in the area within two days on January 28 and 29. Five of them had magnitudes greater than 4.0 and the largest one was 5.4. We relocated hypocenters by using the double difference method (Waldhauser and Ellsworth, 2000) and found their migration from the hypocenter of an earthquake with M4.9 at 0739am on January 28 (JST, 2239pm UT on January 27). We then analyzed stress drops of 17 earthquakes with M > 3.5 that occurred from January, 2000 to June, 2012 in the area of the activity. We calculated empirical Green's functions from waveforms of earthquakes with magnitudes of 3.0 to 3.2 and estimated stress drops of the earthquakes assuming that the source spectra can be expressed as the omega-squared model. We found that earthquakes of the cluster activity in January, 2012 had smaller stress drops by an order of magnitude than the values of earthquakes that occurred in the same area before the activity. This result would suggest that the fluid increased the pore pressure and triggered the cluster activity, which is consistent with the migration of hypocenters.

S101PS.19

S101PS - Seismological Observation and Interpretation

Poster

Seismo-acoustic array for seismic monitoring of NPP at a platform territory

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Safety standards provide seismic and geodynamic monitoring of seismic and geophysical conditions in the local area around the nuclear power plants (NPP) both during the periods of their erection and exploitation. Considering the magnitude repeat function, we estimate probability of earthquakes of different energy that can be registered within 1 year in the area of NPP. For East-European Craton (EEC) it is about 6 with 0 magnitude and more then 60 with -1 magnitude. Such earthquakes have the name «instrumental earthquake», as they are recorded and processed only by high precision digital equipment. Highly sensitive seismic observation tools allowed EEC to be considered as low seismic activity territory, as weak events are quite frequent here. But necessity in registering and locating the source of weak signals with max precision makes serious constraints on the apparatus and methods of seismic monitoring - in particular where seismic monitoring is performed in the areas with thick sedimentation masses under a significant anthropogenic bondage. For this purpose, instead of using a net of single stations it is proposed to make use of small-aperture seismic array having a set of advantages. For example, it allows much better detection and location of weak signals. We jointly install a nine-element 1-km aperture seismo-array with three acoustic-elements. This array are used during the monitoring of NPP to identify and locate events associated with industrial blasting and week local events. We compare the seismic data processing results and regularities revealed during the analyses with the data obtained from satellite image interpretation of fault structures. The results confirm most small and micro-earthquakes locate in the fault zones and zones of «dynamic influence of faults».

S101PS.20

S101PS - Seismological Observation and Interpretation

Poster

Seismicity and seismogenic structures in Central Italy: new insigths from the SLAM passive experiment

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We investigate the background seismicity of Central Italy in the area including southern Latium, Abruzzi and Molise (SLAM project). Within this region, the central Apenninic chain has been historically affected by many strong earthquakes, some of them very destructive such as the 1349 event (Mw ~6.7) located at the border between southern Latium and western Molise, the 1654 event (Mw ~6.4) in the southern Latium-Abruzzi area, and the 1805 Boiano earthquake in the northern Matese range (Mw 6.7). The last important seismic sequence occurred in May 1984 in the Comino Valley, southestern Latium (Mw 5.8). The recent activity is characterized by diffuse low-magnitude seismicity, punctuated by localised small sequences during 2009-2012. Our study focuses on the analysis of seismicity recorded in the period 2009-2013. We present earthquake locations and focal mechanism solutions obtained by standard procedures and an optimized regional 1D velocity model based on the Velest algorithm. The waveform data set was collected from the digital recordings of the permanent stations of the Italian national seismic network, the Abruzzi and Molise regional seismic networks, and from a dense seismic survey carried out in the region between November 2011 and May 2013. The temporary network consisted of 17 three-component seismic stations all equipped with Reftek RT130 digitizers and Lennartz 3D/5s sensors. The deployment of this array improved significantly the detection and location of background seismicity. We relocated more than 4300 events with magnitude ML ranging from about 0.5 to 4.2. Earthquakes distribution shows hypocentral depths concentrated within the upper crust, between 2 and 20 km of depth, and is mostly clustered along the Apenninic chain axis. The computed fault-plane solutions generally display normal fault mechanisms, confirming the extensional NE-SW processes active since Pleistocene in the study region.

S101PS.21

S101PS - Seismological Observation and Interpretation

Poster

Time dependent changes of pore pressure before and after the 2011 Tohoku earthquake

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Changes in well water level, streamflow and chemical composition changes of ground water accompanied by earthquakes have been widely observed. Groundwater monitoring is especially important for understanding of mechanism of earthquake-related change. We are monitoring continuous pore pressure and atmospheric pressure with a recording interval of 1 second at the Kamioka mine, Gifu Prefecture, central Japan. Pore pressure decreased after the 2011 Tohoku earthquake (M 9.1) on 11 March. In general, causes of the pore pressure changes include meteorological effects, Earth tide and crustal deformation. Here, we focused on the Earth tide response before and after the earthquake. The observed data during the period from April 2005 to December 2011 were divided into time windows of one month (744 hour). The tidal analysis program, BAYTAP-G (Tamura, 1995) is used to extract tidal responses of pore pressure from the divided data. Amplitudes of M_2 and O_1 components decreased after the Tohoku earthquake, which can possibily be due to: (1) the increase of the permeability (2) the elastic coefficient change of the rocks. We estimated the hydraulic diffusivity supposing that the cause of the tidal amplitude change is the increase of the permeability. This yields an increase of the diffusivity from 0.03m^2/s to 0.09 m^2/s. Increase of the hydraulic diffusivity is consistent with pore pressure reduction. But in actually, the effects of the elastic coefficient changes of the rocks cannot be excluded. We analyzed the data before and after the 2007 Noto Hanto Earthquake (M6.9) and apparent amplitude changes cannot be detected. These results imply that only large deformations caused by very large earthquakes, such as the Tohoku earthquake, cause changes of the hydraulic diffusivity and the elastic coefficient.

S101PS.22

S101PS - Seismological Observation and Interpretation

Poster

Re-examination of large 20th century earthquakes along the southern Japan trench -The 1927 and 1953 off Boso earthquakes

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We re-examine hypocenters, focal mechanisms and fault models for large earthquakes off Boso region along the southern Japan Trench. The relocated epicenter of the 1927 Boso earthquake, from newly collected S and S-P times, is about 100 km to the west of that of Japan Meteorological Agency (JMA). Off Boso, several large earthquakes (e.g., the 1953 Boso earthquake) and tsunami earthquakes (e.g., the 1677 Empo earthquake) have occurred, but their recurrence periods are not well known. Two earthquakes, one on August 18, 1927 with *M*jma 6.9 and *M*t 7.4, and the other on November 25, 1953 with *M*jma 7.4 and *M*t 7.8, have different epicenters and tsunami source areas. While the 1927 epicenter was located southeast of the 1953 epicenter, the 1927 tsunami source was estimated northwest of the 1953 tsunami source (Hatori,1975). We identified the locations of tide gauge stations in 1920's, and recalculated the tsunami travel time. The tsunami source area was located a little southwest of that of Hatori (1975). To relocate epicenter, we collected seismic waveforms and original arrival time reports from the local meteorological observatories of the 1927 earthquake, and re-examined those S-P times. At some observatories, the value reported as a preliminary tremor in 1927 was not S-P but L-P time. Even if there were no report from a local meteorological observatory, there were some observatories where seismic waveform records remain, and P and S wave arrival times were written on them. Re-examined S-P time distribution of the 1927 earthquake looks similar to that of the 1953 earthquake. The 1927 epicenter is estimated at 141.7°E and 34.2°N, while that of JMA (2004) is 142.4°E and 33.8°N. The 1953 epicenter by JMA is 141.4°E, 34.2°N.

S101PS.23

S101PS - Seismological Observation and Interpretation

Poster

Rupture characteristics of the MW7.9 Wenchuan earthquake of 12 May 2008 as revealed by the relocated main shock and major aftershocks

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The main shock with MW7.9 and major aftershocks with magnitude MS5.0 and larger of Wenchuan earthquake of 12 May 2008 were relocated using the data recorded by the China Digital Seismic Network (CDSN), the Sichuan Digital Seismic Network (SDSN) and Zipingpu Reservoir Seismic Station. The relocated precise hypocenters have average errors about 0.5 km in horizontal directions and about 1 km in focal depth direction. The hypocentral distribution and the focal mechanisms of the relocated major aftershocks have consistently showed complexities of the geometry of the rupture surface of the Wenchuan earthquake and clearly indicated that the major aftershocks of the earthquake mostly occurred at the lower periphery of, and the gap between the two substantial slip-concentrated pitches just underneath the two meizoseismal areas, Yingxiu-Dujiangyan-Wenchuan and Beichuan areas, respectively, as revealed by the inversion of source rupture process of the main shock. The complementary pattern of the main shock rupture areas and the major aftershock areas of the great Wenchuan earthquake implied that complete moment released occurred in the substantial slip-concentrated pitches and that the occurrences of the major aftershocks were the delayed rupture process spreading on or near the fault-plane of the main shock.

S101PS.24

S101PS - Seismological Observation and Interpretation

Poster

3D velocity structure of upper crust beneath NW Bohemia/Vogtland

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The 3D structure of the upper crust beneath west Bohemia/Vogtland region, analyzed with travel time tomography and ambient noise surface wave tomography using existing data. This region is characterized by a series of phenomena like occurrence of repeated earthquake swarms, surface exhalation, CO_2 enriched fluids, mofettes and has been proposed as an excellent location for an ICDP drilling project targeted to a better understanding of the crust in an active magmatic environment. We performed a 3D tomography using P-and S-wave travel times of local earthquakes. The data set were taken from permanent and temporary seismic networks in Germany and Czech Republic, as well as active seismic experiments. A simultaneous inversion of P and S wave 1D velocity models together with relocations of hypocenters and station corrections was performed. The obtained minimum 1D velocity model was used as starting model for the 3D Vp and Vp/Vs velocity models. Then Vp and Vp/Vs in the 3D grid model have been determined. We observed lower Vp/Vs ratio in depth of 5-10 km close to the foci of earthquake swarms and higher Vp/Vs ratio is observed in Saxoturingian zone and surrounding area. Surface wave tomography using ambient noise provides additional constraints on shear wave velocities. We use the vertical and transverse component ambient noise data to estimate both Rayleigh and Love waves from ambient noise cross-correlation waveforms to investigate the crustal seismic structure of W-Bohemia/Vogtland. More than 2000 Rayleigh and Love group-velocity dispersion curves are obtained by time-frequency analysis of stacked ambient noise cross-correlation functions between station pairs.At each period between 1 and 10 s, group velocity maps are constructed, all corresponding to different sampling depths, and thus together giving an indication of the 3D shear wave velocity structure extending to a depth of about 15 km.

S101PS.25

S101PS - Seismological Observation and Interpretation

Poster

Seismic activity of Tokyo Metropolitan area and the subducted plate under Japanese islands

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The Japanese government has estimated the probability of earthquake occurrence with magnitude 7-class in Tokyo Metropolitan area during the next 30 years as 70 %. This estimation is based on five events that occurred in this area in the late 120 years. The estimation, however, has not been sufficient because of the peculiarity of this region that it is laying on more complicated tectonic condition than other subduction zones in world. There are two subducted plates beneath this area. The various types of earthquakes occurring there had not yet been revealed that by which plates each earthquakes are affected and where does the interaction of the plates exists. Therefore, it is necessary to reveal precise velocity structure and to classify these earthquakes into inter-plate earthquakes and intra-plate ones. Then, we have been constructing a seismic observation network since 6 years ago. Tokyo Metropolitan area is a densely populated region of about 40 million people. It is the center of Japan both in politics and in economy. Human activities have been conducting quite busily; this region is unsuitable for seismic observation. Then, we have decided to make an ultra high dense seismic observation network. We named it the Metropolitan Seismometer Observation Network; MeSO-net. MeSO-net consists of 296 seismic stations. Minimum interval is about 2km and average interval is about 5km.We picked the P- and S-wave arrival times manually. We applied double-difference tomography method to the dataset and estimated the velocity structure. We depicted the plate boundaries from the newly developed velocity model. And, we referred to the locations of the repeating earthquakes, the distributions of the hypocenters and the focal mechanisms. Our plate model became relatively flat and a little shallower than previous one.

S101PS.26

S101PS - Seismological Observation and Interpretation

Poster

Development of a short-span strainmeter for observation of deformation associated with deep low-frequency tremors

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Crustal deformations, such as strain and tilt changes, have been observed associated with deep low-frequency tremors occurring below the Kii peninsula and Shikoku. Strain measurements by an extensometer at Kishu operated by DPRI, Kyoto University, for example, show that the closer sources with epicentral distance of 30 - 40 km, have large deformations with strain changes of 10-9 to 10-8 occurring within several days. Although the traditional extensometer observations can these detect strain changes, it is difficult to make interpretations because of the limited number of stations An instrument that is inexpensive and is easy to install will make possible strain array observations. We designed a short-span extensometer that is 1.5 - 2 m-long measure. The measure is made from a metal with a small temperature expansion constant and hanging by a thin string at one end. A linear variable differential transformer (LVDT) is used to detect displacement. Strong coupling of the instrument to the ground is important for stable observations, so three anchor bolts fixed to the base of the instrument are cemented into a 30-cm-deep hole. As a test example, we constructed a one component short-span extensometer and installed it in a tunnel of Donzurubou observatory, Nara prefecture. Earth tides and strain oscillation caused by a teleseismic event are clearly observed by the short-span extensometer. We expect that the crustal deformation associated with deep low-frequency tremors can be observed by an array of these short-span extensometer, that have a length of 1.5-m.

S101PS.27

S101PS - Seismological Observation and Interpretation

Poster

CEN-ION: The Central Ionian (Greece) Seismic Network and Microseismicity Monitoring

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The area of central Ionian Islands, namely Lefkada and Kefalonia, constitutes the most active zone of shallow seismicity in the Aegean and its surroundings. The 2003 Lefkada seismic sequence provided for first time the proper data for a detailed look at the properties of the dominant rupture system, as well as on the activation of secondary structures capable to produce additional and severe damage, thus posing significant seismic hazard. A portable seismic network was deployed in the study area consisting of seven 3-component digital stations equipped with broad-band (30s) and short period (1Hz) sensors, all equipped with GPS antenna for timing. These stations operate in continuous mode since the middle of 2007 with a sampling rate of 125 samples/sec. The spacing between stations varies between 5 to 10 km, to monitor microseismicity at a low detection threshold and allowing accurate earthquake locations to obtain accurate microseismicity locations, which in turn is exploited to reveal properties of smaller localized active structures and the large-scale crustal faulting. The microseismicity substantially agrees with the historic seismicity and delineates a relatively narrow, major zone of activity that extends along the western coasts of both Islands. Cross sections were used in order to provide a detailed characterization of the microseismicity and a high-resolution picture of the seismically defined structures. The yielding location improvement contributes to the geometry identification of the active structures, which were previously obscured by location errors. Our results evidence the contribution of the CEN-ION comparatively dense seismic network, which was designed and installed at this specific area, for studying microseismicity and revealing the identification, geometry and kinematic properties of local but important active structures, which constitute a critical input for the study area seismic hazard assessment.

S101PS.28

S101PS - Seismological Observation and Interpretation

Poster

The 28th november 2005 mb=6.2 earthquake in qeshm, South Iran

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Recently the seismic activity in south east extension of Zagros has been increased, remarkably. Among the several significant earthquakes, several in Qeshm island about 57 km southwest of Bandar Abbas. In this paper, the geology including detailed fault map and the seismicity including teleseismic and locally recorded earthquakes during the past 100 years are presented. Focal mechanism of strong earthquakes were determined and discussed with the stress field in the region. The earthquakes are shallow indicating that seismogenic layer in this island has a thickness not larger than 20 km. On 27th November 2005 an earthquake with Mb=6.2 in west of Qeshm about 57 km southwest of Bandar Abbas and produced damage and destruction in the area. The mainshock was followed by considerable aftershock. We discuss the source parmeters of the mainshock and aftershock sequence and present a risk analysis in the region.

S101PS.29

S101PS - Seismological Observation and Interpretation

Poster

Source characteristics of recent destructive earthquakes in Kerman province, South East Iran

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Kerman region is surrounded by the depressions of Great Kavir in north and Lut in east, and Zagros ranges in the south and west. The major Quaternary faults in the area are Kuhbanan fault with northwest-southeast direction and Nayband fault with a length of 400 km and north-south trend. In contrast to the Zagros seismically active zone where no apparent surface fault trace is observable following even a large earthquake, in Kerman region, strong earthquakes are often associated with well recognizable surface faulting. During 1981-2005 several destructive earthquakes caused extensive damages and heavy human loss. Among them, the 2003 Bam earthquake with magnitude 6.5 killed more that 40,000 people and was one of the natural disasters in the world. In this paper, the observed teleseimic bodywaves in GDSN stations from five earthquakes, with magnitudes greater than 6.5, are modeled in order to investigate the source characteristics. The results of the field and seismological investigations as well as the out comes of aftershocks activity are used as supplementary information to constrain the source parameters. The results of waveform modeling indicate that the majority of these earthquakes are multiple events and have complex source process. Directivity produces high intensity and great destruction, during the source process. The fault system in this region is also complex, following a combination of reverse and strike-slip faulting. There is evidence that the occurrence of a significant earthquake might affect the stress field in the region and play some roles in the future seismic activity. Finally, the results of this study are compared and discussed with the results of other studies.

S101PS.30

S101PS - Seismological Observation and Interpretation

Poster

Rupture characteristics of the 2006 Silakhor earthquake in Lorestan region in Iran

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Iran is located in a complex tectonic area, where continental shortening takes place due to the collision of the Arabian and Eurasian plates. This Arabia-Eurasia Convergence occasionally causes destructive earthquake such as the Silakhor Earthquake in Zagros suture zone, in between Drood and Brujerd cities in Lorestan province, producing extensive destruction but relatively low rate of human loss. The March 31 2006 Silakhor Earthquake, with a magnitude of Mw=6.2, occurred on Friday at 4:47:03 local time near the village of Chalan-Cholan in Lorestan province. It was preceded by two large foreshocks with magnitudes of Mn = 4.7, 5.2 and followed by two relatively large aftershocks of Mn=4.9 and 5.3. The Silakhor plain was seriously affected in earthquake: about 70 people were killed and more than 2000 were injured. More than 30 foreshocks and many aftershocks were recorded in the Silakhor. Earthquake. Such extensive foreshock- mainshock -aftershock sequences for an earthquake of moderate. magnitude (Mw = 6.2) is unusual. In this research, we determine of source parameters and rupture characteristics of the 2006 Silakhor Earthquake in Lorestan region. By using empirical green function, strong ground motion is modeled. One of the important methods for strong ground motion modeling, is the use of aftershocks as green function for earthquakes. All seismic stations that recorded Silakhor earthquake are located at a distance of at least 100 kilometers from the epicenter. The region in this study enclosed between 48.4 to 49.2 east longitudes, and 33.3 to 34 north latitudes. The focal mechanism of the main shock was determined by using the polarity data of the first arrival waves in the seismic stations. The mechanism for the mainshock was obtained as Strike/Dip/Rake = 310 , 46 , 171 .

S101PS.31

S101PS - Seismological Observation and Interpretation

Poster

Post seismic activity in Rudbar region, NW Iran, revealed by local seismic network

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On June 20, 1990 at 21:00:10.9 GMT a shallow destructive earthquake with Ms=7.3 occurred in Rudbar, northwest Iran. The maximum intensity was X and more than 40,000 people were killed. The activated fault consists of at least three main NW-SE trending discontinuous left-lateral fault segments, extending for more than 80 km. In this study, the seismicity of Rudbar region is investigated by using data from the national seismic network and we present the post seismic activity in Rudbar by analazing the earthquakes recorded by local seismic network during the past 22 years. The epicentral distribution of the 1990 Rudbar aftershocks suggests a fault length about 90-110 km. Rupture during the 1990 Rudbar mainshock initiated near the northwestern end of the activated fault and extended to southeast in a unilateral manner. The frequency and the magnitude diagrams as well as the epicentral distribution of aftershocks and the earthquakes that have been located in Rudbar region, untill now, all indicate that the seismic activity in the south east extension of Rudbar is significant. Thus, the occurance of a destructive earthquake in this area is not out of expectation.

S101PS.32

S101PS - Seismological Observation and Interpretation

Poster

Crustal structure of Southeast of Caspian Sea, North of Persia, using local seismological network data

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This paper is concerned with the southeast of Caspian Sea micro-seismicity kinematically. This area covers eastern Alborz, eastern part of Caspian Fault, the northern flat at northeast of Alborz and eastern part of Kopeh-Dagh which are Persian Seismotectonics provinces. The Alborz Mountains, as a folded and faulting region, is a seismically active area of crustal shortening in Iran. Strong seismicity at the area could be identified by the October 29th, 1985, Gorgan earthquake (MS=6.0), 2004 (mb=5.6) and 2005 (mb=5.2) earthquakes. Due to lack of seismological data and without any fault outcrops in southeast Caspian Sea, little is known about seismotectonics and the crustal structure of the area, therefore a micro-seismological study was necessary in the research area for recognition the sub-surface tectonics. To look for the details of the micro-seismicity of the studied area, data combination of a local network (9 months in 2009-2010) owned by Geological Survey of Iran and regional networks of Geophysics Institute of University of Tehran and International Institute of Earthquake Engineering and Seismology of Iran were used. Data processing provided us a Vp/Vs ratio about 1.7 and a 4-layer crustal velocity structure. Inverting the travel times data concluded a P wave velocity range from 6.0 km/s related to the surface to 6.7 km/s at 24 km depth. The velocity model and micro-earthquakes depth distribution suggest 6 km for sedimentary cover width, 20 km for upper and lower crystalline crust boundary and 24 km width for seismogenic layer. Although the seismicity dispersal show seismic activity of the Shahroud fault system in eastern Alborz, it has less association with the Caspian fault, rather it makes a NNW-SSE lineament at the northern flat of Gorgan city in northeast Alborz. Maybe shallow seismicity is related to Karnaveh fault system (from Kopeh-Dagh) and deep seismicity occurred following changing the stress field caused by 2004 and 2005 earthquakes.

S101PS.33

S101PS - Seismological Observation and Interpretation

Poster

Evidence for a causative fault for the August 11, 2012 Ahar-Varzaghan earthquakes using nonlinear earthquake relocation

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On August 11, 2012, two middle-sized earthquakes (Mw = 6.5, Mw = 6.3) occurred in East Azerbaijan Province, Northwest of Iran within 11 minutes. After these earthquakes, a lot of aftershocks occurred in the area, which caused major damage to the villages and near cities and killed more than 400 people. Ahar Area had not experienced any remarkable historical or instrumental earthquake to date; therefore, it has not been associated with any major fault, therefore, finding evidence for a causative fault was the main reason of this study. To investigate the information on a causative fault, we relocated aftershocks using the NonLinLoc algorithm. In this algorithm, the location of an earthquake is defined using Probability Density Functions (PDF) of all possible points around the hypocenter.

Our data covered aftershocks occurred between August 4 and October 11, 2012 i.e. one week before the first mainshock and one month after that. Around 420 aftershocks with magnitudes larger than 2.5 were recorded by Iranian Seismological Center (IRSC). Furthermore, to increase the network coverage on our study region, we added three broad-band stations of the International Institute of Earthquake Engineering and Seismology (IIEES). We used a 1D P and S-velocity model as a presumed model in NLL re-location process.

Our results showed a strong correlation between the number of phases used to relocate and locate errors. This proved the efficiency of adding IIEES stations to the IRSC dataset. Relocation results showed a considerable improvement on the IRSC results especially on depth and approved the existence of two different mechanisms on Ahar sequence. Epicenter and focal depth uncertainties of the results were mostly less than 3 km.

Keyword: Ahar, aftershocks, nonlinear algorithm, relocation.

S101PS.34

S101PS - Seismological Observation and Interpretation

Poster

Triggering sequence of seismicity by dynamic stress changes from the 2011 Mw 9.0 Tohoku-Oki earthquake

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Increases in seismicity have been widely observed at varying distances from the source area following large earthquakes. This study reports remote triggering over Japan by the 2011 Mw 9.0 Tohoku-Oki earthquake.

Early post-seismic events triggered by the Tohoku-Oki earthquake are detected by using a high-pass filtering technique. These events systematically propagated over Japan in a southwestern direction, associated with the large seismic waves from the source. The propagation front was consistent with the arrivals of large amplitude surface waves traveling at 3.1 to 3.3 km/s and extending to a distance of 1,350 km. Triggered events include volcanic earthquakes, shallow tectonic earthquakes, intra-plate earthquakes, and non-volcanic tremor. Static stress changes were one to two orders smaller than dynamic stress changes at remote distance, indicating that static stress was not the main mechanism of the triggering. The value necessary for the dynamic triggering is more than about 500 kPa in stress or about 10^{-6} in strain. The early post-seismicity has a different spatial pattern compared to the later post-seismicity that occurred across Japan over the next days to weeks.

Also it is examined to detect seismic events triggered by the first arriving P-wave that preceded triggering surface waves. During the arrival of P-waves, both the P-waves and triggered events are in the high-frequency range, therefore a spectral method is used. This method uses a reference event to correct for source and propagation effects, so that the local response near the station can be examined in detail. P-wave triggering was found in the regions, where non-volcanic tremor was been observed triggered, and some seismic and volcanic regions. The triggering strain due to P-waves is of the order of 10^{-8} to 10^{-7}, which is 1 to 2 orders of magnitude smaller than the triggering strain necessary for the surface wave triggering.

S101PS.35

S101PS - Seismological Observation and Interpretation

Poster

Microseismicity preceding the 2010 Eyjafjallajökull flank eruption

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We have used an automated coalescence microseismic mapping (CMM) technique to locate ~20,000 microearthquakes that occurred in the two weeks prior to the March 2010 eruption of Eyjafjallajökull volcano in Iceland. These earthquakes are attributed to melt movement in the subsurface as the volcanic edifice inflated, which can be seen in geodetic measurements over the same time period. P and S arrival times have been manually refined for 964 of these events, which were then relatively relocated. To first order, seismic activity migrated eastwards toward the site of the flank eruption at Fimmvörðuháls (on 20 March 2010). The majority of earthquakes are located in tight spatial clusters at 3–5 km depth under the east flank of the volcano. These clusters are vertically elongated over a 1–2 km depth range and are suggestive of magmatic conduits. However, we show using synthetic tests that the morphology of these clusters could be generated solely by a small amount of random error in the time picks. Furthermore, groups of events in several clusters display almost identical waveforms and the same pattern of P-wave first-motion polarities at all stations, which suggests closely similar earthquake source mechanisms. In fact, for several clusters, the cluster's apparent elongation cannot be distinguished confidently from a single repetitive earthquake source in each case. We interpret the pattern of seismicity as relating to constrictions to magma flow as a sill was inflating beneath the flank of the volcano. Such constrictions may represent pressure valves or 'trapdoors' between compartments of the sill in which magma flow was aseismic.

S101PS.36

S101PS - Seismological Observation and Interpretation

Poster

Spatiotemporal properties of the 2011 Oichalia seismic swarm, SW Peloponnese, Greece

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During the time period August - December 2011, a seismic swarm took place in the area of Oichalia, north Messinia province, at the southern part of Peloponnese. The largest earthquakes occurred in 14/8/2011 (Mw=4.8) and 10/10/2011 (Mw=4.7), followed by a large number of aftershocks. The shallow seismic sequence composed of over 1700 events and was studied using data from local temporary and regional permanent seismic stations to investigate the fault geometry, stress field, evolution of seismicity and seismic properties. Data were analyzed in terms of manual arrival-time picking and the earthquakes were located with the HYPOINVERSE algorithm, using a custom local velocity model, calculated with an iterative error minimization procedure. Hypocentral solutions were further improved by applying the double-difference algorithm (HypoDD). Focal mechanisms were obtained by both regional moment tensor inversion and P-wave first motion polarities. The relocated seismicity forms a band as narrow as 3 km (measured approximately E-W) beneath the central part of the surface rupture, less than half as wide as that from catalogue locations, with an average depth of 8.7 km Both spatial distribution of the seismicity and focal mechanisms show that the re-activated fault is a dip-slip normal fault trending NNW-SSE and dipping ~50°;WSW. The average T axes orientation is N70°E. The above observations are compatible with the orientation of ground cracks observed in situ surveys. The temporal distribution of the swarm follows a NNW to SSE direction with time, towards a large seismogenic zone, which was last activated on September 13, 1986, with an Ms=6.0 earthquake. Migration of seismicity may be related to ascend of hydrothermal fluids as evidenced by local seismic tomography results.

S101PS.37

S101PS - Seismological Observation and Interpretation

Poster

Constraints and/or *a-priori* information used in local earthquake (LE) tomography

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LE tomography is today a standard method for deriving images of the subsurface. In e.g. volcanic regions with ample seismicity it is often the method with the potential to deliver images with the highest spatial resolution. Given that the seismicity rate is high, the method also has the potential to track changes in physical properties and state variables with time in regions of the model. Bedevilling the method, among other things, are errors associated with the uncertainties in determining source locations. The location strategy in standard LE applications utilizes single event location techniques that often result in standard errors larger than the cell dimensions in the velocity inversion. It is well known that by using e.g. cross-correlation techniques of waveforms from closely spaced events the (relative) event location errors may be drastically reduced. This is utilized in e.g. double difference tomography, claiming improved velocity images as a result of the improved event locations. In this presentation we compare different location strategies in LE tomography, including different applications of difference operators and a maximum-likelihood application. The results for both the event locations and the derived velocity reconstructions are compared with results obtained from tomography with "standard" event locations. The tests are carried out primarily on synthetic models and data. It turns out that the results are strongly dependent on the characteristics of the noise that is added to the data. The different strategies are also applied to real data from a volcano-tectonic region.

S101PS.38

S101PS - Seismological Observation and Interpretation

Poster

Seismic activity near the Moriyoshi-zan volcano in Akita Prefecture, northeastern Japan, possibly driven by geofluid

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The great 2011 Off the Pacific coast of Tohoku Earthquake brought increased seismicity in many areas apart from the source fault, for example, in Akita prefecture in the Japan Sea side of Tohoku district. Seismic activity near the Moriyoshi-zan volcano in the area is quite interesting in the light of contribution of geofluid, because we observe migration of seismicity, reflected/scattered phase, and deep low-frequency earthquakes. Seismic activity in the most active cluster with a dimension of about 3 km both horizontally and vertically shows clear migration, however, the direction and speed are variable. The activity started near the center in the horizontal location, then migrated to the northeast, and jumped to the west, and migrated again to the south and to the north. This complex pattern suggests repeated injection of geofluid from the bottom of cluster. A prominent reflected/scattered phase observed at a station to the west of cluster supports the idea of geofluid contribution. The time interval between this later phase and S wave depends on the hypocenter location, suggesting gently dipping zone of scattereres to the west. The westward bottom of reflector/scatterers is close to the upper limit of low-frequency earthquakes occurring in a depth range from the lower crust and uppermost mantle. The low-frequency earthquakes that occur well below the elastic plastic boundary are interpreted as the events generated by the activity of geofluid. Thus, a possible scenario is that the geofluid in the upper mantle ascended vertically accompanying low-frequency earthquakes, then built up in the middle crust forming a zone of reflector/scatterers, and finally, induced by the Tohoku Earthquake, intruded into the upper crust causing seismicity with complex migration pattern.

Acknowledgements: We used arrival time data of the JMA catalog. We thank the NIED and Tohoku University for providing waveform data. This work was supported by JSPS KAKENHI Grant Number 21109002.

S101PS.39

S101PS - Seismological Observation and Interpretation

Poster

Results of measurements of non-seismic reversible geodeformations

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In 2002, Kazusige Obara has published results of a study of slow earthquakes. But Kapochkin B.B. information about the existence of this type of movement published in 1998 as a result of destruction of engineering structures. Later non-seismic deformation with an amplitude more than 10 cm and duration of up to several tens of hours confirmed by measurements: mariograph coastal stations, satellite altimetry, the measurement data of the permanent GPS networks, broadband seismograph, satellite interferometry data, sensors of registration system tsunamis and recorded on video. Character of movements, their causes and destructive properties are published in four monographs. Investigated the destructive impact of these deformations on the different types of engineering structures. Installed the connection of these deformations with earthquakes. Earthquakes and non-seismic deformation change each other in time with periods of 3.5, 7, 14 days. This type of deformation is typically formed in non-seismic areas. Deformation with an amplitude of 30 cm and a period of 5 -10 seconds are fixed in the video in April 2011 in Japan after the catastrophic earthquake on March 11. The conclusion about the nature of the transformation of non-seismic deformation to the earthquake when the state of the earth's crust changes. The causes deformations - the processes of global scale. The data confirm the activity relationship of these deformations with the change of the planet Earth. The connection periodic geodeformations with two week cycle of angular velocity of the Earth. The deformations are local.

S101PS.40

S101PS - Seismological Observation and Interpretation

Poster

Mapping crustal heterogeneity using Lg-wave 2D Q-tomography around the Alborz region

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Regional variations of seismic attenuation in the Alborz region, north and northwest Iran, has been estimated using Lg waves. The study region constitutes a part of northern margin of Alpine-Himalayan seismic belt. The northern limit of the Alborz region is defined by the stable South Caspian Block.
The dataset consist of vertical component seismograms from local and regional events occurred during the period of 2006-2013 with epicentral distances larger than 100 km recorded at over 90 seismic stations that are evenly distributed throughout the entire region. The data were processed using a stack spectral ratio method to obtain Q0 (Q at 1 Hz) and frequency dependence of each ray path between different station-event pairs. Stable single-trace measurements of Lg coda Q were then used to produce 2D tomographic map using back-projection technique. The final resulting map was also implemented to regionalize large-scale lateral variations of coda Q for Lg waves. Our final results indicate that large-scale lateral variations of Lg coda Q were found to correlate well with major tectonic features of the study area. Most of the Alborz region is tectonically active, and like other tectonically active regions, has relatively low or moderate coda Q values. South Caspian Block showed higher code Q value indicating the most stable block within our study area. The lowest values of coda Q are associated with the east Turkey. The lateral variation of frequency dependence of Lg coda Q correlates, in most regions, with that of Q at 1 Hz. Our investigations indicate that the resolving power of Lg coda Q imaging is controlled mostly by the trade-off between the stability and the spatial resolution of the coda Q inversion.

S101S1.01

S101S1 - Seismological Observation and Interpretation

Oral

Developments at the ISC: ISC-GEM Catalogue, Bulletin Re-Build and Event Bibliography

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The International Seismological Centre (ISC) is a non-governmental non-profit making organization funded by 62 research and operational institutions around the world and charged with production of the ISC Bulletin – the definitive summary of the global seismicity based on reports from over 130 institutions worldwide. Jointly with NEIC, the ISC runs the International Seismic Station Registry (IR). The ISC provides a number of additional services including the depository of the IASPEI Reference Event list (GT), EHB and ISS data. The ISC assists to the IRIS DMC in providing waveform data for specific seismic events.

The ISC has a substantial development programme that ensures that the ISC data remain an important requirement for geophysical research. We modernized the ISC event location and magnitude computation procedures. We are working on the project of re-building the entire ISC Bulletin (1960-2010) by re-computing the hypocenters and magnitudes with the new location algorithm using ak135 velocity model, identifying and filling the gaps in data, correcting known errors and introducing essential additional bulletin data from temporary deployments. The ISC took a leading role in compiling the ISC-GEM Instrumental Seismic Catalogue (1900-2009) that is now available from the ISC website. The ISC is also planning to provide a new interactive service where users would be able to download references to scientific publications related to specific seismic events in the area of interest.

S101S1.02

S101S1 - Seismological Observation and Interpretation

Oral

Recent developments in the ISC location procedures

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The new location algorithm developed for the International Seismological Centre (ISC) has been operational since January 2011. By providing improved hypocentre and magnitude estimates, the ISC locator has increased the efficiency and productivity of the ISC review process to generate the reviewed ISC bulletin. The second release of the ISC locator represents major improvements in speed and facilitates multicore processing. To support the validation of travel-time predictions from 3D velocity models, the ISC has developed a version of the ISC locator that accommodates local and regional travel-time predictions provided by the Regional Seismic Travel Time (RSTT) software package developed by the US DoE National Laboratories. Both the standard and the RSTT-enabled ISC locator can be downloaded from the ISC website.

In order to produce a homogeneous bulletin of the seismicity of the Earth spanning 50+ years, the ISC has launched an effort to rebuild the entire ISC Bulletin. This not only includes relocating events with the new ISC locator, but also the addition of data sets, both from permanent and temporary networks, that were not available at the time when a particular monthly ISC Bulletin was published. We anticipate that the rebuild of the ISC Bulletin will have been completed by 2014.

S101S1.03

S101S1 - Seismological Observation and Interpretation

Oral

Teleseismic detection and measurement of catastrophic landslides

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Catastrophic landslides involve the sudden acceleration and deceleration of millions of tons of rocks and debris in response to the forces of gravity and dissipation. Their unpredictability and frequent location in remote areas have made observations of large landslide dynamics very rare. In this work we show that routine monitoring of the global long-period seismic wavefield regularly detects and locates massive landslides with long-period surface-wave magnitudes around 5.0. Inverse modeling of the teleseismic data in terms of a time-varying force vector acting on the surface of the Earth leads to the determination of a landslide force history (LFH), which, by Newton's third law, provides a remote means of inferring the momentum change of the landslide mass. Augmented by geometric constraints obtained by satellite imagery, the seismically determined dynamic parameters of the landslide can be used to infer mean landslide mass and runout trajectory. We have carried out seismic inversions of 29 landslides and the aggregate results reveal multiple scaling dependencies among inferred dynamic properties, such as maximum force, duration, and energy. The scaling is consistent with a simple model of landslide acceleration in which the height drop and slide depth scale linearly with the length of the failing slope. The results also suggest that a rapid estimate can be made of the mean landslide mass from the long-period surface-wave magnitude alone.

S101S1.04

S101S1 - Seismological Observation and Interpretation

Oral

Location of immediate aftershocks using seismogram envelopes as templates

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Though the location of immediate aftershocks is very important because the number of aftershocks decays exponentially, it is difficult due to coda wave of mainshock and successive occurrence of afterrshocks. Here we propose a new method of location using seismogram envelopes as templates. The method composes of two processes. The first process is the calculation of cross-correlation coefficients between a continuous (target) and template envelopes. We prepare envelopes by taking the logarithm of root-mean-squared amplitude of band-pass filtered seismograms. We perform a calculation by shifting the origin time and corresponding time windows to obtain a set of cross-correlation values for pairs of (origin time, template). The second process is the event detection. We search for the events in descending order of cross-correlation in a time window excluding the dead times around the previously detected events. At present, we regard template location as the event location. Magnitude is calculated by the amplitude ratio of target and template envelopes. We applied this method to a large inland earthquake with extensive aftershock activity, the 2004 Mid-Niigata Prefecture Earthquake (M = 6.8) in central Japan. During a period of one-hour from the mainshock, we could detect 71 events, which are comparable to the number of the catalog events. We can detect more events by using additional templates. The location of events are generally near the catalog location, however, the magnitude is systematically larger than the catalog value. Though we should develop methods of relative location of events against templates and magnitude estimates, we conclude that the proposed method works adequately even just after the mainshock of large inland earthquake. Acknowledgement: We thank JMA, NIED, and the University of Tokyo for providing arrival time data, and waveform data. This work was supported by JSPS KAKENHI Grant Number 23540487.

S101S1.05

S101S1 - Seismological Observation and Interpretation

Oral

Three-dimensional seismic velocity structure as determined by double-difference tomography in the Emeelt fault

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We focus on the main active seismic zones in the area of Ulaanbaatar which can have the main impact on the seismic risk of the Capital of Mongolia. A seismic activity is taking place near and within Ulaanbaatar area since 2005. The seismicity observed by local permanent network has reveals the significant increase of seismic activity in the Ulaanbaatar area. Twice more earthquakes were recorded during the last 6 years than between 1970 and 2004 in the considering area. These swarms consist of more than 1600 events within magnitude range of 0.5 to 4.2. Most of these events are located close to the 2 major active structures that are NS-Emeelt and EW-Hustai striking faults. This paper discusses some results of the analysis of this high seismic activity recorded by permanent and dedicated mobile networks. For precise study of the seismic activity region, we had installed a number of temporary seismic stations since December of 2008. Double-difference tomography was used to estimate the three-dimensional velocity structures in the Emeelt fault based on the travel time data collected during seismic observation.

S101S1.06

S101S1 - Seismological Observation and Interpretation

Oral

1D seismic velocity model with GT5 events in Brazil and tests of crustal thickness corrections to improve the RSTT Model for Sou

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Good 3D lithospheric velocity models are necessary for reliable epicentre determination. To test different models, we compiled a set of 17 Brazilian reference events, magnitudes 4.0 to 5.1. Only four were truly GT5 events. Most of the events had the epicenter assigned to the middle of the aftershock zone determined by aftershock studies, with origin times calculated with IASP91 table using teleseismic stations. The travel times were normalized to zero depths and compared to some 1D models. The average residuals, up to 1640km, were -2.6s ± 1.9s (for IASP91 model), -1.9s ± 1.7s (Herrin1968), and 0.4 ± 1.5s (Brazilian NewBR). Corrections for crustal thicknesses, using the model of Assumpcao et al.(2012), to a 40 km crust changed the average residuals very little: -2.2s ± 1.9s (IASP91), -1.4s ± 1.6s (Herrin1968), and 0.8 ± 1.3s (NewBR). The raw travel times (uncorrected for event depth and crustal thickness) were compared with the current RSTT model (basically CRUST2.0 in South America) giving average residual of +0.2s ± 1.3s, the smallest of all models. Crustal thickness corrections, while necessary, have limited impact in reducing travel time scatter, and accounting for upper mantle heterogeneities is more important to improve regional travel times in Brazil.

S101S1.07

S101S1 - Seismological Observation and Interpretation

Oral

A new viewpoint to asses earthquake location uncertainties using a non-linear probabilistic method, a case study of NW Iran

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NW Iran and eastern Turkey is one of the most active seismic areas in the world and is the location of a young continent-continent collision zone. This region is so interesting for seismologists because of its complex tectonic, destructive earthquakes and high rate of earthquake occurrences. Relocating earthquakes to find a more accurate catalog is one of the main methods to improve our understanding of the subsurface features such as depth of seismogenic zone, and faults geometry. In this study we present a catalog with significant improvement in accuracy of earthquake hypocenters compared to results routinely produced by global and even local seismic networks. We use a fully non-linear probabilistic method, NLLOC (Nonlinear Location). This method has some advantages compared to linearized methods, i.e. possibility to use 3D velocity models, incorporating the systematic and phase picking errors in computations and giving better estimates of uncertainties in areas with poor distribution of seismic stations. Our database consists of more than 8000 events with M>2.5 between 2006 to 2011. To obtain a more homogenous event catalog, we considered different conditions to filter out the data. In addition we developed a new method to evaluate hypocentral uncertainties using information available in PDFs (probabilistic density functions). The synthetic tests show that our new hypocenter uncertainties are more accurate and closer to «real errors». Our results show that the horizontal error of 45% of relocated events (about 3600 events) is less than 6 km and the vertical uncertainties associated to 60% of all events (about 4800 events) is less than 10 km. The majority of earthquakes are relocated within the upper crust and there are no events deeper than Moho discontinuity. Our results also present a more clear view of major fault structures compared to results obtained by local seismic networks.

S101S1.08

S101S1 - Seismological Observation and Interpretation

Oral

The Archangelsk seismic network

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The Archangelsk seismic network (ASN) consists of 11 observation points, three of which are part of the Geophysical Survey of Russian Academy of Sciences. In carrying out seismic monitoring the ASN focuses on earthquakes within the Western Arctic sector and its surrounding areas. In addition to the previously installed on the Arkhangelsk region the broadband stations «Klimovskaya» (KLM), 2004 and «Leshukonskoye» (LSH), 2006, a significant contribution to the study of seismicity of the Arctic make new stations, located directly in the Arctic zone - «Amderma» (AMD), 2010 and the «Franz Josef Land» (ZFI), 2011. At the moment, seismological station ZFI consists of three sets of equipment (two broadband seismometer CMG-6TD and one short-period seismometer CMG-40T). Seismic stations are located 250 m and 800 m from each other. All new stations are high-efficient both teleseismic and regional monitoring.

One of the main station characteristics is spectral level of seismic noise. Seismic noise spectral density analyses in broad frequency range shown that noise levels at ASN stations are different but noise variations, associated with diurnal variation, are small. This condition determines a high efficiency of the stations both recorded signal quantity and record quality. Additionally noise levels were measured on different islands of Barents Sea during summer field work on 2012 for future deployment of seismic stations (arrays).

All network stations have digital records and data transfer to Data Center in Archangelsk. Interactive seismological bulletin is also created on the basis of Archangelsk stations network beginning from the second half of 2002. Some hundred seismic events (including chemical explosions) were occurred in Barents region during this time. Created database will be useful for identification purposes in this region. Also it will allow obtaining new information on the seismic and geodynamic processes in the Arctic region.

S101S2.01

S101S2 - Seismological Observation and Interpretation

Oral

ISC-GEM Catalogue: Global and regional seismic moment release

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Largely due to the substantial increase in the volume of observational data used in the determination of revised locations and magnitudes, the new ISC-GEM catalogue offers an improved view of 110 years of global seismicity. In this paper we use these new data to interpret global and regional seismic moment release during the 1900-2009 period. Each earthquake in the catalogue is characterized by either a direct measurement of Mw or an Mw proxy estimate. Based on these Mw estimates we demonstrate temporal and spatial variations in global and regional moment release. We observe a total moment release over the 110-year period of 8.2(10**23) N-m. The moment release of 13 great earthquakes, Mw 8.5+ or moment (M0) greater than 6 (10**21) N-m, during 1900-2009 period was 5.4(10**23) N-m, accounting for more than half of this total moment release. Most of that high moment release occurred between 1946 and 1965 followed by a period of relatively lower magnitude events until the 2004 Sumatra and 2005 Java great earthquakes, suggesting the onset of another time period of great earthquakes. Excluding jumps related to these great events, a fairly constant moment release rate of 0.035(10**23) N-m/year for lower magnitude events is observed over the 110-year period. Spatially, most significant moment release is located along subduction zones. Some variations in lower level moment release can be seen along oceanic ridges, perhaps related to local spreading rates. Earthquakes and moment release in the China region are distributed over a vast region with a variety of tectonic styles and geodynamic processes, including oceanic and continental plate boundaries, and internal deformation along active faults. The Iran region is also one of contrasting tectonic styles, with low moment release in the Zagros apparently accommodating continental collision by crustal thickening and distributed deformation, and high moment release along block boundaries.

S101S2.02

S101S2 - Seismological Observation and Interpretation

Oral

Magnitude composition and completeness assessment of the ISC-GEM Global Instrumental Earthquake Catalogue (1900-2009)

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Improved seismic hazard studies necessitate that earthquake catalogues are to be homogeneous (to the largest extent possible) over time in their fundamental parameters, such as location and magnitude. Moreover, it became very popular in the seismic hazard community to consider the moment magnitude Mw as the preferred estimate among the different magnitude scales. Thus, the Global Earthquake Model Foundation (GEM) requested that the ISC-GEM Global Earthquake Catalogue is expressed in Mw. This contribution outlines the re-computation and compilation of the magnitudes listed in the ISC-GEM catalogue. We re-computed Ms and mb benefiting from new hypocentres, previously unavailable amplitude-period data digitized during this project, and a more reliable algorithm for magnitude estimation. Direct values of Mw (i.e., based on seismic moment computation) were compiled either from the Global Centroid Moment Tensor catalogue (www.globalcmt.org) or from publications with reliable seismic moment (largely for earthquakes before 1976). For events with no direct value of Mw, we applied newly derived conversion relationships for Ms-Mw and mb-Mw. We tested both linear orthogonal and non-linear exponential models but finally preferred non-linear ones as they provided better Mw proxies compared to direct values of Mw. Thus, each earthquake in the ISC-GEM catalogue is characterized by either a direct (64%) or a proxy (36%) estimate of Mw and the magnitude source is flagged accordingly. Uncertainties in magnitude estimations are also available in the catalogue and users are strongly encouraged to take them into account in any application of the catalogue. The magnitude completeness is not homogeneous over the 110 year covered by the ISC-GEM catalogue. The catalogue appears to be complete down to 5.6 and 6.4 in the period 1964-2009 and 1900-1963, respectively. Further time and resources would be necessary to homogenize the magnitude completeness over the entire length of the catalogue.

S101S2.03

S101S2 - Seismological Observation and Interpretation

Oral

Earthquake catalog in East Asia including historical events

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The earthquake catalogs were published by many the organizations like as JMA issued the seismological bulletins from 1923, ISS from 1918 to 1963, USGS and ISC from 1964, Korea Meteorological Administration from 1978, Korea Institute of Geoscience & Mineral Resources from 1994, and Institute of Geophysics, China Earthquake Administration, from 1978. The historical earthquakes were complied in many ways by many researchers. Utsu(2002) complied the destructive earthquake catalog in the world. It was the very important result, but there are still some problems. It did not include the undestructive earthquakes and some duplications for the same event were found, because the origin time was not used in UT for all event. Engdahl & Villasenor(2002) compiled the global earthquake catalog in 20c. Their result was very useful for many researchers, but the locations of some hypocenters were not suitable. There were large differences of the hypocenter locations from those of JMA. For example, the hypocenter of the 1952 Tokachi-0ki earthquakes was at Hidaka region by them, but actually it was in the Pacific Ocean. Some events in the Japan Sea were much deeper than in their catalog. The hypocenters by JMA in Taiwan in 1930s were much better than others, as JMA redetermied hypocenters there using old reported data.

The many domestic catalogues were rather uniform in its own country, but still included the limitation. For example, the 1700 Tsushima-Iki M7 earthquake was located between Kyushu and Korea in Japanese catalog, but it was not found in Korean catalogs. The event in the same day was located inside of the Korean peninsular in Korean catalogs. It shows the importance of the international cooperation for the research of the historical earthquakes. Additionally, the calendar and the time must be uniformed. The data in Japan, Korea, China, Vietnam and Philippine were compiled.

S101S2.04

S101S2 - Seismological Observation and Interpretation

Oral

Information content of focal-mechanism-independent magnitudes computed at the U.S. Geological Survey/National Earthquake Information Center (USGS/NEIC)

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The USGS/NEIC has for several years been implementing standard procedures, adopted at the 2005 IASPEI General Assembly, for the computation of magnitude-types denoted ML, Ms_BB, Ms_20, mb, mB_BB, and mb_Lg. In addition to the IASPEI magnitudes, the USGS/NEIC computes additional magnitude-types (Md, Ms_Vx, and Mwp) whose calculation procedures, as with the IASPEI magnitudes but unlike Mw and Me, are formally independent of the earthquake focal-mechanism. For an earthquake of M > 6, the USGS/NEIC data-processing software commonly makes a total of more than two-thousand amplitude measurements for the group of focal-mechanism-independent magnitude types. One or more of following attributes of a focal-mechanism-independent event-magnitude or station-magnitude increases the chances that the magnitude will provide critical information related to the earthquake source: (a) the magnitude can be computed when an Mw cannot be computed by moment-tensor inversion; (b) the magnitude is among the earliest that can be computed for a just-occurred earthquake; (c) the magnitude samples a part of the source spectrum that is not sampled by other magnitudes; (d) the magnitude reflects the radiation pattern of the earthquake differently than other magnitudes; (e) the magnitude is similar to magnitudes that can be computed from historical seismograms or that have been computed and published in easily accessible bulletins over a long time-period; (f) the magnitude-measurement procedure is documented to the extent that it can be independently replicated; (g) the magnitude is computed by a simple procedure but can provide a test of the validity of a source-parameter computed by a complex procedure. We present case-histories of the use of focal-mechanism-independent magnitudes to enrich understanding of earthquake processes.

S101S2.05

S101S2 - Seismological Observation and Interpretation

Oral

Evaluation of Lg-based magnitude scales for eastern North America, or Why are Canadian magnitudes higher than the USGS's?

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Moment magnitude is generally the preferred magnitude for characterizing earthquake size, but while it can be derived from regional moment tensor inversion for M~>4 events, this is not practical for smaller earthquakes, nor is it sufficiently rapid. In eastern Canada, Nuttli magnitude (mN) remains the most commonly used magnitude scale. Bent's 2011 conversion relation for mN to Mw should ideally be applied to large data sets and not to individual earthquakes. As part of a larger study to develop best magnitude practices for Canadian earthquakes, three Lg based magnitude scales are evaluated and compared: the Nuttli (1973) mN scale as applied by the Geological Survey of Canada (GSC), the IASPEI (2011) mb_Lg scale adopted by the USGS (bandpass filtered), and Herrmann and Kijko's (1983) mLg(f) scale. While old GSC readings from analog records included ~WWSSN filtering, modern digital readings are read from substantially-unfiltered records. Lg-based magnitudes calculated by the USGS (and mLg(f)) give magnitudes that, on average, are much closer to the expected or calculated Mw values for eastern Canadian earthquakes than the mNs in the Canadian database; the GSC mN magnitudes are about 0.5 units higher. Among other things mb_Lg uses the third-highest peak velocity, not the maximum peak velocity used in most other magnitude scales; this represents a 0.1 unit magnitude reduction. mN - mLg(f) differences on a point-by-point basis show a clear dependence on both distance and period; both are undesirable. Multivariate regression was used to develop a conversion relation between the two that removes these effects. An in-depth comparison of the mN and mb_Lg scales is ongoing. Ultimately, the goal is to select an existing magnitude scale or develop a new one that allows rapid magnitude calculation from velocity records, that is representative of the true earthquake size and that is independent of the data distribution.

S101S2.06

S101S2 - Seismological Observation and Interpretation

Oral

Crustal coda-wave properties in France and magnitude calibration

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Accurate magnitude estimation is necessary to establish reliable seismicity catalogs in order to assess seismic hazard. It is well known that crustal coda wave amplitudes present a lower variability than the direct waves (Mayeda et al., 2003). This amplitude stability offers great advantages for estimating accurate magnitude from a limited set of stations. To analyze coda waves in France, we have used 609 regional events recorded at 38 stations of the LDG French short-period seismic network during the 2000-2011 period. A systematic study of the regional and frequency properties of coda-wave envelops has been performed which has revealed a clear coda parameter variations between the different tectonic and geological regions in France. This first investigation allowed us to determine coda properties and the isotropic source radiation term in the frequency domain. In a second step, in order to develop a coda magnitude methodology applicable on new digital seismograms as well as on old paper records, we have observed coda envelops directly in the time domain. Although coda wave generation is frequency dependent, we tested the single-scattering model on broad-band records and estimated site and propagation terms. We find that the site factors at each station strongly influence coda amplitudes. The site factors of coda waves are very similar to those related to Lg waves. In order to estimate the source amplitude, we propose to measure the amplitude of coda waves in time-windows adapted to a range of magnitudes and epicentral distances. After a calibration with Mw or Ml from different laboratories, this time domain coda magnitudes estimation has been compared with the source radiation measurements provided by classical spectral approaches.

S101S2.07

S101S2 - Seismological Observation and Interpretation

Oral

The frequency-magnitude relation of broadband recorded AE under a triaxial compressive condition

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The frequency-magnitude relationships of earthquakes for various datasets were reported to satisfy Gutenberg-Richter's law. It has been suggested that a key parameter of this relationship, *b*-value, has spatio-temporal variation. In laboratory experiments, it has been reported that micro fractures in a rock sample (acoustic emissions; AE) also satisfy G-R's law [Scholz, 1968]. Though AE has been studied to understand detailed process of faulting, *b*-values in laboratory were not reliable because AE signals were recorded with PZT (piezo-electric elements) that had a narrow frequency range and strong resonance. To estimate reliable *b*-values from the AE records, seismic moments of AE events should be calculated from broadband AE records.

In this study, we tried to estimate *b*-values from broadband AE records. Yoshimitsu [2013] succeed to record broadband AE waveforms during a triaxial rock fracture experiment. They estimated seismic moments of events in two clusters that occurred after the peak strength. The moment magnitudes of the events were distributed around -7. As a result, *b*-values were estimated around 2 in both clusters, which are higher than normal *b*-values for natural earthquakes (around 1). The values look similar to those of volcanic or swarm-like events which usually show higher *b*-values ($1 < b < 3$). The causes of such high *b*-values have been considered as a crack density increment and/or high pore pressure. Both clusters had extremely high seismic rate in localized regions, and previous studies also indicated cracks should be increasingly generated during a period with a rapid decrease in differential stress after the peak strength. Hence, in the period of the two clusters, generation of a large number of cracks generated in the localized regions made *b*-values significantly high.

S101S2.08

S101S2 - Seismological Observation and Interpretation

Oral

Is there a need to redefine Mw and Me?

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Mw has been scaled to statistically not well constrained (just a few dozen data points) and/or not properly treated classical empirical magnitude and seismic energy (Es)-magnitude relationships. This similarly applies to the energy magnitude Me, which we consider as a complement to Mw. We tested, therefore, whether modern standard magnitudes, their mutual and Es relationships, allow to reproduce the currently used Mw and Me formulas. The critical Gutenberg-Richter (1956) scaling relationships for deriving these formulas are: (1) mB = 0.63Ms + 2.5 with mB measured at periods 2 to 20 s (nowadays 0.2 to 30 s) and Ms around 20 s as well as (2) logEs = 2.4mB - 1.2. Inserting (1) into (2), Richter (1958) proposed (3) logEs = 1.5Ms + 4.8. Hanks and Kanamori (1979) used the latter to the derive the current Mw formula, Choy and Boatwright (1995) modified it to (4) log Es = 1.5Ms = 4.4 by regressing directly measured logEs data over USGS Ms_20 but fixing the slope to 1.5. All these relationships are standard regressions. Our respective Orthogonal regressions (OR), based on more than 950 data points each of IASPEI standard mB, Ms_20, as well as of direct logEs measurements at the GFZ and USGS, differ significantly from (1-3) but agree for logEs(GFZ) very well with (4). Calculating with the revised formulas and the GFZ measured ratio logEs/logMo = -4.6 instead of the Kanamori (1977) value -4.8 new Mw and Me formulas then they yield for logMo ~ 17 and 23 values that agree within -0.04 and -0.07 m.u. with Mw and for logEs ~ 12 to 18 within -0.11 and -0.05 m.u. with Me calculated with the current formulas. When basing, however, the revisions of both the Mw and Me formulas on the OR logEs(USGS) over Ms_20 data, the differences reaches several tenths of m.u., also, when scaling alternatively Me via logEs to mB instead of Ms_20, which would be in better agreement with (2) and Gutenberg's original intention to estimate Es via (A/T)max in a wide range of periods.

S101S3.01

S101S3 - Seismological Observation and Interpretation

Oral

Crustal heterogeneity and its relation to seismic activity in the Kinki district, Southwest Japan

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Activity of microearthquakes is very high in the central to northern part of the Kinki district, southwest Japan. We discuss the detailed image of crustal heterogeneity in this region from a viewpoint of delineating its correlation with the earthquake occurrence in space and time. We estimated a 3-D distribution of relative scattering coefficients in the Kinki district by inversion of coda envelopes from local earthquakes. We analyzed about 2,000 seismograms from about 150 earthquakes which occurred in 2002 and 2003, recorded at about 50 stations in this region. The result shows the existence of a remarkable scattering zone at depths from 20 to 30 km, just below the high microseismicity area. The strong scattering zone is well correlated with the location of S-wave reflectors estimated by previous studies, and the present study has revealed more detailed image of the heterogeneous structures. The result of 3-D velocity tomography shows the strong scattering zone has relatively lower velocities and higher Vp/Vs ratio. Deep low-frequency earthquakes occur at a depth of 30-40 km just below this strong scattering zone. We suppose the existence of fluids, dehydrated form the subducting Philippines Sea plate, at the zone of strong scattering. We consider that this scattering zone should have a strong influence on the active microearthquakes just above it, for example it supplies fluids to the seismogenic zone in the upper crust. We have a data base of earthquakes in recent 30 years in this region. We will discuss the correlations between the temporal variation in microseismicity and that in scattering images, aiming at detecting some evidence of crustal fluids affecting the earthquake occurrence.

S101S3.02

S101S3 - Seismological Observation and Interpretation

Oral

Significant scattering of teleseismic P-wave at the near Japan Trench

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We found a significant scattered wave train in Japan after the arrival of near-vertical incidence of P-wave of the Off West Coast, New Zealand Earthquake (Mw7.6) in 2009 by using a dense, high-sensitive seismograph network (Hi-net) operated by NIED. The scattered wave train is dominant in the vertical component at period band of 20-50 s with a propagation velocity of 3 km/s. It propagates cylindrically to west from Kanto area, central Japan. This signal contains only low-frequency components and no local earthquakes were reported at that time. All of these facts suggest that the observed wave train is a scattered wave originated nearfield by incoming P wave from distant earthquake.

To locate the conversion point of the scattered waves, we first separated scattered wave train from large-amplitude direct waves. Firstly, we stacked seismic traces along the wavefront of the direct waves to cancel out the scattered wave propagating from different direction to each station to make a clear direct wave packet. Then, the stacked trace is subtracted from the raw seismogram to enhance scattered waves. By analyzing the subtracted traces based on an array data processing technique, we located the scatterer at around the Boso triple junction of three plates, southeast of Kanto area.

To clarify what kind of structure develops such large scattered waves, we conducted a finite difference method simulation of seismic wave propagation using high-resolution subsurface structure model with topography and bathymetry. Simulation results revealed that strong scattered waves are generated along the Japan Trench, and are guided to the direction normal to the trench axis due to the reverberation between seafloor and the Pacific plate boundary. In addition, the reverberation of scattered waves in thick (~9000 m) seawater column above the Boso triple junction enhance and elongate the scattered waves significantly, which explains observed feature of scattered waves.

S101S3.03

S101S3 - Seismological Observation and Interpretation

Oral

The crustal anisotropy obtained from shear-wave splitting in the northern Kanto and Tohoku regions

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Beneath Japan, the Pacific and Philippine Sea plates are descending toward west and north, respectively. The stress distribution of inland of Japan is expected to be complex. Shear-wave splitting is an ideal tool for determining the orientation and form of the stress field in an area. The shear-wave splitting method was used to understand the stress field in the northern Kanto and Tohoku regions. We analyzed crustal earthquakes at depths of <30 km during this study. Those earthquakes are from Jan. 1, 2000 to Mar. 10, 2011. The dataset consists of earthquakes that occurred before the 2011 Tohoku earthquake. The seismic stations operated by the National Research Institute of Earth Science and Disaster Prevention (NIED), the Japan Meteorological Agency, and the University of Tokyo are used. The shear-wave splitting results for earthquakes prior to the 2011 Tohoku earthquake are laterally variable. The polarization directions which were observed at the seismic stations located in the western part of the area suggested that the polarization direction with WNW-ESE. The direction is consistent with the direction of regional stress field which are caused by the subduction of the Pacific plate. However, the polarization direction with the north-south direction was found at the eastmost seismic stations of the northern part of Kanto and Tohoku regions. The direction is clearly inconsistent with the direction of the regional stress field. But, the characteristic, that the E-W and N-S polarization directions were observed at the western and eastern parts of the region, respectively, was as same as the result of Iidaka and Obara (2013), which was observed in the southern part of the Tohoku region. The cause of the lateral variation was researched considering the mechanism of subduction.

S101S3.04

S101S3 - Seismological Observation and Interpretation

Oral

Seismic anisotropy from local, teleseismic and ambient noise records in southeast margin zone of Tibetan plateau in China

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The southeast margin zone of Tibetan Plateau is dominated by the collision between the Indian and Eurasian plates. Major faults in the study area are of right-lateral strike-slip faults. Most of the faults at the east side of the Honghe fault are mainly oriented at N-S or NE, while at the west side the faults are mostly NW oriented. Crustal strain measurements and focal mechanism solutions indicated that the principal compressive stress axis in this zone is nearly N-S. Many researchers study seismic anisotropy by body wave or surface wave. However, it seems some comprehensive analysis of different techniques was omitted in detect of same tectonic zone. We try to show an example to image the seismic anisotropy in some zone from the crust to the upper mantle by various techniques.

In the southeast margin zone of Tibetan Plateau, there is a regional Yunnan Seismic Network composed of 46 permanent digital seismic broadband stations. We adopt shear-wave splitting of local records to study seismic anisotropy in the crust and adopt the splitting of XKS (i.e. SKS, PKS and SKKS) phases from teleseismic records to detect seismic anisotropy in the upper mantle. Except body waves, surface waves are adopted to study the lithosphere due to the great advantages in various periods. This study shows significant complicated seismic anisotropy in the crust. The shear-wave splitting in the crust is of close connection with the stress and the faults, similar to the study of Gao et al (2011) in North China. Although much complicated, the polarizations of fast shear-waves in the crust are predominantly in north-south direction, different with orientations of fast axes of XKS phases through the upper mantle. It suggests different deformation mechanisms between the crust and the upper mantle. We also obtained azimuthally anisotropic phase velocities of Rayleigh waves from ambient noise data in different frequency.

S101S3.05

S101S3 - Seismological Observation and Interpretation

Oral

Random heterogeneities in the Philippine Sea plate inferred from guided waves

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Seismological experiments using broadband ocean bottom seismometers (BBOBSs) were conducted at off Shikoku, western Japan locating over the Philippine Sea from 2005 to 2006. During the observation periods, high-quality Po and So waveforms preceded by direct P waves from deep forcus earthquakes were recorded. Prominent features of the direct P and S waves, and Po and So phases from deep earthquakes are summarized as follows. (1) The frequency content of Po and So waves is up to 20 Hz, which is much higher than that of direct P and S waves. The frequency content of So waves is slightly higher than that of Po waves. (2) The travel time interval between the direct P and Po phases varies with the event depth (and the epicentral distance). (3) The Po and So phases gradually build up and decay with extremely long durations (1–2 mins). The durations of the Po phase are longer than that of the So phase, and extend into the onset of the So phase. These features indicate that the Po and So phases propagate as guided waves in the oceanic lithosphere with intense scattering, whereas the P and S waves travel directly from the sources. In order to investigate the nature of the oceanic lithosphere guided waves, we performed numerical FDM simulations of two-dimensional (2-D) seismic wave propagation in a realistic oceanic lithosphere model. Applying the method described by Furumura and Kennett [2005; 2008], we conducted parallel FDM modeling of high-frequency (fmax=5 Hz) seismic wave propagation in heterogeneous structure in order to explain observed feature of the direct P/S and scattering Po/So phases. We will demonstrate that the low-frequency direct P and S waves propagate in the asthenosphere and that the following large-amplitude, high-frequency, and long-duration Po and So waves are developed by multiple forward scattering of P and S waves due to laterally elongated heterogeneities in both the subducting and horizontal parts of the oceanic lithosphere.

S101S3.06

S101S3 - Seismological Observation and Interpretation

Oral

Spatio-temporal variations of S wave attenuation field in the region of Nevada test site

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We have been studying characteristics of short-period shear wave attenuation field in the region of Nevada test site (NTS). We were analyzing recordings of underground nuclear explosions (UNEs) and earthquakes, obtained in 1975-2012 at epicentral distances up to 1000 km. Methods, based on an analysis of amplitude ratios of Sn and Pn, Lg and Pg waves at regional distances, and also S coda envelopes for local events were used. It was shown, that essential temporal variations of the attenuation field structure in the earth's crust and uppermost mantle of the NTS region were observed during a period considered. The strongest variations took place in the area of Pahute Mesa, where about 2/3 of the largest UNEs were conducted. The data obtained allow us to suppose, that the temporal variations of the attenuation field are connected with active deep fluid migration. We compare common characteristics of the attenuation field in the regions of three large nuclear test sites (NTS, Semipalatinsk and Lop Nor).

S101S4.01

S101S4 - Seismological Observation and Interpretation

Oral

Rapid and routine determination of seismic source parameters

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On May 2012 the Emilia Romagna region, North Italy, was struck by a seismic sequence. The two main-shocks on May 20 and May 29 with M_L=5.9 and M_L=5.8, respectively, were followed by relevant aftershocks with M_L>4. Using a procedure implemented by the SeisRaM group of the Department of Mathematics and Geosciences of the University of Trieste, the seismic moment is estimated in real time, as well as the moment magnitude and the corner frequency of the events recorded by strong motion instruments. Assuming the Brune source model and using spectral analysis, the seismic source parameters are calculated following Andrews (1986). A strong motion dataset consisting of high-quality recording associated to 17 events is analyzed. The strong-motion data are collected in real-time or quasi real-time by the software Antelope® (BRTT, Boulder). The data is pre-processed and the quality of each record is checked using its signal-to-noise (SNR) ratio that provides the frequency window of the signal to be analyzed. The mean is removed, the instrumental response is applied, and the signal is filtered using a Gaussian and a Butterworth band pass filter. Applying the Fast Fourier Transform the signal spectrum is obtained. The spectrum is corrected for geometrical spreading and intrinsic attenuation to retrieve the source spectrum from which seismic source parameters are estimated. The Emilia 2012 seismic sequence was a great opportunity to validate the procedure. Moment magnitude estimates are in reasonable agreement with the local magnitude and moment magnitude values calculated by other Institutions; the corner frequency estimations, however, are still unstable. A more detailed analysis on the attenuation and spreading of waves will most probably lead to improved estimates of seismic source parameters. This real-time automatic procedure is now routinely used at DMG and at the Department of Civil Defense in Rome for a rapid determination of earthquake parameters.

S101S4.02

S101S4 - Seismological Observation and Interpretation

Oral

Focal mechanisms of medium-small earthquakes and seismotectonic stress in the Shanxi rift system, North China

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The Shanxi Rift System is one of the most active Pliocene-Quaternary continental rift systems in China. Its formation and development is a response to the escape tectonics caused by the Himalayan uplift from the southwest, and at the same time by the counter-clockwise rotation of the intervening Ordos crustal block. Densification of regional and local recording networks has taken place in recent years, greatly improving the potential for seismotectonic studies. In this study, we attempt to derive focal mechanisms for all earthquakes of $Ml \geq 2.5$ since 2008 in the Shanxi rift system. For the larger events, we apply the time-domain moment tensor inversion, whereas the smaller events are studied based on P-wave polarities. Combining the obtained focal mechanism solutions and previous solutions of large events, we perform a stress inversion to obtain the stress field for this region. These results allow further insight into the regional seismotectonics and variable stress field, and to some extent enhance our understanding of the origin and properties of earthquakes at a regional scale, and also of the regional seismic hazard.

S101S4.03

S101S4 - Seismological Observation and Interpretation

Oral

Velocity spectral stacking for extracting the source and path effects for small-to-moderate earthquakes in Southern Ontario

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We analyzed over 3000 Fourier spectra from 370 earthquakes of energy magnitude (M_E) 1.1 to 6.0 recorded by the Southern Ontario Seismic Network (SOSN) /POLARIS networks during the period 1991-2010 in the area of southern Ontario and western Quebec. We employed a range of velocity stacking methods to significantly reduce the problem of variability due to wave scattering. This enabled us to determine underlying non-random spectral features, including source effects, site effects and anelastic attenuation effects on spectral shape. The analysis technique is that we stack the velocity spectra of the whole observed data set into one or two bins and then compare that sum (the “observed stack”) to the theoretical expectation for corresponding stacks of simulated signals (the “theoretical stack”), for a given set of input parameters. A grid search technique is used to find the input parameter combination that optimizes the agreement between the observed and theoretical stacks. By stacking the spectra in different ways, different underlying spectral features are explored.We find that the method works surprisingly well, allowing us to determine the apparent anelastic attenuation effects on the spectral shape, the average effect of site response, and some basic features of the source spectra. Key results of our study are: (1) there is no unique pair of values of the coefficients Qo and n of the frequency-dependent Quality factor relationship $Q = Qof^n$, but there exist pairs of Qo and n along a curve in Qo-n space that are equivalent in terms of their effect on spectral shape; (2) the relationship between log corner frequency and energy magnitude is linear, with a slope close to (-0.22) that strongly supports non-self-similar scaling for the studied small-to-moderate events; (3) the relation between moment magnitude (**M**) and energy magnitude (M_E) was found to be **M** = 8/9 M_E.

S101S4.04

S101S4 - Seismological Observation and Interpretation

Oral

High-frequency Po/So propagation in the oceanic lithosphere

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The phases Po/So are very distinctive high-frequency signals travelling often more than 1000-3000 km through the oceanic lithosphere and recorded at the ocean bottom seismographs with a long coda. We demonstrate that such Po/So signals are developed by multiple forward scattering of high-frequency body P and S wave in heterogeneous oceanic lithosphere based on the analysis of observed set of waveforms and finte-difference simulation of high-frequency seismic wave propagation in heterogeneous structures. An important component of the propagation is provided by reverberation in the water column and sediments linked to P and S propagation in the oceanic lithosphere. The nature of the observed Po and So phases with high frequencies and long coda is well represented by multiple forward scattering in a lithospheric structure with and quasi-laminate heterogeneity with horizontal scales much larger than vertical. Despite the generally good propagation of Po/So to stations in the western Pacific such as from the Japan subduction zone to the Wake island ocean bottom stations near Tonga, the propagation in eastern Pacific, e.g., to the H2O station on an old telephone cable between Hawaii and the mainland USA is rather poor for So (Kennett, Zhao and Furumura, 2009). Such poor transmission of the high-frequency Po/So signals along the young (< 25 Ma) oceanic plate can be explained by the ineffective propagation of high-frequency signals in a thinner lithosphere with influence also from oblique propagation across major transform fault systems in the eastern Pacific with changes in lithospheric thickness.

S101S4.05

S101S4 - Seismological Observation and Interpretation

Oral

Aftershock decay with distance from a Fault

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The hypothesis that p-value is a function of distance from the mainshock can be evaluated with the new data available with accurate relocations of earthquakes. We compile aftershock data from three major earthquakes: Landers, Hector Mine, and Sierra El Mayor, that have been relocated with waveform cross correlation and double difference locations. The distance of each aftershock from the principal slip surface in the SCEC Community Fault Model is determined and used to group the events. The change in earthquake rate from the pre-mainshock level is plotted for aftershocks within concentric annuli around the fault surface. Preliminary results show that the decay of aftershocks for the Landers earthquake occurs at the same rate for events very near and those at larger (>50 km) distances from the fault. These results will be compared with the sequences following the Hector Mine and Sierra El Mayor events, to see if our preliminary results are generally applicable.

S101S4.06

S101S4 - Seismological Observation and Interpretation

Oral

Identification of response and timing issues at permanent European broadband stations from automated data analysis

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To tackle the ever increasing amount of available broadband seismic data from European network providers for routine analysis, manual data processing and retrieval of certain observables (e.g. dispersive traveltimes, polarisation parameters) needs to be replaced by automated processing tools. We developed an automated routine to measure inter-station phase velocity curves of fundamental mode Rayleigh and Love waves by pairwise cross-correlating seismograms from all available permanent stations in Central and Northern Europe. Making use of path-specific reference models based on CRUST2.0, only three parameters that control the acceptable bandwidth of a given observation are required for our automated routine to identify and pick acceptable dispersion curves. As the measurements are based on the phase difference of the waveforms at two stations, the measurements are 2π ambiguous and we select the solution that is in general closest to our reference curve.

While applying this routine to the entire dataset, we observe at some stations systematic deviations from the expected measurement which may not be related to wave propagation effects. These include timing and response information issues, of the latter most prominently polarity switches. As we compare wavefields that propagate in both directions between two stations, both these effects lead to distinct deviative patterns in the measurements. A polarity problem at one station, for example, leads to dispersion measurements that are offset from the reference curve with a PI offset instead of the expected 2π. Timing issues on the other hand lead to symmetric deviations (for the two propagation directions) that are in general smaller than π.

Statistical analysis of our measurements against the expected dispersion curves from our reference models allows us to construct a map of anomalous stations in Europe. Furthermore, we have also indications that some instruments may not only have phase but also amplitude issues

S102PS.01

S102PS - Recent large/destructive earthquakes

Poster

Small repeating earthquakes and inter-plate aseismic slip after the 2011 off the Pacific coast of Tohoku earthquake

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The 2011 off the Pacific coast of Tohoku earthquake (Mw9.0) was the largest earthquake in recorded history in Japan. For the stress changes by this earthquake, many aftershocks and induced earthquakes have occurred in and around the source regions. Here I show the space-time characteristics of the inter-plate aseismic slip from sequences of small repeating earthquakes in Japan after the 2011 Tohoku earthquake. I have already detected small repeating earthquakes occurred at the upper boundary of the subducting plates before the 2011 Tohoku earthquake. The slip-rates estimated from these sequences had indicated the space-time changes of the inter-plate aseismic slips. After the 2011 Tohoku earthquake, seismic activities of small repeating earthquakes become active around the source regions. They are particularly active in the northwestern deeper part of the main-shock and its large aftershocks. The cumulative slip is more than 4 m in the most frequent area and is consistent to the value estimated from GPS data analysis. Detected sequences also show post-seismic slips at the trench-side of the northern and southern part of the source region in the subducting Pacific plate and in the subducting Philippine Sea plate beneath the metropolitan district, which suggest induced inter-plate slips. In two years after the earthquake, the slip-rates are three to five times of the relative plate motion in the north and western part, but they are almost decreasing to the rate before the main-shock in the southern part. On the other hand, I cannot detect small repeating earthquakes within coseismic slip areas of the main-shock and large aftershocks after the main-shock. Distributions of small repeating earthquakes probably outline their large slip areas. Therefore, I suggest that both coseismic slip areas and after-slip areas of large earthquakes can estimate from the space-time changes of small repeating earthquakes.

S102PS.03

S102PS - Recent large/destructive earthquakes

Poster

Astronomical geodetic stations that take the advantage of the spherical shape, rotation of the earth and gravity field

Tanaka, H. 1

1 Individual, Japan

The author was confused by the definition of the deflection of the vertical. At the time of John Milne, it was the dynamic gravity field change, but now almost only accepted as the natural anomaly from reference ellipsoid. Because of the overwhelming GPS survey, reference ellipsoid is so virtual figure of the earth, that the deflection of the vertical drags very little attention among scientists, and even seems to have lost the first sense. It is clear that a reference ellipsoid is merely a mathematical model that systematically ignores tidal effects and gravity field anomalies, no matter how we try to take them into account. The advantage of the astronomical coordinates is that we can project the earth on celestial sphere, i.e. planetarium. It is directly connected with the universe. In this presentation, the better astronomical observation network for geodetic purpose that can more directly describe the figure of the earth with the universe is proposed, by combining the three techniques, astronomical observation, triangulation, and leveling, that fully take the advantage of spherical figure and rotation of the earth, as well as gravity field.

S102S1.01

S102S1 - Recent large/destructive earthquakes

Oral

Mw=5.7 earthquake of 23.12.2012 in the Black Sea and its aftershock process

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Strong Mw = 5.7 earthquake occurred on 23.12.2012 at 13:31:42.46 in the Black Sea (Abkhazia) at the distance of 37 km from the coast, 38 km from Ochamchire, 51 km from Sukhumi, 46 km from Anaklia, Georgia, and 158 km from Sochi, Russia. To locate the event we used data of 37 seismic stations from Russia ad Georgia. The final estimation of the hypocenter coordinates are 42.510N ± 1.9km, 41.047E ± 1.6km; the depth is 10 km. The epicenter is connected to a regional fault. The source is a strike slip fault.

The earthquake of 2012 has a great interest for the regional seismology as it is the strongest one in the history of seismic monitoring since 1900 in that part of the Black Sea and only two earthquakes had occurred in sea before 2012 had the magnitude greater than the last one. The earthquake of 2012 was followed by aftershocks which have been continuing till now. According to Russian Geophysical Survey and Turkish Earthquake Department there were 207 aftershocks with ML > 2 from 23.12.2012 till 31.01.2013. The aftershock epicenters agree with the regional fault system. An intensity of the aftershock process reached 41 events with ML > 2 per day in the first 24 hours after the mainshock.

In 57.2 hours after the mainshock an event with ML=5.4, which initiated a new aftershock sequence, occurred. We studied each of the two aftershock sequences by LPL model and the process as a whole by ETAS model to check forecasting possibility. Based on LPL model fitting we would suppose that during the period from 1.5 till 60 hours after the mainshock time an aftershock with the magnitude comparable with those of the mainshock was expected. It was the period when an event with ML = 5.5 had occurred. We also conclude from the modeling that the fault zone has a smooth geometry. Predicting aftershocks number by EATAS model has a high probability of the forecast implementation. The forecast error is less than 5% for all days excluding 23.12.2012 when the error is 30%.

The research was supported by Russian Foundation for Basic Research (Project 13-05-00158 A).

S102S1.02

S102S1 - Recent large/destructive earthquakes

Oral

Seismic patterns of the Van earthquake (ML 7.2, 23 October 2011), Eastern Anatolia high plateau

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To illustrate seismic patterns and the causative mechanism of the Van earthquake and its aftershocks (more than 6000 events) in E-Anatolia, we used earthquake data set from Kandilli Observatory and Earthquake Research Institute (KOERI-2011, 2012) and seismic reflection profiles collected in Lake Van (ICDP-2004, PaleoVan project). We estimated the earthquake clustering patterns and deformational structures in the aftershock zones of the Van earthquake. We used the hypocenter depths and seismic density patterns collected from the seismograms of 6000 aftershocks recorded at VANB–Broadband station during 2011 October–2012 August.

Dense clustering and multi-fractal patterns of aftershock events during 10 months are mainly confined to the zone characterized by fault-bounded “transpressional” area with very low magnetic anomaly. This may describe the rigid, competent and brittle portions of upper crustal rotational block and the causative fault zone, where strain incompatibilities are concentrated. It is inferred from seismic reflection profiles and crustal model that strain accumulation, localization and concentration of the crustal stress, associated with the intrusive-extrusive events of rising magmatic bodies, contribute significant stress perturbation to the crustal regime to cause the Van earthquake. This supports that intrusive events can accumulate a great amount of strain energy to result in long-term aftershock patterns. In hypocentral cross-sections, very distinct detachment surface between 5 to 10 km has also been recognized on the causative, south dipping N-boundary fault. This can be attributed to the magmatic fluid filled-ductile shear zone.

The 2011 Van mainshock 3D-volumetric density distribution of the hypocenters is detected to be associated with an upper crustal ductile shear zone and multi-fractal sets of heterogeneous strains.

S102S1.03

S102S1 - Recent large/destructive earthquakes

Oral

September 18, 2011 Sikkim-Nepal border earthquake – Lessons learnt

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A strong earthquake of magnitude 6.8 on 18th September 2011 evening strike in the Nepal-Sikkim border was a remarkable event in the long history of the Himalayan earthquakes which presented a unique opportunity to reflect on the unacceptable rising trend of the seismic risk in the hilly regions. It triggered a large number of landslides and caused massive damage to buildings and infrastructure. This Sunday evening earthquake is being proven a big black day for resident of Sikkim, a state of north east India, which falls in Zone V (according to Bureau of Indian Standard's map). Landslides, rock falls, and mud¬slides were main responsible for most loss of life and damage to infrastructure and also related economic losses. It is seen that most multistory reinforced concrete buildings, which were non-engineered structure sustained considerable damage due to shaking. As reported, the total loss of life in India is 78, 60 in Sikkim, and the rest in West Bengal and Bihar, the other two states of India. The total loss has been estimated at around US $500 mil¬lion. No doubt, in magnitude and scale of destruction, this might not be a landmark earthquake, but as per records available, there have been four earthquakes over magnitude eight in the Himalayas - 1897 Shillong, 1905 Kangra, 1934 Bihar-Nepal border and 1950 Arunachal Pradesh. So, the occurrence of a large magnitude earthquake cannot be ruled out. In this paper an attempt has been made to highlight the lessons learnt from Sikkim earthquake which may has done something that is likely to challenge the authorities to re-assess the country's relief issues of disaster mitigation and management in the inhospitable region of the Himalayas which is one of the most seismically active regions of the country. Also tried to study the social, economic and scientific impacts and other related disaster mitigation aspects with many valuable lessons learnt from this tragic event of the Sikkim earthquake of 18th September 2011.

S102S1.04

S102S1 - Recent large/destructive earthquakes

Oral

Coulomb stress changes due to the Tohoku-oki earthquake - A variability study

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Stress changes induced by the Mw 9 Tohoku-oki earthquake of March 9, 2011, were determined for neighbouring faults. These covered the segments of the Japan trench that were not ruptured during the triggering event, the Kurile trench (SE of Hokkaido), the northern Izu-Bonin trench as well as the Sagami trough. In the latter, especially the potential rupture planes of the 1923 Kanto earthquake (near Tokyo) were investigated. The aim was to see whether the Coulomb stress had increased on these faults, indicating a higher probability for a future earthquake. -

As many parameters of these models turned out to be known not very precisely, we studied the variability of the stress changes when model parameters were slightly changed. These parameters were: the latitude and longitude of the receiver faults, their depths, the strike and dip angles of these faults as well as the likely rake angle for slip on them. The main criterion to compare the modelling results was the area of positive Coulomb stress change. Moreover, as slip distributions vary considerably, we also compared a homogeneous slip distribution with a strongly clustered one inverted from GPS data. -

As the slip is clustered off-shore in the latter one, the Coulomb stress changes were smaller at all considered target faults, sometimes even changed sign from stress increase to decrease. The variation of model parameters for the neighbouring target faults mentioned above provided stable results in most, but not all cases. This got worse, when the distribution of Coulomb stress above the empirical trigger threshold of 0.01 MPa was considered.

S102S1.05

S102S1 - Recent large/destructive earthquakes

Oral

The ISC-GEM Global Instrumental Earthquake Catalogue (1900-2009): Overview

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The ISC-GEM Global Instrumental Earthquake Catalogue represents the final product of a two-year project sponsored by the GEM Foundation. The catalogue is available at the ISC website (www.isc.ac.uk/iscgem) and consists of approximately 20,000 instrumentally recorded moderate to large earthquakes that occurred during the 110-year period between 1900 and 2009.

We have made every effort to guarantee the homogeneity of the earthquake hypocenter and magnitude parameters. All hypocentres after 1903 have been relocated using the two-stage procedure that includes the EHB technique to constrain event depths and the new ISC location algorithm and ak135 velocity model to recalculate the epicenter locations. Each event in the ISC-GEM Catalogue is characterised by a magnitude expressed in Mw scale with an uncertainty. Where possible, we used Mw based on a reliable determination of seismic moment either from the GCMT catalogue(1976-2009) or an individual scientific article (1900-1979). Proxy Mw were used in all other cases (the majority), based on the newly developed empirical relationships with MS and mb. All MS and mb were re-computed using the IASPEI procedures and the vast number of new amplitude and period measurements that were manually entered into the ISC database from historical station bulletins.

The ISC-GEM Catalogue will have a multidisciplinary use in a wide range of studies such as earthquake seismic hazard and risk, global seismicity, inner structure of the Earth, tectonics, nuclear monitoring research etc. It may also serve as a reference to be used for calibration purposes by those compiling regional seismicity catalogues.

S102S1.06

S102S1 - Recent large/destructive earthquakes

Oral

A new ISC service: The Event Bibliography (1900-2012)

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The International Seismological Centre (ISC) maintains the definitive worldwide summary of seismic events: earthquakes, mining induced events and explosions. A small yet not insignificant proportion of these events have been closely studied by individual researchers. These studies resulted in scientific publications in peer-reviewed journals, books, PhD thesis and individual reports. Some of the greatest earthquakes were described in several hundreds of articles published over a period of several decades. The ISC recently made a significant effort in linking bibliographical references (incl. doi) with event identifiers in the ISC database. This allows us to offer a new interactive map-based web service that makes it possible to select those scientific publications related to either specific events or events in the area of interest, covering the period over 100 years. Additional search parameters such as event type, date and magnitude, or publication author, journal or date are available. Results are offered in several standard output formats. The journals included in our database encompass a variety of fields in geosciences (e.g., engineering seismology, earthquake seismology, geodesy, tectonophysics, monitoring research, tsunami, geology, hydrogeology etc.), thus making this database useful in multidisciplinary studies. The ISC event bibliography is monthly updated and now includes over 12,000 individual publications from over 450 titles related to events between 1900 and 2012.

S102S1.07

S102S1 - Recent large/destructive earthquakes

Oral

State of tectonic stress before and after the 2004 mega earthquake Mw 9.3 in Andaman-Sumatra Subduction Zone

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A large set of global CMT solutions in the Andaman-Sumatra-Java subduction zone are used for inversion analysis by the Gephart's method to examine the state of tectonic stress before and after the 2004 tsunamigenic mega earthquake Mw 9.3 in this region. Some 1239 CMT solutions are obtained; 348 solutions before (during 1976 - December, 2004) and 891 solutions after (during December, 2004 - 2008) the 2004 mega event. We have identified several clusters of events in different tectonic blocks and studied the stress pattern of each cluster. We have further examined temporal variation of state of stress in each subdivided region. A dramatic change of orientation of the maximum and intermediate stress axes has been observed in the Sumatra region after a large earthquake Mw 7.4 in 2002. This change is attributed to a precursory phenomena for the December, 2004 mega event Mw 9.3. After the 2004 mega event and the 2005 great event Mw 8.7 in this region, orientation of the two stress axes returned to the original position as they were before the 2002 large event. In the Java region, a similar dramatic temporal change in stress axes is observed after a few large earthquakes during 2006-2009. It is conjectured that the Java region may experience great/large earthquakes that would bring back the original state of stress. This conjecture is, however, based on the observations in the Sumatra region as well as in the reported global observations.

S102S1.08

S102S1 - Recent large/destructive earthquakes

Oral

Rupture process of the 2004 Sumatra earthquake using teleseismic body waves

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The 2004 Sumatra earthquake was one of the largest earthquakes in recorded history, and had a ~1500 km long rupture of more than 500 seconds duration. To describe the whole rupture process of this earthquake, records of at least 500 seconds in duration were required for analysis. However, it is difficult to compute later phases using traditional rupture process analysis based on ray theory, which often uses the duration of analysis before the arrival of the later phases. In addition, such methods never compute a long period phase like a W phase. Although Ammon et al., (2005) inverted the rupture process using the Spectral Element Method which can compute the phases discussed above, they used body and surface waves at slightly long period range from 20 to 2000 seconds. This study analyzes the rupture process of this earthquake using the Green's functions calculated by the Direct Solution Method (DSM). The Green's functions were computed up to 1 Hz for IASP91 model (Kennett and Engdahl, 1991) using the DSM software developed by Dr.Takeuchi (http://www.eri.u-tokyo.ac.jp/takeuchi/software/). The slip distributions were also determined using the waveform inversion scheme presented in Kikuchi et al. (2003). The main results of waveform inversion are as follows: the moment magnitude, Mw, was determined to be 9.1; the source duration was 500 seconds; and the rupture velocity was 2.5-3.0 km/s. The synthetic seismograms matched well with the observations including the later phases and W phase. The largest slip area was estimated to be located from south west to west of the Sumatra islands, the second and third largest slip areas were estimated to be around the Nicobar islands, but almost no slip was found around the Andaman region.

S102S1.09

S102S1 - Recent large/destructive earthquakes

Oral

Shaking and impacts from the October 2012 magnitude 7.7 earthquake near Haida Gwaii

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Last October's magnitude 7.7 earthquake in the region of Haida Gwaii, Canada (formerly the Queen Charlotte Islands) is the second largest recorded in Canadian history. It was felt throughout British Columbia and as far away as the Yukon, Alberta and Montana, roughly 1500 km from the epicentre. In some locations (notably on Haida Gwaii), the perceivable shaking lasted 1.5 - 2 minutes, with very strong shaking for about 30 seconds. Strong motion seismometers recorded ground motions at three locations in the region, to a maximum horizontal acceleration of 0.2 g. Nevertheless, this earthquake resulted in very limited damage partly due to the population centres being located at least 80 km from the epicentre and 60 km from the fault rupture, but also due to the generally low, wood-frame construction on the islands. While relatively little visible impact and few, minor injuries resulted, many people were significantly traumatized by the experience and the numerous felt aftershocks.

We will examine the various physical effects (e.g. landslides, building damage, loss of hot springs) from the shaking by this large earthquake, catalogued by NRCan field crews and by the inhabitants of Haida Gwaii. We also determine how the intensities gleaned from analysis of eye-witness accounts may have been affected by the rupture dynamics of the earthquake and the effects of surface materials as a guide toward the potential impact on the various Haida Gwaii communities from future large earthquakes. October's earthquake may also be used as a proxy for earthquakes in other, more populated areas of British Columbia, Canada and the world.

S103PS.01

S103PS - Triggered and induced seismicity

Poster

Ability to control the earthquake source activity

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Besides many anthropogenic disasters of the past century, uncontrolled industrial activity led to an ever increasing number of earthquakes. But the opportunities to impact these changes and to create methods to manage focal processes have been limited due to the absence of a physical parameter that reflects the stress state of the medium and its variations. Our studies revealed an indirect feature that characterizes these changes - microseisms. Detection of their anomalies prior to earthquakes radically changed the development of ideas about the earthquake source and the forms of energy transformation from it, nonlinear character of a number of processes in the lithosphere, and their relations with other earth spheres. It was shown that microseisms carry important information about the processes of earthquake preparation, which can be monitored and impacted, using the energy of the planet, adjusting to it and replicating it. They indicate that the planet is a dynamic object, ever-changing, responsive even to very weak impact, self-restoring and self-regulating. The geophysical studies and experiments were carried out in different regions and allowed making a number of important theoretical and practical conclusions based on new physical ideas. The steps for managing stress state of the medium include: - For clarity of experiment selection of foci where earthquakes with $M \geq 5$ occurred in the previous 3-5 years, with the frequency of their recurrence of 30-50 years or more; - Geophysical studies of the source area medium's parameters and conducting test impacts to assess its sensitivity; - Development and implementation of the impact program to enhance the focal activity up to the time of self-excitation mode. Conducting ground experiments with simultaneous satellite measurements of manifestations, intensities and variations of geophysical fields will allow creating a database for remote evaluation of the state of the medium in various geological conditions.

S103PS.02

S103PS - Triggered and induced seismicity

Poster

A study on collapse earthquake triggered by rainstorm in karst area of Guangxi, China

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According to hydrogeological structure of seismic area and its adjacent regions, spatio-temporal correlation between heavy rain and earthquake, spatial distribution of earthquakes, focal mechanism and direction of first motion of seismic wave, this paper researched earthquake swarm activity of Lingyun and Fengshan in Guangxi from June to July, 2010. The results are as follows:

(1)Development degrees of karst structures such as karst cave i underground river and sunroof are very high in the epicenter and surrounding areas. The epicentral area is located in combining site of limestone, mudstone and sandstone, and junction fracture of NW and NE is a good channel for fluid infiltration.

(2)There is an obvious temporal and spatial correlation between rainfall and earthquake, and a similar earthquake swarm occurred locally in 2008.

(3)Earthquake swarm occurred in 3 i?2 km^2 area, and the maximum focal depth is about 1km.

(4)The focal mechanism solution of relatively large earthquakes is similar to collapse earthquake.

(5)Judging from proportional distribution of the U-D first motion direction of earthquake on time and magnitude, the upwards motion may be produced by gas explosion, the downwards motion may be caused by karst collapse. (6)The phenomenons, such as earthquake sound, ground water out, the crack, earthquake damage, are in accord with the characteristics of karst collapse earthquake.

Therefore, this earthquake swarm activity is caused by rainstorm and inland inundation, no relation to tectonic activity. If the local circumstances is drought for long, when the heavy rain comes, water permeate ground quickly, water in carst increases rapidly to huge pressure difference, which leads to the activity of explosion, erosion, eclipse and water hammer, and trigger karst cave or karst collapse, which is the mechanism of the earthquake swarm occurred.

S103PS.03

S103PS - Triggered and induced seismicity

Poster

Reservoir triggered seismicity in the Song Tranh 2 dam region, Central Vietnam

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Song Tranh 2 Vietnamese hydro-power plant is located by Song Tranh river in Bac Tra My district in central Quang Nam Province. The plant became fully operational in November 2011, after the upstream water level had reached the prescribed height of 165-170m. Four minor seismic events that occurred in the Song Tranh 2 dam area in November 2011 and other technical reasons caused that in March/April 2012 the water level was decreased to some 140m. Earthquakes began reappearing in the dam's region in September 2012. Three out of four events that occurred in this month had magnitudes of more than 4.0. The apogee of activity was in eight days from 16/10 to 23/10/2012. Altogether 65 events were noticed and the largest was M4.6. After this period the earthquake productivity strongly decreased, though it has been continuing. The strongest event so far, M4.7, occurred on 15/11/2012. The seismicity is clearly triggered by the Song Tranh 2 reservoir as the region had been practically inactive before the dam was built. Here we study this seismicity with the aim to estimate limiting parameters of the seismic hazard. We also analyze uncertainty of the estimates posed by the distinct non-stationarity of this seismic process.

S103PS.04

S103PS - Triggered and induced seismicity

Poster

Probabilistic seismic hazard analysis for mining-induced seismicity: Part B - Example of application

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The probabilistic seismic hazard analysis for mining-induced seismicity is used to predict limiting values of ground motion at the dams of Zelazny Most tailings pond until 2042. Zelazny Most, the largest in Europe copper ore flotation waste repository is located in the area impacted by the seismic activity induced by underground exploitation of the ore. The pond is enclosed with earth dams reaching 50m height. For the sake of dams' stability new mining plans are analyzed from the point of view of the seismic hazard, which their implementation can induce to the dams. The analysis presented here is the fourth update of the hazard estimates. The ground motion is represented by the peak horizontal and peak vertical acceleration. The limiting values are determined by 5 and 10 pre-cent exceedance probability. Both strategies of the hazard analysis method, the general and the detailed, are applied. The general analysis identifies the future mining panels, which will have the most significant influence on the future ground motion. Seismic impact of those panels is reconsidered in the detailed hazard analysis, when the planned rate of mining as well as possible seismic activity variations around those panels, correlated with the planned advances of the mining front, are accounted for. Within the prediction horizon of 30 years one should not expect the peak horizontal acceleration value of $2 m/s^2$ be exceeded along the dams.

S103PS.05

S103PS - Triggered and induced seismicity

Poster

Fluid extraction vs. deformation and seismicity pattern in the Cerro Prieto geothermal field (Baja California, Mexico) during 1973-2009

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Because of its tectonic situation (southern part of San Andreas Fault system) the area of the Cerro Prieto Geothermal Field (CPGF) is characterized by high seismicity, recent volcanism, tectonic deformation and hydrothermal activity (Lomnitz et al, 1970, Elders et al., 1984; Su árez-Vidal et al., 2008). Since the geothermal field production started in 1973 significant subsidence and seismicity increase has been observed (Glowacka and Nava, 1996, Fabriol and Munguía, 1997, Glowacka et al., 1999) and a relation between fluid extraction and/or injection and seismicity has been suggested. In the present study we use the tectonic situation from Suarez et al. (2008), geodetic leveling data presented in Glowacka et al. (1999, 2012), and Envisat ASAR satellite images received within the C1P 3508 ESA (European Space Agency) project, as well as data from the geotechnical instruments network REDECVAM (Mexicali Valley Crustal Strain Measurement Array). Published data (CFE, 2009) about the volume of extracted fluid are also used. We use the seismic catalogs from the regional network RESNOM (Northwestern Mexico Seismic Network) and the Southern California Seismic Network. Analysis of existing deformation data shows that extraction increases at wells situated in the NE of the geothermal field increase the rate of subsidence, and slip on faults, in the NE part of the Cerro Prieto pull-apart basin. Changes in the production pattern are also related to changes in the pressure observed at the bottom of the extracted reservoir. During the 1973 - 2009 period, four earthquakes (1987, M=5.4, 2006, M=5.4, 2009, M=5.1 and M=5.8) and in 2008 a swarm including 3 events with magnitude higher than 5 were recorded in the area, very close to the CPGF, suggesting seismicity migration to the NE within Cerro Prieto pull-apart basin. We analyze space and time seismicity changes to evaluate if the subsidence accommodation observed in the Cerro Prieto pull-apart basin is seismic or aseismic.

S103PS.06

S103PS - Triggered and induced seismicity

Poster

The seismic event at Völkersen of November 22, 2012 - seismic observations and determination of focal parameters

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On November 22, 2012 at 20:38:12 UTC an earthquake of magnitude ML = 2.8 occurred in the district of Verden near the village of Völkersen in Northern Germany. The event was felt by large segments of the population within a radius of about 20 km. Seismic signals could still be detected 600 km away at the seismic stations of the German Regional Seismic Network in the Bavarian Forest. The epicenter of the current event is located near the boundaries of the natural gas field of Völkersen. In that area 4 events with magnitudes 1.9 to 2.9 have already taken place within the last 5 years. Similarly active is the area around the adjacent gas field of Söhlingen. There, the last event occurred on February 13, 2012 with a magnitude of 2.9 near the village of Visselhövede.

Despite their relatively small magnitudes these two groups of events are of particular interest: Their close spatial vicinity to the gas fields and the fact that the wider environment is considered to be almost aseismic suggest a connection with the local gas production as possible causes.

To investigate the causes of the events in more details, BGR set up 11 mobile seismic stations in the immediate vicinity of the known epicenters in collaboration with the Universities of Potsdam and Hamburg at the beginning of June 2012. The aim of the project is to obtain more accurate focal depths and focal mechanisms than before on the basis of the increased station number.

For the event of November 22, 2012 we were able now to compile an unique dataset of near focal and azimuthally well-distributed observations. First hypocenter determinations indicate a focal depth between 3 and 7 km, which is thus in the depth range of the natural gas extraction. Focal mechanisms calculated for a pure double-couple source and for the moment tensor will be presented and interpreted with respect to the fault systems in the region and to possible causes of the earthquakes.

S103S1.01

S103S1 - Triggered and induced seismicity

Oral

Routine relative location for mines

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Rock mass subjected to mining is complex and wave velocities change as mining progresses, though to a different degree in mines employing different mining methods. With uncertain wave velocities location errors increase with increase in hypocentral distances. If the velocity model is inaccurate or if velocities change significantly with time, one can attempt to relocate events by so called relative location. This procedure requires an accurately located master event (e.g. calibration blast or a single production shot) in the proximity of the event to be relocated (called the target event), that has reliable arrival times at stations used in the relocation procedure. In essence, relative location is equivalent to absolute location with seismic sensors at the same distance from the seismic event as the distance between the target and the master event. However, the relative location errors are more sensitive to uncertainties in arrival times and since location error estimates of these two methods are not comparable it is difficult to judge which one is better. If the target events are close enough to the master event the relative locations are more accurate than the absolute location but relative errors increase quickly with a distance between the target event and the master event. We derived errors for the relative and the absolute locations which allow comparison between these methods. By linearising the set of non-linear travel time equations and assuming Gaussian distributed errors for the input data, quick and accurate standard deviations of the location variables are obtained, similar to the way standard deviation of the absolute locations was derived in. Therefore, relative location is better if its estimated standard deviation is smaller than the one for absolute location. The method was tested on two sets of calibration blasts. In both cases errors in relative location were 36% lower than in absolute location.

S103S1.02

S103S1 - Triggered and induced seismicity

Oral

Coseismic intermediate principal stress changes impact on rock fracture process in the Rudna mine

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In the present work we study a modifying impact of the coseismic stress transfer due to two strong tremors on the seismic process directly linked to mining works. The studied seismic data is associated with mining exploitation in one of the mining sections of Rudna copper ore mine in Poland. From the beginning the works in the selected mine section have been accompanied by seismic activity with occasional strong tremors. In this study two strong tremors of local magnitudes 3.7 and 3.5 are considered. The first event was triggered successfully by destressing blasting. The second event took place during excavation works in less than three weeks after the first one and on the area of simultaneous enhancement of both shear and normal stress change, caused by the first event. It turns out that the stress change due to coseismic slip of these two analyzed strong tremors influenced significantly the location and rate of smaller subsequent events in the next few months. The analysis shows high correlation between the location of week seismicity and the areas of intermediate principal stress decrease. At high intermediate principal stress changes the rock fracture process is apparently suppressed. This stress change impact seems to prevail over the influence of time-varying stress alteration caused by advancement of the mining front. This work was supported by National Science Centre, Poland under the research project No. NN525393539.

S103S1.03

S103S1 - Triggered and induced seismicity

Oral

Relationship between the seismic source parameters and geological structures for Kiirunavaara Mine

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The Swedish mine Kiirunavaara is the world's second largest hard-rock underground mine. The deposit consisting of pure magnetite is 4 km long divided into ten production "Blocks". The mining method is sublevel caving. In 2007 the mine turned into seismically very active. During 4 months the mine experienced 4 large seismic events in Blocks 19 and 33 with large rockfalls and one fatality. Since then the mine has continued to be seismically active in 7 out of 10 Blocks. One of the measures for managing the seismicity was the installation of a mine wide seismic system with 132 geophones. An interpreted model of possible faults based on the seismic parameters of manually grouped clusters of seismic events replaces today the lacking structural geological model. Recent thorough analysis of seismic data was undertaken, to verify the structural geological model and to gain a better understanding of the seismic process in the mine. Initial work on the focal mechanisms and the seismic moment tensor analysis started with Block 19 and 33 as they are the most hazardous ones. The purpose was to understand if most of the damaging events are related to geological structures or not. For Block 19, the focal mechanisms and seismic moment tensor are calculated for the period January and April 2010. The solutions are obtained for a homogeneous seismic model using IMS software. The predominant orientation of the nodal planes from both the focal mechanisms and double-couple component of the moment tensor are compared with the orientation of the grouped clusters of seismic events. The results show a close relationship to one of the predominant orientations of the interpreted structures based on the clusters of the seismic events. About 1/3 of the seismic events from this time period turned out to be related to other rock mechanical processes than reactivation of geological structures. Similar type of work is done for Block 33. In this case, the analysis focused on damaging seismic events.

S103S1.04

S103S1 - Triggered and induced seismicity

Oral

Modeling seismicity rate changes resulting from static stress triggering due to small (MW1.9) event recorded at deep gold mine

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The evaluation of spatiotemporal evolution of seismicity using Rate-and-State formulation (Dieterich, 1994) was presented in number of papers, concerning mostly natural seismicity. In this paper we use this approach to the nano- and picoseismicity related to MW 1.9 event that occurred in Mponeng deep gold mine, South Africa. Mining tremors occurring following and preceding the seismic event were well recorded due to the JAGUARS' high-frequency seismic network installed about 90 m below the Ventersdorp contact reef exploitation level and about 30 m below the main shock hypocenter. The sensitivity of the network allows measuring seismic events with frequencies up to 200 kHz and magnitudes as low as M -5.0 (seismic source size of a few cm). Because the main shock occurred in the middle of Christmas vacation period, the seismic data are also not polluted by man-made noises. This all makes the JAGUARS project an excellent site to investigate the rate-and-state law for the seismicity recorded in-situ and compare it to the results obtained in laboratory experiments on rock samples. We used the nano- and picoseismicity occurring immediately before the main shock as a reference seismicity, which rate will determine the rate of seismicity after the main shock. The observed seismicity was divided into depth intervals. For each of these intervals the reference seismicity and the static Coulomb stress changes were estimated in order to receive the expected rates of events and compare it with observed sequence of aftershocks. This work was supported by National Science Centre, Poland under the research project No. NN525393539.

S103S1.05

S103S1 - Triggered and induced seismicity

Oral

Probabilistic seismic hazard analysis for mining-induced seismicity: Part A - Method

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Alterations of local stress field, caused by mining operations, are key factors controlling the mining-induced seismic process. Such alterations are time-varying thus the seismicity accompanying mining is non-stationary. In this connection the seismic hazard estimates for mining-induced seismicity are predictions referring to a specific time period rather than solely to the length of such a period. The presented here probabilistic seismic hazard estimation method, developed to respond to needs of copper ore mining industry in Poland, takes into account the mentioned specific features of the mining seismic process. Two kinds of data are processed: past data on mining activity and seismic activity in particular mining panels or larger units and future plans of mining works. Based on similarities in mining and geological conditions between the mined out panels and the planned panels, the past activity data from selected areas are used as alternative statistical models of the seismic activity expected to accompany the future mining. The variants of the seismic process and the ground motion propagation rules are integrated using the logic tree methodology. Two different strategies can be applied when performing the analysis. In a general hazard study the seismic activity around future mining panels is assumed to remain constant regarding all: the activity rate, source size and source location probability distributions. The general analysis takes into account a multitude of future panels. The detailed hazard analysis takes into considerations only a few future panels. The seismic activity associated with these panels is assumed to change in the course of mining works. The source locations are modeled as moving along with the planned advance of mining front. The time variations of the source size parameters of hazard in future panels are inferred from the time variations of these parameters in the mined out panels, which are the most similar to the future ones.

S103S1.06

S103S1 - Triggered and induced seismicity

Oral

Decreasing the seismic risk at the Kiirunavaara mine

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As a result of the increasing mining depth in a highly stressed hard rock surrounding, the Kiirunavaara underground iron ore mine has become a seismically active mine in recent years. The increased seismicity of the mine is exhibited with large magnitude seismic events and associated rock damages in the mine infrastructure. Subsequently a mine wide seismic risk management plan has been implemented to control the challenge. This includes expanding and updating the seismic monitoring system, construction of a more comprehensive geological model, and devising strategic and tactical controls to seismic risk.A strategic control of seismic risk focuses on proactively averting seismic risk by creating an environment where the occurrence of large seismic events becomes less frequent. The first step in doing so is the creation of a comprehensive structural geology map based on seismic data. The next step is the planning of extraction sequence in the mine. With the application of sound engineering judgement and with the help of the structural geology maps, the sequencing of the extraction of ore can be planned in a way where large seismic events are minimized. A tactical control of mining induced seismicity involves the devising and installation of rock support systems that can resist dynamic loads and the temporary exclusion in high seismic risk areas when necessary. Accordingly new dynamic supports have been introduced to the mine in the forgoing years which incorporate schedule of dynamic supports in seismicity prone locations. Criterion for the exclusion of risky areas has also been developed and implemented. The audit of the effectiveness of these control measures can be done by picking certain key performance indicators such as frequency of large magnitude seismic events, rock falls, and accidents. With more improvement still required, analysis of the key performance indicators has shown that the seismic risk management plan at the Kiirunavaara mine is effective.

S103S1.07

S103S1 - Triggered and induced seismicity

Oral

The complexity of size distribution of seismic sources induced by different technologies

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The size distribution of source, determined by complexity of the seismic process, is one of key parameters in the description of seismicity. Induced seismicity results from combination of geological and technological factors and therefore the size distribution of induced events can disobey the Gutenberg-Richter law. The aim of this work is to find out to which extent the size distribution complexity is a common feature of induced seismic process regardless an inducing technology.

The following data is used in the analysis: the data related to seismic activity accompanying production of geothermal energy (Basel Deep-Heat-Mining), the seismic activity triggered by surface water reservoir (Acu reservoir), the seismic activity accompanying oil exploitation (Romashkino oil field) and the seismic data from underground mine (Mponeng deep gold mine).

To test the size distribution complexity the smoothed-bootstrap test for multimodality is implemented and adapted to study asymmetric and strongly pitched distributions. The study confirmed the complexity for induced seismic processes. Multimodality or the existence of bumps in a probability density function indicates heterogeneity of the population likely resulting from more than one process. In case of mining seismicity such a complexity is probably due to mixing outcomes of two seismic processes: the one directly linked to mining operation and the other one resulting from an interaction of the mining stress field alterations and the remnant tectonic stress field. Similar reasons can explain deviations from Gutenberg-Richter relations of other induced cases.

This work has been done in the framework of the internal research project No. 1C/IGF PAN/2012/ML for young scientists, financed by the Institute of Geophysics, Polish Academy of Sciences for the period 2012-2013.

S103S1.08

S103S1 - Triggered and induced seismicity

Oral

EPOS Working Group 10: Infrastructure for georesources

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EPOS Working Group 10 Infrastructure for Georesources aims to integrate the Research Infrastructure (RI) in the area of seismicity induced by human activity. The group has brought together representatives from the scientific community and industry from 10 European countries. WG10 focuses on priorities: 1) to facilitate a step-change in the IS research perspective from the present, technology-oriented approach, to one centered on physical problem, without, however, losing touch with technological conditions of IS generation; 2) to intensify scientific international cooperation; 3) to improve research efficiency by facilitating instantaneous access to data, results and methodologies; and 4) to strengthen cooperation between industry and science. This will be achieved by creation of Induced Seismicity Node within EPOS. The IS Node will be opened to broader community including research and industrial groups, educational centers, administrational bodies. WG10 will develop a synergy between science and industry. Appropriate data gathered by industry will be passed to research centers. Science will respond with appropriate methodologies and ready-to-use solutions that are transferred back to the industry. The IS RI to be integrated comprises three components: data, software and reports. The IS data consists of seismic data and auxiliary data: geological, geomechanical, technological, etc.. The second component of the IS RI are software tools for data handling and visualization, the standard and advanced software for research and newly proposed algorithms for tests and development. The third group of IS RI consist of both peer reviewed and unreviewed literature. WG10 is working out strategic solutions for integration, the development of thematic core services to be provided by a future IS Node, and adequate science plan for IS Node. Measurable benefits of the integration will be the intensification of studies on hazard and risk associated with anthropogenic seismicity.

S103S2.01

S103S2 - Triggered and induced seismicity

Oral

Scientific deep drilling to study reservoir triggered earthquakes at Koyna, Western India

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A major scientific programme including scientific drilling to investigate reservoir triggered seismicity in the Koyna area near the western coast of India has been launched. The Koyna area is the premier site of Reservoir Triggered Seismicity (RTS), where triggered earthquakes have been occurring in a restricted area of 20x30 km2 since the impoundment of Shivajisagar Lake in 1962. The RTS was further enhanced by impoundment of the nearby located Warna reservoir in 1985. The seismicity distribution during the past ~5 years defines two seismic zones in the area, each about 10 km long, relatively narrow (~2 km) and shallow (6-8 km). The earthquake activity is governed by the annual water cycle, increasing in response to the rapid filling of the reservoirs during the monsoon rains as well as the post-monsoon unloading cycle.

We plan to set up a deep borehole observatory at ~7 km depth to directly measure the physical and mechanical properties of rocks, pore fluid pressure, hydrology, temperature, and other parameters of an intra-plate active fault zone in the «near-field» of earthquakes, before during and after their occurrence. Down-hole measurements complemented by observations on cores and cuttings, analyses of fluid and gas samples, geophysical and geological characterization studies including fault zone monitoring would shed light on the genesis of RTS. The first phase investigations including compilation of existing datasets, acquisition of new datasets and exploratory drilling aimed at delineation of the fine structure of the subsurface fault zone(s) is underway. Drilling of the first borehole has reached a depth of 1000 m and has revealed ~933 m –» thicK Deccan Traps sequence underlain by granitic basement rocks in the area, for the first time. Downhole geophysical logging and measurements of heat flow, in-situ stress, hydrological parameters, etc. will guide the planning for scientific deep drilling during the next phase.

S103S2.02

S103S2 - Triggered and induced seismicity

Oral

Estimation of fractal distribution for induced seismicity in Masjed Soleyman dam (South West of Iran)

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Masjed Soleyman dam site is located in the Zagros Mountain of western Iran, which is one of the most seismically active zones of the Alpe-Himalayan belt. After impounding the dam, the seismicity of area increased considerably, showing the impact of reservoir (177 m height, 261 million m3) in changing the rate of seismicity in the area. We have analyzed the seismicity of area in terms of the spatial variations of fractal dimension and have compared it with b-value in the frequency-magnitude relation. About 1924 well-located events recorded during 15 months from June, 2006 to August, 2007 were selected for the analysis. To map the variation of fractal dimension as a function of space, the entire area was set into 0.05° × 0.05° grids. An overlapping of 0.025° is made for a comprehensive picture of the map. The 23 grids were created interactively, and the region with events less than 40 did not used in this estimation. Fractal dimension (D) and b-value of each grid were estimated and the results show a desirable correlation between D and b-value that indicates on existing of induced seismicity in the dam area. The impact of increasing pure fluid pressure on both parameters (fractal dimension D and b-value) is truly observable for this area.

S103S2.03

S103S2 - Triggered and induced seismicity

Oral

Seismicity induced by oil production in an area of active tectonics: is there conclusive evidence about triggering earthquakes?

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It has been complemented observing earthquake activity performed by the National Seismological Network in a region of the Eastern foothills of Colombia, through the installation for 40 days of a monitoring network with 29 accelerometric stations, around the heavy oil Chichimene field (Meta Department). The experiment was to evaluate the activity before, during and after the development of fracking activities in a production well (TD approx. 11,300 feet) and contrast it with the typical seismic activity in the region. The events recorded were initially located from a 3D velocity model derived from seismic data and well logs nearby. Later, events were discriminated to establish the frequency of induced seismicity, natural events surrounding region and the possible earthquakes triggered by fracking. Although all data collected has allowed to improve knowledge about the physical properties of the reservoir and the area surrounding it (e.g. lateral variations of seismic velocity and attenuation, the stress field orientation, the induced fracture dimension, etc) has not been possible to conclusively infer a cause-effect relationship between fracking process and seismicity around the area. We present some hypothesis about the seismotectonic conditions, and earthquake activity derived from the exploration and production activities.

S103S2.04

S103S2 - Triggered and induced seismicity

Oral

Microseismicity of an oil/gas field- A case study

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We analyzed more than 6,000 microseismic events recorded by two separate seismic networks over an oil and gas field in the Middle East. The magnitude of events ranged from MW = -2 to +3. The events were located using a detailed 1-D velocity model derived from well logs. A non-linear grid search algorithm was used for locations. The locations were validated for a representative subset of events by calculating the synthetic seismograms and matching with the observed. Most of the events occurred at the depth of the gas reservoir at about 1 km. Most epicenters fell on pre-existing faults, mapped by 3-D seismic reflection surveys. There are two sets of faults: those with NE-SW strikes and less prominent conjugate faults with NW-SE strike. The earthquakes result from the compaction of the gas bearing formation and re-activation of the faults due to the associated changes in the stress regime. The focal mechanisms of a selected number of events are determined by waveform inversion. During the waveform inversion, we maximize both the phase and amplitude matching between the observed and modeled waveforms. In addition, we use the polarities of the first P-wave arrivals and the average S/P amplitude ratios to better constrain the matching. An objective function is constructed to include all four criteria. An optimized grid search method is used to search over all possible ranges of source parameters (strike, dip and rake). To speed up the algorithm, a library of Green's functions is pre-calculated for each of the moment tensor components and possible earthquake locations using the 1-D velocity model. The determined focal mechanisms show that the majority of the normal faulting events have a strike direction parallel with the major NE-SW faults in the region, and reverse faulting events have a strike perpendicular to this direction. This result indicates that the maximum horizontal stress trends in the NE-SW direction.

S103S2.05

S103S2 - Triggered and induced seismicity

Oral

Fluid-induced seismicity in the Johannesburg area, South Africa

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Mining activity in the Witwatersrand region of South Africa led to induced seismicity, which has been observed since the first decade of the 20th century. ERPM mine, the last active mine in the Central Rand Goldfields, was closed in November 2008. The closure has resulted in the closure of pumping stations which previously maintained the underground water level. As a direct consequence, the water has been allowed to flood the mine voids causing an increase in seismic activity.

In order to estimate the direct influence of the shutdown of pumping stations on seismic activity, a network of strong ground motion sensors was installed around the Johannesburg area. Seismic events were located and relocated using the double-difference method. Most events are located within the boundaries of old mines. There is no diffusion process observed through migrating seismicity taking place in the ERPM mine area.

Relations between source parameters such as seismic energy, seismic moment, corner frequency, static stress drop and apparent stress drop are presented. The seismic moment spans roughly 3.5 orders of magnitude from 1010 to 5x10 13 Nm. The static stress varies between 10 -2 and 25 MPa. Analysis of data shows that the static stress drop has a tendency to increase with seismic moment.

A 3-dimensional code was used to create models to simulate the effect of pore pressure on the mine void and an intersecting geological discontinuity. Displacements were triggered along the contacts of the geological discontinuities. Those observed in the shallow model at depth around 600m resulted in larger displacements compared to those observed in the deep model at 3000m.

Probabilistic seismic hazard analysis was performed for the Johannesburg area. Hazard maps were produced for PGA and Spectral Acceleration at return period of 475 years. Spectral acceleration values of greater than 0.2g are anticipated. Such values can result in damage to infrastructure in the city.

S103S2.06

S103S2 - Triggered and induced seismicity

Oral

Acoustic emission monitoring of hydraulic fracturing laboratory experiment with supercritical and liquid CO_2, water and viscous oil

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Carbon dioxide (CO_2) is often used for miscible flooding to enhance oil recovery in depleted petroleum reservoirs, and recently its injection has been examined for shale gas recovery as well. Using CO_2 as fracturing and circulating fluid has also been proposed in hot dry rock geothermal energy extraction, because it eliminates scaling in the surface piping due to the inability of CO_2 to dissolve mineral species. In these projects, possibility of combining CO_2 sequestration is considered.

CO_2 usually becomes supercritical (SC-CO_2) at depths greater than 1,000 m, while it is liquid (L-CO_2) at low temperature. The viscosity of L-CO_2 is one order lower than that of normal liquid water, and that of SC-CO_2 is much lower still. To clarify fracture behavior induced with injection of the low viscosity fluid, we made hydraulic fracturing experiments in 17 cm cubic granite blocks having a 2 cm diameter central hole by injecting SC-CO_2, L-CO_2, water and viscous oil, which has a 100 times larger viscosity than that of water. At first, it was found that the lower fluid injections show the lower breakdown pressures. To characterize the induced cracks, a fractal dimension of AE source distribution was obtained. In addition, a most likely flat plane for AE source distribution was estimated, by minimizing a sum of squares of a distance from a located source to the flat plane, and the average distance from a source to the estimated flat plane, Lav, was obtained. The numbers, FD and Lav, increased with decrease of fluid viscosity. The results indicate that the AE sources with the lower viscosity fluid injection tended to distribute the more three dimensionally in the larger area. In other word, injection of the lower viscosity fluid like SC-CO_2 tends to generate cracks spreading more three dimensionally without extending along a flat plane than that of the larger viscosity fluid like water and gel, which is often used for stimulation of oil and gas production.

S104PS.01

S104PS - Ambient noise

Poster

Surface wave tomography of southwestern Scandinavia using ambient seismic noise and earthquake data

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Structural models of southwestern Scandinavia obtained from P and S wave tomography have been published recently as an outcome of the TopoScandiaDeep project. In this study, we use records of temporal seismic networks in southern Norway, Denmark, and southwestern Sweden as well as permanent broadband stations of the Norwegian, Danish and Swedish national seismic networks to perform a surface waves tomography of the region. We cross-correlated ambient seismic noise records of 2 years or a few months length, depending on the available temporal overlap between stations of different networks, to determine empirical Green's functions for Rayleigh and Love waves. Frequency-Time analysis is used to measure phase velocity dispersion curves between 3 and 30 seconds period. The dispersion curves are inverted for phase velocity maps. Furthermore, recordings of regional and teleseismic earthquakes are analyzed to determine the phase velocities maps at longer periods. The combined dispersion curves from seismic noise and earthquakes are inverted for local 1D S wave velocity depth profiles. Results are integrated into a structural model of southern Norway from a recent surface tomography study. Finally, we interpret and compare the inverted structures with the existing models of southern Scandinavia regarding crustal and uppermost mantle structures. In particular, we study the narrow lithospheric transition around the Sorgenfrei-Tornquist Zone.

S104PS.02

S104PS - Ambient noise

Poster

Microseisms generated by typhoon

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Every year over 10 typhoons occur in western Pacific Ocean regions and Taiwan experiences, on average, more than 4 typhoons yearly. Typhoons usually cause serious damage in the Taiwan region. The ambient noise data recorded by the broadband seismic stations in the Taiwan region are analyzed to explore the characteristics of microseisms generated by typhoon. Results show that the spectral amplitudes of microseism in the frequency band of about 0.2-0.3 Hz increased significantly by a factor of about 8 when typhoon approached the coast of Taiwan. On the contrary, the spectral amplitudes of microtremor in the frequency band of 2-3 Hz revealed significant diurnal variations.

S104PS.03

S104PS - Ambient noise

Poster

Numerical simulation of H/V spectral ratios of microtremors with directional dependence caused by lateral heterogeneity

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As observational evidence of directional dependence of Horizontal-to-Vertical (H/V) spectral ratios of microtremors (or ambient noise) , we have obtained data at a site in Uji campus, Kyoto University, Japan, where the bedrock depth varies from east to west from 250m to 420m within the distance of 1 km. This directional dependence can be considered to be the result of 2D subsurface structure. The authors have proposed a new theory to calculate the H/V spectral ratio of microtremors (HVRM) assuming that the wave field is diffuse. This new theory can be applied to understand the subsurface velocity structure as well as the condition of lateral heterogeneity, since the new theory to calculate the HVRM is not limited to horizontally flat-layered 1D structures. For a sufficiently flat, horizontally layered structure, we can easily calculate the theoretical Green's function for that 1D model, but for a laterally heterogeneous underground structure, such as the case of Uji campus, a numerical approach is needed to interpret the H/V spectral ratios. We performed numerical simulation of H/V spectral ratio by Spectral Element Method using point source in both the 1D and 2D models to examine the effect of the 2D basin structure on the HVRM. As a result, we found that a simple 2D basin structure clearly changes the characteristics of the H/V spectral ratio in both perpendicular and parallel directions relative to the basin edge and we have succeeded to simulate qualitatively the difference between the two orthogonal horizontal components as seen in the observed HVRM at Uji campus. We used a more detailed 2D basin structure to numerically simulate the directional dependence of the H/V spectral ratios quantitatively. Also, in order to investigate the validity of our method, we performed numerical simulation of H/V spectral ratios with randomly distributed surface point sources.

S104PS.04

S104PS - Ambient noise

Poster

Correlograms of microseismic noise - Some theoretical considerations

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Microseismic noise is generated by ocean swell at sea and consists primarily of surface waves. Since the establishment of ambient-seismic-noise methods in seismology about 8 years ago it has become common practice to correlate microseismic noise recorded at pairs of seismographs to isolate the component of the noise that propagates between them and is related to the seismic Green's functions for a source at one seismograph recorded at the other. We analyse the expectation of the correlogram for two different characterizations of the source distribution of microseismic noise; 1) a distribution of impulsive point sources distributed and propagating in two dimensions and 2) a distribution of plane waves from all directions in the plane. We find that the two characterizations are equivalent as long as the distributed source region is uniform and extends beyond a distance from the seismographs corresponding to several times the seismograph spacing. The expected correlogram is in that case the imaginary part of the surface-wave component of the Green's function as shown earlier by Sanchez-Sesma et al (2006). We argue that the latter distribution is an appropriate and sufficient description of microseismic ambient noise recorded on land in most cases. It results in a particularly simple relationship between the expected correlogram and the energy flux of noise as it varies with direction. This allows for simple modelling of the effects of a non-uniform distribution of noise sources on the correlogram, in particular, how our ability to recover the Green's function suffers as a function of frequency, seismograph spacing and deviation from a uniform source distribution.

S104PS.05

S104PS - Ambient noise

Poster

Characterization of Azorean soils using ambient vibrations measurements

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The Azores Archipelago is located on a unique tectonic setting – the Azores Plateau – which encloses the unstable triple junction between the Eurasian, Nubian and North American plates. It is formed by nine volcanic islands, aligned WNW-ESE, divided in three groups. The islands of São Jorge, Faial and Pico belong to the central group whose seismicity is characterized by low to moderate magnitude single events or swarms. A significant local earthquake occurred offshore the three islands in July 9th, 1998, causing severe damage in Faial and Pico islands, but also affecting São Jorge. It is well known that subsurface soil conditions have a considerable influence on seismic ground motion characteristics. In spite of similarities in almost all Azorean soils, their seismic response can be different due to the heterogeneities of the volcanic formations and local structure. The goal of this work is to characterize the different soils, checking for the properties that can produce different seismic behaviour, in order to better understand their contribution to seismic ground motion. A comprehensive ambient vibrations survey was performed in São Jorge, Faial and Pico islands. Data was acquired through single-station measurements, along linear and circular arrays. H/V analysis was performed to estimate of the fundamental frequency of the sampled sites. Phase velocity dispersion curves were obtained, using high frequency-wavenumber (HRFK) and spatial autocorrelation (SPAC) methods. To obtain the shear wave velocity profiles, inversion were performed using the Improved Neighbourhood Algorithm (NA) implemented in the Dinver routine (Geopsy software). Joint inversion of H/V and dispersion curves was also attempt. This work was performed in the scope of “Strong ground motion for Azores – SiGMA” project, financed by the Portuguese Science and Technology Foundation (PTDC/CTE-GIX/121957/2010).

S104PS.06

S104PS - Ambient noise

Poster

Effects of non-uniform source distributions on microseismic-noise correlograms

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It has been demonstrated theoretically and experimentally that the seismic Green's function for a source at one seismograph recorded at another can be retrieved from both coda waves and ambient noise by correlating the coda or noise, provided a diffuse distribution of scatterers or noise sources, respectively. This has been described theoretically for idealized source (scatterer) distributions, both in two and three dimensions (Roux et al. 2005, Sanchez-Sesma et al. 2006). For microseismic ambient noise the noise sources are distant in many cases and the problem can be described in terms of a distribution of plane waves from all directions, randomly distributed in time. In that case the expectation of the cross correlation of the recordings at two seismographs in a homogeneous medium can be derived from the azimuthal distribution of the incoming energy density. Based on this approach, the effects of a non-uniform distribution of noise sources on the noise correlogram, and consequently the recovered Green's function, can be investigated in a simple and efficient way. We present numerical simulations of the effect of non-uniform source distributions on deviations from the Green's function as a function of frequency and seismograph spacing.

S104PS.07

S104PS - Ambient noise

Poster

Ambient noise tomographic study of the East African Rift in Mozambique

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A wide range of studies has shown that the cross-correlations of ambient noise can provide an estimate of the Greens functions between pairs of stations. With this purpose we initiated the ambient noise study for Mozambique. Extensively investigated from the Red Sea to southern Tanzania, the East African Rift (EAR) structure is still unknown on its southern tip, Mozambique. The M7 Machaze earthquake of 2006, in central Mozambique, shed new light on the location of the rifting activity, motivating the current study. Seismic studies in Mozambique are scarce due to poor instrumental coverage, but in March 2011 project MOZART (funded by FCT, Portugal) deployed 30 broadband (120s) seismic stations from the SEISUK Pool in central Mozambique and NE South Africa, with the purpose of conducting a tomographic study of the EAR in Mozambique. We applied the Ambient Noise Tomography (ANT) method using broadband seismic data from March 2011 until July 2012. Cross-correlations are computed between all pairs of stations in order to produce the empirical Green functions. From the cross-correlations we obtained Rayleigh wave group velocity curves for each interstation path. The inversion of the dispersion curves allowed us to obtain maps with the lateral variation of Rayleigh-wave group-velocity as a function of period. We also perform an inversion of some selected group velocity dispersion measurements in order to obtain 1D models of the S-wave velocity.

S104PS.08

S104PS - Ambient noise

Poster

The velocity perturbation beneath the Sichuan-Yunnan region from Ambient Seismic Noise tomography

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The Sichuan-Yunnan region is characterized by high concentrations of shallow and intermediate depth seismicity. In the recent years the 2008 Wenchuan MS 8.0 earthquake and 2010 Yushu MS 7.1 earthquake occurred without noticeable precursors. Ambient seismic noise tomography, is becoming an increasingly well established method to estimate surface wave speeds. Compare with traditional earthquake tomography, the ambient noise tomography is able to estimate velocity perturbation, based on the repeatability of the measurements. We collect continuous seismograms, spanning the periods from 2008 to 2012 recorded by 293 broadband stations. After making preprocess, we apply the cross correlation technique to ambient noise data. We analyze the relationship between the SNR and the sum time, accumulate the cross correlation time series for each day and obtain 8 data sets. Using the automatic frequency-time analysis, Rayleigh wave group velocity dispersion curves are measured. Each set of dispersion curves is obtained for 8414 paths. In ambient noise tomography, the average lateral resolution with about 100km is estimated using the method described by Yanovskaya et al. (1990). A 2-D surface-wave tomography, is used to calculate lateral variation sets in group velocity distribution at different periods. At the short period of 15s, the Sichuan Basin and the area along the Red River fault show low velocity anomalies (-5%iª -3%) while the high velocity anomalies (5%iª 8%) lie in the Songpan ¨CGanze block and western Yunnan province. In the 20s map, the main low velocity anomaly (-5%iª -3%) also lies in the Sichuan Basin and Tengchong Volcano-Geothermal area. Analyzing the group velocity distribution in different time, we detect there is velocity perturbation between in the map before the 2010 Yushu MS 7.1 earthquake and in the map after the gigantic shock. The study is supported by the Chinese National Science Foundation (40804009) and CEA Spark Plan (XH1032).

S104PS.09

S104PS - Ambient noise

Poster

Radial anisotropy in the crust from ambient noise tomography in North China

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Rayleigh and Love wave phase velocity dispersion maps at periods from 6 to 40 s from ambient seismic noise recorded by the North China Seismic Array are used to determine the 3-D shear wave velocity and radial anisotropy in the crust and uppermost mantle beneath North China. Significant lateral variation of shear wave velocity and radial anisotropy across the North China are obtained, indicating a variable tectonic process. Shear wave velocity in the upper crust correlates well with geologic provinces on the first order. High velocity anomalies are generally imaged beneath the Yanshan uplift and Taihangshan uplift, while slow seismic velocity is observed beneath the North China and Datong basin. In agreement with previous studies, low velocity anomalies are imaged in the middle and lower crust beneath Shanxi rift and in the middle crust beneath Tangshan seismic zone, which could be attributed to high temperature and partial melt. A Rayleigh and Love discrepancy at periods from 10 to 20 s is observed in some zones and indicates the presence of radial anisotropy in the crust. The Tangshan zone is characterized by relative high velocity anomaly and by strong radial anisotropy with VSH > VSV in the lower crust. The high velocity anomaly probably reflects magmatic intrusion and the strong anisotropy might be resulted from layering of the intrusion and horizontal alignment of crustal minerals due to vigorous extensional deformation. However, low velocity anomaly and small radial anisotropy are observed beneath the Shanxi rift, which can be interpreted as a largely unextended crust and the presence of partial melt in the uppermost mantle, indicating a weak and early-stage rifting process.

S104PS.10

S104PS - Ambient noise

Poster

Determine site effect of Zarqa City and Hashemite University Campus based on microtremors field measurements: A microzonation study

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Zarqa governorate is one of the important governorates in Jordan. It is the second populated after the capital Amman, the location of Zarqa gives the city a great importance because it lies on the main high ways leading to Syria, Iraq and Saudi Arabia, most of Jordan's industries, power plants and strategic projects are located in Zarqa, which gives this city a special importance. The Nakamura's technique is applied in this study for both areas; Zarqa city and Hashemite University Campus in order to determine the resonance frequencies and amplification factors for each site then draw there maps which will be of a great use in the field of civil and structural engineering by enriching the building codes. The results of our study show that; values of resonance frequency F are not affected by the time of recording. While values of amplification factor A can vary accordingly. Results also show that the amplification factor A varies from 0.8 to 8.55 in Zarqa city and varies from 0.4 to 9.36 in Hashemite University Campus, the resonance frequency (F) also varies between 0.37 Hz and 2.98 Hz in Zarqa city and varies from 0.59 Hz to 1.77 Hz in Hashemite University Campus, that means some constructions in the study area, in case of a major earthquake, may experience minor damages respectively.

S104PS.11

S104PS - Ambient noise

Poster

Using ellipticity information for microzonation: application to the Dargahan region,Iran

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Neotectonic and Seismotectonic activities together have caused Major seismicity in Iran. Dargahan city located in east of Iran has a high risk for earthquakes. For calculating amplification factor of soil, it is necessary to know elastic properties of soil especially above the bedrock. One of the best ways to achieve this goal is implementing ambient noise.H/V technique has been proven very convenient for estimating fundamental frequency and amplification factor. To obtain an appropriate estimation for depth of bedrock, one can use different methodologies based upon ambient noise.In this project we utilized the continuous wavelet transform in order to extract the Rayleigh-Wave from ambient noise. Using Rayleigh-wave properties better estimation for bed rock can be found.Time-frequency analysis on each of the three components was performed. Velocity structure of the region was obtained by use of H/V technique. Furthermore by keeping special attention on depth of the bedrock, continuous wavelet transform was implemented, and velocity structure was suggested. The result shows an improvement in velocity structure model obtained by this method, comparing to past techniques.

S104PS.12

S104PS - Ambient noise

Poster

Seismic emission tomography techniques

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Active primary emitters of seismic waves (seismic focus zones, volcanic tremor, seismic noise associated with ore or hydrocarbon deposits, hydrothermal zones, seismic noise caused by various technological processes of field development, etc.), as well as secondary sources of scattered waves (e.g. strong inhomogeneities acting as bright reradiators of any wave processes in the medium) can appear as endogenous emission sources.

The presence of sources of seismic irradiation results in the appearance of coherent components in the stochastic seismic wave field recorded on the surface by a seismic array. Based on estimations of the energy of the coherent components, it is possible to develop a 3-D model of seismic activity of the media or images of noisy objects.

The first experimental studies were performed in an active hydrothermal area in North Iceland. For the first time, we obtained spatial distribution of energy of endogenous microseisms whose pattern was stable over time, and located MS sources in the area under study (approximately 5 km x 6 km, and up to 2 km in depth).

This work became the basis for the development of further multiple passive seismic techniques, which are now widely used in exploration geophysics and seismology.

S104PS.13

S104PS - Ambient noise

Poster

Landslide characterization through seismic noise investigation

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The purpose of this study is to evaluate the capabilities of seismic noise data for detection of landslide sliding surfaces using the H/V spectral ratio (Nakamura method). The case study is *Passo della Morte* landslide, located in the Nord East of Italy (Carnic Alps) along the left side of the *Tagliamento* River. Its surface is approximately 530 thousand m^2 and movements are up to 5 cm/year of on most active zones. The risk associated with this phenomenon is the interference with a National Road (N.R. 52) and two road tunnels. Moreover, *Tagliamento* River flowing at the landslide toe, a possible damming has to be taken into account. Several studies have been carried out to characterize the landslide behavior, via multiple displacement measuring techniques (laser scanner, GPS, extensimeter, inclinometer, TDR), micro-seismic monitoring systems (seismometer and acoustic emission sensor) and seismic survey (GPR and seismic refraction). The main objectives of this investigation are: determine the depth of landslide sliding surface in various sites and reconstruct its geometry by applying the law [$f_0=V_s/4H$] to the resonance frequencies found with Nakamura method. Measurements sites have been set 200m apart on a regular grid covering all the surface to be monitored. Seismic noise has been recorded using a Lennartz seismometer (LE-3D/5s) connected to a Quanterra Q330 (Kinemetrics) acquisition system. Results have been validated by means of several boreholes performed in the examined area. On the other hand, the H/V spectral ratios in the horizontal plane as a function of the azimuth have been analyzed in order to investigate the directivity in seismic site response on the landslide. The results obtained with this work will be presented.

S104PS.14

S104PS - Ambient noise

Poster

An analysis of the H/V spectrum of ambient noise at liquefaction sites

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Deformation features such as sand blows and lateral spreads from recent earthquakes provide opportunities to assess site response and amplification to estimate effects of ground shaking. Here we report observations from sites the source zones of 2001 Bhuj (Mw 7.6) and 1988 Bihar-Nepal (Mw 6.6) earthquakes, both noted for extensive liquefaction. We used H/V spectral ratios for site characterization in terms of predominant frequency using ambient noise recordings. The source zones of Bhuj earthquake (Kachchh rift) and the Bihar-Nepal earthquake (Himalaya) are in regions hosting thick sediment overburden and are associated with extensive liquefaction and ground failure. The proneness of these regions to large earthquakes and the associated high seismic risk have been demonstrated by the 1819 (Mw 7.5) the 1934 (M 8.2) earthquakes, sourced in the same regions. Based on the post-earthquake reports of 1988 and 2001 earthquakes, we chose two sites of large liquefaction (1–3 m radius) where ambient noise recordings were carried out using tri-axial seismometers (1 s period). H/V spectral ratio curves were generated using the Geopsy tool, for a frequency range of 0.1–15 Hz. Interestingly, all of the four curves show similar pattern of two peaks within the range of 0.1-2 Hz with a distinct trough between them. Above 2 Hz, the ratios are almost flat and have no significant variations. In general, a clear H/V peak at low frequency could signify the presence of thick sediment with low shear wave velocity (Vs). The double dominant peaks in low frequencies could potentially mean multiple sediment layers with distinct impedance contrasts. Whether they reflect the intrinsic nature of the sediments or whether they suggest re-disposition of sediment from liquefaction is an issue to be resolved. We also explore whether the use of shallow seismic profiles could significantly aid in relating the H/V spectral ratios with respect to the ground conditions.

S104PS.15

S104PS - Ambient noise

Poster

An Application of Ambient Seismic Tomography Method to Determine Faults in the Tehran basin, Iran

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The Tehran basin is surrounded by many active fault zones, e.g., the Mosha, the North Tehran and the South/North Rey faults, but our knowledge about the 3D velocity structure of the Tehran basin is limited. Because of the low seismicity and the high populated of study area, neither classical local earthquake tomography nor exploration methods are suitable to be applied in Tehran basin. Thus, the ANT method is especially useful in area like Tehran/Iran which contains low seismicity. In this study, we use continuous data recorded by TDMMO (Tehran Disaster Mitigation and Management Organization) and IRSC (Iranian Seismological Center) networks in the Tehran/Iran area. The TDMMO and IRSC networks are equipped with CMG-5T Guralp acceleration proportional sensor and SS-1 Kinemetrics velocity proportional sensor, respectively. We use data from 28 stations for 20 months from 2009/Oct. to 2011/May. After dividing the data to 10 minute time-windows, we follow common-low-frequency technique presented by Bensen et al. (2007). After computation the cross-correlation between vertical component seismograms from pair of stations with matched sensor types, we apply our new stacking method which is based on large RMS values in the time-interval that we expect to receive surface waves. Group velocity dispersion curves are obtained using phase match filtering and frequency-time analysis techniques. Finally, after obtaining 2D velocity maps for each period, Vs velocity maps is extracted applying iterative inversion method. Vs velocity maps show that the bedrock depth varies between 400-1400 m from north to south at the Tehran region. The maps also reveal low-velocity anomalies which present a high correlation with geological features of the study area. Abrupt transitions between regions of high- to low-velocity anomalies show the main faults withing the study area.

S104S1.01

S104S1 - Ambient noise

Oral

Love and Rayleigh phase-velocity maps, 5-35 s, of western and central USA from USArray data

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Continuous long-period data recorded on more than 1500 USArray seismic stations operating in the western and central US are used to map phase velocities of Love and Rayleigh waves at short periods (5-35 s) using a noise-correlation technique. Vertical and transverse records for all station pairs separated by less than 600 km are cross correlated in 4-hour-long segments, and the resulting spectra are stacked for the time period of station operation. Dispersion curves are determined from the locations of zeros in the real component of the correlation spectra using the method of Aki (1957). Phase-velocity maps expanded on a quarter-degree pixel grid are estimated by inversion of phase-velocity measurements. Comparison with predicted phase-velocity maps based on the model CRUST2.0 show good agreement at the longer periods. Variations in the shorter-period maps are dominated by sedimentary layers, whose effects on phase velocities are not well predicted by existing crustal velocity models.

S104S1.02

S104S1 - Ambient noise

Oral

Body waves in the deep Earth as observed through correlation of ambient seismic noise

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Surface waves are dominant in correlation of seismic noise as the sources of the noise are located at the surface. If the noise are perfectly distributed, or if the noise is diffuse it is theoretically possible to extract the full Green's function between two sensors, but body waves travelling through the deep Earth have so far been elusive. Our recent results do however show that it is possible to extract both both P- and S-waves. These body wave observations range from multiply reflected body waves in the crust, through P waves reflected at the top and bottom of the mantle transition zone, to body waves travelling deep in the Earth. These body waves are observed at all distances between seismic sensors, and when the technique is applied on a large set of stations at a global scale, we obtain a seismic section that compares very well with similar sections observed from earthquake data. Notably, only moderate stacking is necessary, so the body waves extracted from noise correlations can be used for imaging purposes, both a a lithospheric scale, complementing seismic sources for teleseismic tomography, to observations of systematic variations of travel times with latitude for waves that propagate through the Earth's inner core. Our results also show that even if the seismic noise is not fully diffuse, it does meet some minimum criteria to obtain very rich information of both surface waves and body waves propagating in the deep Earth.

S104S1.03

S104S1 - Ambient noise

Oral

Dominant ambient seismic noise sources in the Southern Ocean and variability over two decades from WRA, Australia

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Background seismic noise (ambient energy) from long timespans of seismic array data represents an archive of the activity of deep ocean and continental shelf-zone ocean waves. We analyse two decades (1990-2009) of data from the Warramunga Seismic Array (WRA), located in inland mainland Australia using array techniques, in particular the high resolution 'Capon' method which highlights backazimuth and slowness of incoming seismic energy. We identify distinct body wave arrivals with two localised groups of backazimuth values dominant over the two decade period. One of these groups of dominant body wave energy backprojects as P waves to the Kerguelen Plateau and the other backprojects as PP waves to the South Atlantic. We examine the hypothesis that the Southern Ocean is becoming more stormy by investigating key locations that are dominant in the body wavefield recorded at WRA, and the seasonal and inter-annual variations of incoming seismic energy.

Studies that use calibrated satellite observations have highlighted a disparity between increasing wind speeds and measured wave heights during storm events in the southern ocean. This has profound implications for models of the global climate system, including the incorporation of atmospheric carbon dioxide into the ocean as increased wind speed reduces the efficacy of ocean uptake. Seismic data, in particular, seismic arrays, allow an independent measurement of ocean wave activity back through several decades. The inland location allows the nature and location body wave energy recorded at WRA to be identified for 3 hourly intervals, for a considerable proportion of two decades. The relationship between storm severity and seismic noise amplitude is not linear, however, seismic array recordings represent an important independent observable in the understanding of the complex Southern Ocean system.

S104S1.04

S104S1 - Ambient noise

Oral

Rapid seismic wave velocity decrease beneath the fault zone of the 2007 Noto Peninsula earthquake, Japan (Mw6.6), detected by using ambient noise

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We re-analyzed the seismic ambient noise around the source region of the 2007 Noto peninsula earthquake, central Japan, to delineate the temporal change of subsurface structure indicated by Ohmi et al., (2008) more quantitatively. We newly calculated auto-correlation functions (ACFs) of band-pass filtered (1.5 Hz - 10 Hz or 2.0 Hz - 10 Hz) ambient seismic noise recorded with short-period seismometer at each single station as well as the Green's functions (GF) among stations using deconvolution method.

First we applied the 'stretch and compression method' to the computed daily ACFs. Results from lag time range of 3s - 10s and 2s - 7s of the ACFs, both of which sample the upper crust portion, are compared. At the seismic stations whose epicentral distance are around 20 km - 40 km, velocity decreases calculated from 2s - 7s lag time range are up to 2.5%, which generally exhibit larger velocity decreases than those estimated from 3s - 10s range, which is up to 1.5%. It is probably because the velocity changes are localized in the shallower portion at these stations. On the other hand, one seismic station located just above the source fault exhibits larger decrease with opposite tendency, which indicates velocity decrease is localized in the deep portion in the fault zone.

Next we analyzed the GFs around the source region. Frequency range of the GFs we analyzed is 0.1 Hz - 1.0 Hz band, which also samples the upper crust portion. Comparison of stacked GFs before and after the mainshock indicates the GFs that sample source region exhibit the velocity decrease of up to 1.8 %, which is rather small compared to that indicated by ACF just above the fault zone.

These analyses indicate that the velocity decrease is generated just after the mainshock and it probably strongly localized around the source fault region at deeper portion, which may be caused by not only the strong motion but also by some other causes around the fault such as fluid injection.

S104S2.01

S104S2 - Ambient noise

Oral

Extracting seismic core phases with array interferometry

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Seismic body waves that sample Earth's core are indispensable for studying the most remote regions of the planet. Traditional core phase studies rely on well-defined earthquake signals, which are spatially and temporally limited. We show that, by stacking ambient-noise cross-correlations between USArray seismometers, body wave phases reflected off the outer core (ScS) and twice refracted through the inner core (PKIKP2) can be clearly extracted. Temporal correlation between the amplitude of these core phases and global seismicity suggests that the signals originate from distant earthquakes and emerge due to array interferometry. Similar results from a seismic array in New Zealand demonstrate that our approach is applicable in other regions and with fewer station pairs. Extraction of core phases by interferometry can significantly improve the spatial sampling of the deep Earth since the technique can be applied anywhere broadband seismic arrays exist.

S104S2.02

S104S2 - Ambient noise

Oral

Green's Function retrieval from non-synchronized noise sources to characterize the subsoil velocity structure

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To retrieve the Green's function using noise records it is necessary to have isotropically distributed sources, or at least to know their directivity. However, when working with noise of human origin at higher frequencies this condition cannot always be fulfilled. To overcome this issue we use seismic noise induced by non-synchronized sources, such as one person jumping or walking to improve the retrieval of the Green's function. This also allows us to change the location of the noise excitation in a controlled way to analyze the effect of the directivity and source distance on the Green's function. On the monitoring station of the Helmholtz Centre for Environmental Research (UFZ) in Bad Lauchstädt, 35 km west of Leipzig, Germany, we recorded this kind of increased noise and active source data, in order to assess the quality of the retrieved Green's function. Using the data of the moving jumping person we found that the Green's function is quite sensitive to the distance of the noise source; we observe that for sources further away from the profile the information for frequencies higher than 20Hz is lost. On the other hand, when the non-synchronized noise sources are close to the ends of the profile we can create seismic time-distance sections which are comparable to those obtained from the active source data. We use these seismic sections to obtain the coefficients of the Fourier-Bessel transform as a representation of the whole seismic wave field. In terms of these coefficients the wave field is inverted for the subsurface velocity structure. We found reasonably similar velocity profiles for the overlapping frequency range of the non-synchronized source data and the active source data. This implies that the actively increased noise, with simple non-synchronized sources (jumping or walking) along the direction of the seismic profile, is suitable to obtain the same information as with an active source experiment.

S104S2.03

S104S2 - Ambient noise

Oral

Ambient noise recorded at dense broadband stations in Portugal, Cape Verde and Mozambique: Characterization and sources

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Several research projects have deployed dense broadband (BB) networks in Portugal and Africa over the last years. Project WILAS (West Iberia Lithosphere and Astenosphere Structure, PTDC/CTE-GIX/097946/2008) increased the number of BB deployed in mainland Portugal to more than 50 (permanent + temporary) during the period 2010 – 2012. In 2011/12 a temporary pool of 12 seismometers continuously recorded BB data in the Madeira archipelago, as part of the DOCTAR (Deep Ocean Test Array Experiment) project. Project CV-PLUME (Investigation on the geometry and deep signature of the Cape Verde mantle plume, PTDC/CTE-GIN/64330/2006) covered the archipelago of Cape Verde, North Atlantic, with 40 temporary BB stations in 2007/08. Project MOZART (Mozambique African Rift Tomography, PTDC/CTE-GIX/103249/2008), covered Mozambique, East Africa, with 30 temporary BB stations in the period 2011 – 2013.

In this presentation we take advantage of the great volume of data recorded to characterize the ambient noise recorded in Portugal (mainland, Madeira and Azores), Morocco, Cape Verde and Mozambique. The noise is characterized by means of probability density functions of power spectral density of continuous data. Time-series of noise levels at different frequencies and spectrograms are computed to visualize the variations of ambient noise over different time periods and frequency bands. We correlate sea level, storm activity, and other atmospheric parameters with the variations in ambient noise level. The analysis performed gives clues concerning data quality (poor quality data is clearly identified), Earth structure (a correlation is visible between sedimentary basins and amplification of seismic noise), and sources of ambient noise at different frequency bands. The data that we use allows us to investigate sources of seismic noise both in the Atlantic and Indian Oceans.

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S104S2.04

S104S2 - Ambient noise

Oral

Observation and simulation of interstation Green's functions obtained from continuous microtremor observation in the Osaka basin

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The Osaka sedimentary basin in Japan is a Quaternary basin filled by the Plio-Pleistocene Osaka group, terrace deposits, and alluvium deposits with thickness of 1 to 3 km over the bedrock, and it is surrounded by mountain ranges formed by active fault systems. The Uemachi active fault system also underlies the Osaka urban area. In order to predict strong ground motions for future events of the Uemachi fault and others, the detailed basin velocity structure model is indispensable as well as the detailed source fault models. Such a basin velocity structure model should be examined from many sides by observations. The velocity structure of the Osaka basin has been extensively investigated by using various geophysical techniques. Based on these surveys and ground motion simulations for observed events, its 3D basin velocity structure models have been developed and improved for decades (e.g., Kagawa et al., 1993; Horikawa et al., 2003; Iwata et al., 2008; Iwaki and Iwata, 2011).

In order to obtain new type of data, we temporarily installed velocity sensors at 15 sites inside the basin to record microtremors continuously from March 2011 to March 2013. The seismic interferometry technique is applied to continuous microtremor records for retrieving interstation Green's functions. Both Rayleigh- and Love-wave type signals are identified in 0.1-0.5 Hz in observed interstation Green's functions. For example, estimated Love-wave group velocity along a line inside the basin is as low as 350 m/s in 0.2-0.5 Hz. Theoretical interstation Green's functions are simulated using the FDM and the present 3D basin velocity structure model. The simulation roughly matches well the observed Green's functions, but we also found discrepancy between them for some station-pairs.

Now we are improving the velocity structure model using incorporating kinds of data (Sekiguchi et al., 2013). We will see the improvement of model performance by comparing simulation results in the further study.

S104S2.05

S104S2 - Ambient noise

Oral

Green's functions from ambient noise: Assumptions and their significance

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Cross-correlation functions between two seismological stations are strongly related to the Green's functions between these stations, and given some assumptions the correspondence between the Green's function and the cross correlation function is exact. We examine to what extent some of these assumptions may mean that the Green's function is not correctly estimated using cross-correlation. It is well known that the Green's function may be biased if the source field is strongly anisotropic. Using a simple extension of existing theory to include a point scatterer we show that the second order differences (i.e. those relating to the scatterer) between the cross correlation function and the Green's function are dependent in a complex manner on the interplay of a non-uniform source field and structure close to the receivers. We also show that even to first order there may be significant differences between the Green's and cross-correlation functions, if the sources are not temporally random. We also briefly consider some complications related to instrumentation. We conclude that in any given case unless the relevant assumptions have been suitable investigated it is difficult to exclude the possibility that the cross correlation function, especially the higher order components, may be a significantly biased representation of the Green's function. In some cases, methods other than cross correlation may be more robust in extracting structural information from continuously registered passive seismic data.

S104S2.06

S104S2 - Ambient noise

Oral

Investigation of milard landslide characteristics using ambient noise measurements

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Unstable slope mass can amplify the input seismic motion and may be reactivate the landslide. The site effects (presence of topography, impedance contrast between the landslide mass and the substratum, effects of lateral boundaries of landslide) is considered having a significant effect on the seismic amplifications. However the understanding of seismic slope response is still limited. Recording of ambient noise can be useful for studying the effects of the sliding mass on the seismic input, recognition of landslide mass characteristic. This paper shows the result of a case study on the seismic behavior of Milard landslide using ambient noise measurement. This landslide is located in North East of Tehran (Iran) adjacent the Latian dam's reservoir and was re-activated in Feb.2006 and damaged road facilities and some houses. The toe of landslide is located under the reservoir water level. The microtremor single station measurements had been conducted on 122 points of landslide and neighboring stable area and a multi-stations measurement will be performed in near future.

The HVSR analysis has been carried out to obtain The predominant frequency (f0), amplification factor (Am), vulnerability index (Kg) and directivity of landslide response. The results show the decreasing trend of resonance frequency and increasing trend of amplification ration over the sliding zone of more displacement, in good agreement with previous geotechnical and monitoring investigations. Moreover a good relation can be observed between the direction of maximum mass displacement and directivity of HVSR results.

S105PS.01

S105PS - Seismology of Polar Regions and Glaciers

Poster

Variations in antarctic icequake activity assessed by automatic classification techniques

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Global warming causes significant mobility of glaciers (e.g. rapid retreat) that produces a large variety of different seismic signals connected with ice berg calving, basal sliding and fracturing of ice. Therefore, evaluating those events (i.e. changes of their occurrence in space and time) allows to monitor glacier dynamics. However, classical seismological trigger mechanisms (e.g. STA/LTA) are unable to discriminate between tectonic and cryogenic seismic event types. Further, the manual classification carried out by an expert is impractical for processing large volumes of continuous data. For that reason, we use an stochastic classifier called Hidden Markov Models to automatically recognize different seismic signal classes observed at the Neumayer seismic network in Antarctica. Due to the lack of a general classification scheme for cryogenic seismic events recorded at the Neumayer stations an intensive study of different types of cryogenic seismic events and their appearance in the seismogram is required first. Our approach allows to start the automatic classification as soon as interesting events are identified, minimizing the problems caused by the missing categorization scheme grown from longstanding expert knowledge (e.g. preparing a large training data set to learn classifier properties).

We identify three regions of clustered seismicity around the Neumayer network manually. Based on this categorization we construct a classifier from corresponding signal types. The automatic scanning procedure shows a strong tidal dependence for seismic events of different backazimuthal regions. Supported by these results we associate the defined seismic signal types with different glacial phenomena. Providing the basis for the investigation of a larger data set we are confidently to detect seasonal and decadal changes in seismicity pattern in Antarctica in order to contribute to a better understanding of glacier dynamics and its embedding in the global warming context.

S105PS.02

S105PS - Seismology of Polar Regions and Glaciers

Poster

Earthquakes and icequakes recorded on drifting ice floes as seismometer platforms

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Recording the seismic activity of polar regions often requires to install seismometers on ice. Across the Arctic Ocean, seismological experiments are only feasible with seismometers mounted on drifting ice floes, which cover year-round the central Arctic Ocean to more than 90%.

During 4 deployments, we acquired 72 days of continuous seismic data on ice floes using small-aperture seismic arrays consisting of 3-4 seismometers. Here we present the variety and characteristics of seismic signals recorded on the ice floes. We obtained clear P-wave signals from teleseismic earthquakes of about magnitude M>6. Distant earthquakes originating in the Arctic Ocean can be reliably recognized by their T-waves. The background noise at the ice floes is larger than that of land based stations especially for frequencies < 0.5 Hz. At higher frequencies, local earthquakes as small as about M 0-1 can be detected. A sharp P-onset, a difficult to identify SP-phase and a train of multiply reflected arrivals from the water column are characteristic for local earthquakes. The earthquake records are intermixed with numerous icequakes travelling horizontally across the array of receivers. They often exhibit a long-period signal coda. The distinction between seismogenic and cryogenic signals is difficult and has been done manually in all our surveys. Apart from short transient signals, the ice floe records include long-lasting tremor signals. In spectrograms, an increased signal energy in a narrow frequency band of about 2-5 Hz is visible for hours. Occasional harmonic tremor signals which are well-known from Antarctic icebergs might be attributed to distant Greenlandic icebergs.

S105PS.03

S105PS - Seismology of Polar Regions and Glaciers

Poster

Observation of low shear-wave velocity at the base of the polar ice sheets: Evidence for enhanced anisotropy

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1 EOST, Seismology, France; 2 IPGP, Seismology, France

The subglacial structure of the arctic and antarctic continents remains unknown because of the presence of thick ice caps. Geological direct investigations are almost impossible and seismological studies of the structure underneath are open to misinterpretations because of the strong reverberations of the seismic waves inside the ice layer. Knowing the thickness and the elastic parameters of the ice layer is important in order to analyze properly the seismic data in studies of the crust structure.

We analyse seismic data from the broadband stations located on the Antarctic and Greenland ice sheets in order to determine the large-scale seismic parameters of the polar ice sheets. The P-to-S converted waves at the ice/rock interface and inside the ice sheets and their multiples (P-receiver functions) are used to estimate the in-situ P-velocity Vp and the P-to-S velocity ratio Vp/Vs of the ice. The thickness of the whole ice layer is precisely known either from Radio Echo Soundings or from ice core drillings allowing thus an accurate determination of Vp and Vp/Vs. At some places in and near the Wilkes Basin, a sedimentary layer is probably squeezed between the ice and the bedrock. We find that the polar ice caps have a two-layer structure, the upper layer of variable thickness about 2/3 of the total thickness with velocities very close to the ice standard values and the lower layer preserving a standard Vp but with about 25% smaller shear-wave velocity and a more or less constant thickness. The shear-velocity drop in the lower layer may be the evidence of a strong anisotropy induced by preferred orientation of ice crystals and by fine layering of soft and hard ice layers. Enhanced water content may also play a significant role. A large variation of ice viscosity with depth is therefore expected and heterogeneous flowing of the polar ice sheet. This heterogeneous flowing may invalidate the use at great depth of ice dating models based on monotonic layer thinning.

S105PS.04

S105PS - Seismology of Polar Regions and Glaciers

Poster

Earthquakes in Greenland

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GEUS, Denmark

In Greenland a station separation of around 400km mean that many earthquakes are only detected on one or two stations. The development of the seismic monitoring have gone from having only three seismic stations in Greenland up to the late 1990'ies, till today where there are 18 permanent stations. All stations are equipped with broadband sensors and all of the permanent stations transmit data in real time. The recent major improvement of the seismic monitoring is performed by the Greenland ice sheet monitoring network (GLISN, http://glisn.info). The primary goal of GLISN is to provide broadband seismic data for the detection of glacial earthquakes. GLISN is now fully implemented with Iridium real time data transfer is in operation at five stations.

In the Ammassalik region in Southeast Greenland, where small earthquakes often are felt, data from a temporary additional station has been utilized for a study covering 9 months in 2008/9. In this period 62 local earthquakes have been analyzed and re-located. Some of the events had formerly been located from distant stations by using a universal earth model. The result of this localization was a scattered distribution of the events in the region. The locations have now been improved by using a local earth model along with phase readings from two local stations not previously included; ANG in Tasiilaq and ISOG in Isortoq. From relocating the events two zones with a higher degree of seismicity than in the rest of the region are observed. The first zone is located by felsic intrusions. The second zone is at the boundary between the Archaean Craton and the Ammasalik region where reworked Archaean gneisses are dominating the geology. During the analysis it was observed that the additional information from the local stations are of great importance for the result. http://glisn.info

S105PS.05

S105PS - Seismology of Polar Regions and Glaciers

Poster

Continuous broadband seismic observation on the Greenland ice sheet under Greenland ice sheet monitoring network

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We have installed the ice sheet broadband seismograph station, called ICESG (DK.ICESG) in June 2011, in collaboration with IRIS Polar Services under the GreenLand Ice Sheet monitoring Network (GLISN), which is a new, international, broadband seismic capability for Greenland being implemented through the collaboration between Denmark, Canada, France, Germany, Italy, Japan, Norway, Poland, Switzerland, and the USA. The primary purpose of GLISN project is to define the fine structure and detailed mechanisms of glacial earthquakes within the Greenland Ice Sheet. These glacial earthquakes in the magnitude range 4.6-5.1 may be modeled as a large glacial ice mass sliding downhill several meters on its basal surface over duration of 30 to 60 seconds. Glacial earthquakes have been observed at seismic stations within Greenland (Larsen et al, 2006), but the coverage was very sparse and a broadband, real-time seismic network was needed to be installed throughout Greenland's Ice Sheet and perimeter. The National Institute for Polar Research and Japan Agency for Marine-Earth Science and Technology are members of GLISN project and we have started to operate ICESG station since 2011. The station is equipped with a CMG-3T broadband seismometer and a Quanterra Q330 data logger. We have visited the station again in May, 2012 and successfully retrieved one year of continuous records from the broadband seismometer and updated the telemetry system to eventually allow real time monitoring of the station. The observed three component seismograms demonstrate that the quality of this ice sheet station is good enough to record not only local earthquakes around Greeland but also teleseismic earthquakes. We could record three component broadband seismograms for April 11, 2012 Off the west coast of Northern Sumatra earthquake (Mw8.6). These seismograms show high signal to noise ratio characteristics of this station.

S105PS.06

S105PS - Seismology of Polar Regions and Glaciers

Poster

The crustal structure in central-eastern Greenland derived from receiver-function analysis

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We present models of the crustal structure for a 300 km x 600 km large area in central-eastern Greenland derived from receiver functions. The project forms part of the TopoGreenland project, which has the objectives of understanding the background for substantial recent uplift around the North Atlantic ocean. So far only very sparse information on the crustal and lithospheric mantle structure in interior Greenland is available due to logistic problems related to the up to 3.4 km thick ice cap. The TopoGreenland seismic data acquisition forms the first regional seismic array in this region.

Data from 24 STS-2 broadband seismometers are available. The model is based on data from two permanent stations, 10 temporary stations that have operated for 3 years on the ice cap, and 12 stations that have operated on rocks in the 200 km wide zone which is only ice covered during the winter. 17 stations were installed along a 600 km long profile at 70°N between the east coast at Scoresby Sund and a location close to the centre of the ice cap. Additional stations cover a 300 km wide band with nominal station spacing of 100 km. The stations operated on the ice and on bedrock between June 2009 and May 2012.

The presented models are based on both Ps and Sp receiver function calculations. Primary aims are to map the Moho depth, as well as the crustal and lithospheric velocity structure. The models will be compared to tectonic features and topography in the area with the objective of assessing isostatic balance of the crust in order to understand the interplay between uplifting mountain chains and earlier rifting and break-up.

S105PS.07

S105PS - Seismology of Polar Regions and Glaciers

Poster

A how-to guide for improving near-real-time seismic data coverage across the Greenland ice sheet

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1 IRIS PASSCAL, United States

Advances in battery and instrumentation technology have led to an increased presence of seismic instrumentation in the polar regions, where stations can now run year-round in Greenland and Antarctica. With the remote nature of many of these stations, telemetry is still impractical at most sites and station visits can be limited to once per one or two years. In many cases, the limited transmission of state of health (SOH) and data snippets (highly decimated waveform samples on the order of one minute in duration per day) has been accomplished by daily or more frequent satellite transmissions. Yet there is still a lot not known about the condition and health of the station until the site visit is actually made, making the correction of severe problems difficult if the right tools and parts were not brought along on every service trip. A new type of telemetry was introduced this past summer to GLISN (GreenLand Ice Sheet monitoring Network), a collaborative project that has installed or upgraded broadband stations in and around Greenland. In the summer of 2012, six stations in the GLISN network, three coastal and three along the ice divide, were serviced and the Iridium Router-Based Unrestricted Digital Internetworking Connectivity Solutions (RUDICS) system was installed using Xeos units to allow for all SOH and 1sps waveform data to be collected during daily scheduled data pulls via satellite. This improved communication between the stations and the network operators has allowed for more efficient troubleshooting of problems, advance awareness of station needs for future site visits, as well as the downloading of windows of higher sample rate data (40 and 100sps) for targeted regional and local earthquake events. These stations, in addition to the 11 stations currently with real-time data, are improving the latency, quality, and quantity of Greenland seismic data.

S105PS.08

S105PS - Seismology of Polar Regions and Glaciers

Poster

Local seismicity in the area of Suasselkä postglacial fault in northern Fennoscandia

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The Drilling Activel Faults in Northern Europe (DAFNE) project aims to investigate, via scientific drilling, the tectonic and structural characteristics of postglacial (PG) faults in northern Fennoscandia. During the last stages of the Weichselian glaciation (ca. 9,000 - 15,000 years B.P.), reduced ice load and relaxation of accumulated tectonic stress resulted in rapid uplift in Fennoscandia. Active faulting occurred with fault scarps up to 150 km long and up to 30 m high. Some of these faults show week seismicity even presently. That is why studying of PGF would create information relevant for proper seismic hazar evaluation and for planning and exploitation of such critical facilities as nuclear waste disposal and underground mines and exploitation of economic raw materials. The main purpose of the DAFNE/FINLAND seismic monitoring experiment was to investigate seismic events originating from the Suasselkä PG fault using densely-spaced DAFNE temporary array. As the fault is located at large distance from permanent stations of regional seismic networks in Fennoscandia, no natural seismicity from the fault was reported. That is why we installed 8 short-period and 4 broad-band 3-component seismic stations in the close vicinity of the fault area in September, 2011. The array recordings have being analyzed manually and automatically, in order to identify natural earthquakes from the fault area. The detected events were relocated and spectral characteristics of signals were analysed, in order to discriminate natural events originating from the fault from both production blasts and mining induced events originating from the Kittila Gold Mine. As a result, we found several dozens of events originating from the fault area with that could be of natural origin.

S105S1.01

S105S1 - Seismology of Polar Regions and Glaciers

Oral

Case-IPY : The experiment and the research inspired by the International Polar Year

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The CASE-IPY project, part of the larger POLENET initiative of geophysical observations for the International Polar Year, was built on the Strasbourg group's previous experience of running seismological stations in Antarctica, both on rock sites (Dumont d'Urville station), and directly on the ice plateau (Concordia station). For CASE-IPY, we deployed 8 temporary seismic stations on the Antarctic plateau: 3 situated near Concordia itself (starting 2008), and the other 5 regularly spaced between Concordia and Vostok (2010-2012), following the maximum in ice topography. The 3 stations near Concordia were used as test sites to experiment different solutions, and to converge on a design for the 5 main stations. We encountered some technical problems in our field deployments that were essentially due to a combination of extreme environmental conditions, isolation of deployment sites, limited available funds and at times sheer bad luck. They resulted in significant equipment failure and very little data recovery from the 5 main stations; the prototype stations, however, continue to function correctly to this day. We shall present the field experiment and the lessons we have learned from it, as well as an overview of research conducted by the group in Strasbourg that was inspired by the International Polar Year. Research topics include the seismic structure of snow and ice from H/V methods and receiver functions, seismic attenuation in the Australian and Antarctic plates from multiple ScS waves, and the seasonal variation of microseismic noise in Antarctica and in the Arctic.

S105S1.02

S105S1 - Seismology of Polar Regions and Glaciers

Oral

Seismic monitoring of the Arctic region - Problems and prospects

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Seismological monitoring of geophysical processes in the European Arctic is important both to establish the level of earthquake risk and to obtain a baseline for background seismicity in the region. Furthermore, improved knowledge about the presence or absence of significant seismic activity in this area is very important for understanding the geodynamics of the Barents region. Such a background estimate of the seismicity is also crucial for the successful application of micro-seismic monitoring during oil and gas production.

The Archangelsk Branch of the Geophysical Survey of RAS operates a network of 11 seismic stations in the region of interest. The goal of this work is to obtain improved accuracy in locating seismic events and to lower the magnitude threshold for reporting seismic events in the GS RAS main publications – the operative seismological catalogue and the seismological bulletin. Currently, the seismic monitoring of the Arctic territory is very uneven, with the best monitoring capability in the western part. This network will make a great contribution in improved monitoring of the eastern part. The network is still under development, but the overall view on seismicity of the Arctic region has already been significantly changed.

The new data being accumulated about the seismicity should essentially affect the estimation of seismic hazard of the region and should be taken into account during the generation of a new map of general seismic zoning. Several source zones have already been revealed in regions previously considered as «aseismic» or of low activity: the area of Arkhangelsk 22.10.2005 (M = 2.5), north of Novaya Zemlya 11.10.2010 (M = 4.5), the North Urals 24.12.2012 (M = 4.0) etc. Note that the long-term exploitation of oil and gas fields and other resources in the region could increase the seismic hazard. A preliminary map of active mines and explosion sites is presented.

S105S1.03

S105S1 - Seismology of Polar Regions and Glaciers

Oral

Studying the microseismicity of the Gakkel Ridge from drifting sea ice

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A small seismic array was deployed on drifting sea ice at the Gakkel Ridge (85° N, 10° E) in the Arctic Ocean using an hovercraft research platform. The array consisted of three new prototype seismic stations placed in a triangle about 5.5 km on the side on 1-2 m thick sea ice. At each station, the signal from a hydrophone just below the ice, was digitized and recorded continuously. A wireless network connected all nodes of the array with a central logging point at the hovercraft where status, position and data was monitored during the experiment. Each station has a GPS which provides accurate position and timing. The array was deployed upstream the rift valley of the anticipated ice drift. It would drift southwards over the valley before it eventually would be too far off the axis to register the small events or could give any hope of reliably locating the events. A total of 25 days of recording were achieved, with about 10 events on average each day. The recorded events have been discriminated from other cryogenic signals, analyzed and their location have been attempted to be determined. We will present the experiment and its approach, with the challenges that were experienced in recording microseismicity in an environment covered with an all-year and continuously moving sea ice. Examples of the events and the results of the processing will be shown.

S105S1.04

S105S1 - Seismology of Polar Regions and Glaciers

Oral

Revisiting current activity on the Pärvie fault - a glacially induced magnitude 8 earthquake in northern Sweden

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As the ice retreated at the end of the Weichselian glaciation, a number of very large earthquakes, M7-8, occurred in northern Fennoscandia. Recent studies indicate that these events were triggered by the glacial isostatic adjustment process, but driven by plate tectonics. Poor knowledge of the deep geometry of the faults and of the ambient stress field, however complicates the mechanical analysis. The expansion of the modern Swedish seismic network (SNSN) into the north in 2004 revealed that these faults are currently active with microearthquakes. A temporary deployment of seismic stations on the 150 km long Pärvie fault was undertaken between 2007-2010. Running stations in remote locations in the mountains at 68 degree north was challenging, with power generated by wind mills and solar panels. The temporary network added significant further data and constraints to the analysis of events on the active fault zone. Here we revisit the Pärvie data, complemented by three more years of sparser data, but at a higher seismicity rate than previously, and refine the locations and depth estimates of the events in order to better constrain the fault zone geometry at depth. Focal mechanisms are calculated for the events and we perform an analysis of the earthquake generating stress field along the fault. Our estimate of current stress along the fault provides input to the analysis of the interaction between tectonic and glacial stresses that triggered rupture on these faults 10,000 years ago.

S105S1.05

S105S1 - Seismology of Polar Regions and Glaciers

Oral

Seismic network operation in the Vatnajökull ice cap, Iceland; towards a volcano early warning system

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Many of Iceland's most active volcanoes are covered by glaciers, thereby limiting access of monitoring equipment to their activity. Their microseismic activity is therefore generally not well monitored. The seismic signals emitted by these volcanic areas are also more varied than those observed from Iceland's subaerial volcanoes and some are not fully explained. Due to melting of the glacier ice above geothermal areas associated with the volcanoes, water often accumulates in their location, to be released in sudden subglacial floods called jökulhlaups. Seismic tremor and ice quakes are associated with the floods and the tremor signal can be seen several tens of kilometres away. There is an on-going debate about the source of the tremor signals, over whether it is the movement of the subglacial water, sudden boiling in the geothermal systems as a result of the sudden pressure drop, or magma-ice interaction in minor subglacial eruptions.

The focus of a new FP7 FUTUREVOLC volcano supersite project is on the development of a multiparametric volcano monitoring and early warning system through real-time processing of seismic and other geophysical signals. This requires high network sensitivity to microseismicity and other signals emanating from the volcanoes, but is problematic at glaciers because of the limited access. In the present warming climate, rock outcrops (nunataks) are emerging from the ice improving accessibility somewhat, but to properly monitor seismic signals from volcanoes deep inside the ice caps, instruments placed in the ice itself are also needed. Continuous, real-time operation of monitoring equipment in harsh climate, heavy snow accumulation and icing conditions on a glacier, however promises to be a considerable challenge. To minimise the number of false alarms from the real-time processing system, the network and processing will need to discriminate between the different tremor sources and track their temporal evolution and location.

S105S2.01

S105S2 - Seismology of Polar Regions and Glaciers

Oral

3D lithosphere structure of the Antarctic plate and its geodynamical implications on the plate evolution

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Seismographs deployed across most of Antarctica since the 4th International Polar Year strongly improved seismic station coverage in the whole continent. Using thousands of fundamental-mode Rayleigh-wave dispersion curves retrieved from the observations of ~120 seismic stations in Antarctica and surrounding regions, we constructed a 3-D S-velocity model for the lithosphere of the Antarctic plate using a single-step surface-wave tomographic method improved from Feng & An (2010), and then inverted for crust and upper-mantle temperatures using the velocities on the basis of thermoelastic properties of mantle minerals (An & Shi, 2007). A Moho depth map of the continent and a lithosphere-asthenosphere boundary depth map of the entire plate are then retrieved from the velocity and temperature models. The lithosphere of East Antarctica (EANT) is greater than 150 km thick and similar to Precambrian cratons elsewhere, however, the crust beneath the Gamburtsev Subglacial Mountains (GSM) is so thick as to be like a present orogeny. This may imply that the crust/lithosphere beneath the core of EANT have never been transformed after the last orogeny and the ancient orogen structure is still kept today. In contrast, the crust and lithosphere beneath West Antarctica are thin and have been extended during Phanerozoic evolution, and the slab which subducted beneath the Antarctic Peninsula ~50 My bp cannot be resolved in our models. The oceanic lithosphere of the Antarctic plate is generally thickened as a function of crustal age, and the iso-temperature contour of the lithospheric upper mantle flattens for old regions, in correspondence with the obviously flattening of old seafloor elevations. However, we do not find significant flattening at the lithosphere base if the areas close to the Kerguelen LIP and St. Paul-Amsterdam hotspot are not considered.

S105S2.02

S105S2 - Seismology of Polar Regions and Glaciers

Oral

Lithospheric structure of Antarctica and implications for geological and cryospheric evolution

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Deployment of the AGAP/GAMSEIS array of 24 broadband seismographs in East Antarctica and the POLENET/ANET deployment of 33 seismographs in West Antarctica reveal the detailed crust and upper mantle structure of Antarctica for the first time. We use 20-180 s Rayleigh phase velocities determined from a two-plane wave decomposition of teleseismic Rayleigh waves to invert for the three dimensional shear velocity structure. In addition, Rayleigh wave group and phase velocities obtained by ambient seismic noise correlation methods provide constraints at shorter periods. Receiver functions provide precise estimates of crustal structure beneath the stations, and P and S wave tomography provides models of upper mantle structure down to ~ 500 km depth along transects of greater seismic station density.

The new seismic results show that the East Antarctic highlands are supported by crust up to ~ 55 km thick, and are underlain by Precambrian continental lithosphere that initially formed during Archean to mid-Proterozoic times. The absence of lithospheric thermal anomalies suggests that the mountains were formed by a compressional orogeny during the Paleozoic. In West Antarctica, the crust and lithosphere are extremely thin near the Bentley Trench and Byrd Basin, which represent currently inactive Cenozoic rift systems. Slow seismic velocities beneath Marie Byrd Land at asthenospheric depths is consistent with a mantle plume. Volcanic earthquakes detected in this region indicate the presence of currently active magma systems. The results suggest large lateral changes in lithospheric thickness, mantle viscosity, and heat flow. Extremely high heat flow is predicted for much of West Antarctica, consistent with recent results from the WAIS ice drilling. Using the seismic results to estimate mantle viscosity, we find several orders of magnitude difference between East and West Antarctica, with significant implications for models of glacial isostatic adjustment.

S105S2.03

S105S2 - Seismology of Polar Regions and Glaciers

Oral

Monitoring of slow seismic events from Arctics using the data of the POLENET/LAPNET broadband temporary array

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* Monitoring of slow glacial seismic events from Greenland at regional distances was one of the major targets ofthe POLENET/LAPNET passive seismic experiment in northern Fennoscandia (northern parts of Finland, Sweden, Norway and Russian Karelia) during the IPY 2007-2009. The POLENET/LAPNET array recorded high-frequency continuous data of 37 temporary stations, which were in operation during the time frame from 01.05.2008 to 31.09.2009, and of 21 stations of selected permanent networks in the Fennoscandia. Most stations of the array were equipped by broadband STS-2 seismometers. Glacial events from Greenland were identified using manual analysis of the continuous POLENET/LAPNET data filtered by a bandpass filter from 35 s to 140 s frequency band. The detected events were located using standard array techniques. Our study proves that glacial earthquakes in Greenland show a strong seasonality, with most of events occurring during summer months in 2007, 2008 and 2009. The detected slow events have their origins not only at marine-terminated glaciers, but also in offshore areas of Greenland. As the epicentres of these events are located mainly in the areas with high speed of ice flow, they could be due to interaction of ice sheet with solid bedrock. However, they could also be tectonic events. We also identified and located a number of slow evens originating from marine-terminated glaciers in Svalbard. In addition, the array detected a number of slow earthquakes from northern part of Mid-Atlantic Ridge, the vicinity of Svalbard, Jan Mayen Island and Arctic Canada. No slow earthquakes from Iceland were recorded during the POLENET/LAPNET experiment. Our result shows that analysis of recordings of broadband stations in low frequency band can provide new information not only about temporary changes in Greenland Ice Scheet, but also about seismicity and spreading processes in the Mid-Atlantic Ridge and other areas of Arctics. (*POLENET/LAPNET Working Group)

S105S2.04

S105S2 - Seismology of Polar Regions and Glaciers

Oral

Frequency dependent noise sources around Greenland

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Seismic noise recorded in the frequency band 0.1 and 0.33 Hz is called secondary microseisms. They are dominantly Rayleigh waves which are generated by the interaction of ocean gravity waves. The corresponding sources and their variation with time are still not poorly constrained. Here we investigate the complex noise generation around Greenland. A statistical analysis of the noise polarization at broadband stations in Greenland (GLISN network), Canada and Europe shows that the detected noise sources are frequency dependent. Stations in Western Canada record low frequency noise generated in the North Atlantic and Pacific oceans and higher frequency noise only from the North Atlantic. Greenland stations do not detect the Pacific sources. Sea ice in the Labrador Sea in winter is well correlated with the decrease of high frequency seismic noise and with the change of the source azimuths. Indeed, in winter the sea ice prevents the generation of noise sources in that area. We then model seismic noise using an oceanographic model that takes into account coastal reflection and show that we are able to accurately model the noise spectra temporal variations and frequency content. The strongest sources are generated in deep ocean close to the ridge axis. Sources generated by coastal reflection are negligible along the Western Canada coast and more important along Greenland and European coasts. We further show that the strongest noise source locations are consistent with the back azimuths derived for the polarization analysis and that they depend on both frequency and bathymetry. Finally we are able to reproduce the high frequency noise variablility related to variationof the sea ice

S105S2.05

S105S2 - Seismology of Polar Regions and Glaciers

Oral

Seismic noise on the Greenland ice sheet

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Over the last decade, the interest in glacier seismology has drastically increased. To date, seismic monitoring has provided valuable information about subglacial processes, iceberg calving and ice deformation. Seismic investigations are an attractive alternative to traditional in-situ glaciological measurements. So-called 'icequakes' reveal details about englacial fracturing, basal processes and englacial water flow. These events can be located with high-density seismic networks, which allows for monitoring of ice flow processes over an extended glacier region.

Most glacier-related seismic investigations have focused on isolated seismic transients emitted by discrete seismic events. However, recent investigations have highlighted continuous seismic sources within glacier ice with characteristics of sustained seismic tremor that resemble those seen in volcanic environments. Accordingly, icequake location and waveform modeling techniques cannot be applied to these signals. On the other hand, glacial tremor location and signal characteristics are of supreme importance, as these parameters elucidate englacial water flow and changes thereof. Such water flow can perturb subglacial conditions and hence critically alter ice flow.

Here we apply linear and adaptive beam-forming techniques to continuous seismic noise records from the Greenland ice sheet. The signals were recorded with a high-density campaign seismic network in summer 2011 on the ablation zone near Jakobshavn Ice Stream. The noise records contain highly coherent signals, whose origin likely depends on the chosen frequency band. We discuss these findings in the context of melt water drainage and transient changes in glacier dynamics.

S105S3.01

S105S3 - Seismology of Polar Regions and Glaciers

Oral

Geophysical constraints on glacial earthquakes and glacier dynamics in Greenland

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NO COUNTRY SELECTED -

Approximately half of the ice-mass loss currently occurring in Greenland is the result of dynamic processes leading to the export of calf ice from the Greenland Ice Sheet's marine margins. Rapid changes in glacier flow speeds, thinning rates, and terminus positions have been observed during the past decade, but remain poorly understood. Many of Greenland's largest glaciers also produce seismic signals equivalent in amplitude to those from tectonic earthquakes of M ~ 5. Interdisciplinary study utilizing seismological, space-based remote-sensing, and geodetic data identifies the source mechanism that generates this seismic signal as discrete ice-loss events of cubic-km scale at the margins of large outlet glaciers. Glacial-earthquake source parameters derived from waveform modeling agree well with independent estimates of changes in glacier geometry from satellite remote-sensing data. Patterns of earthquake occurrence in space and time are closely linked to changes in glacier dynamics, including variations in the grounding state of the calving front. The annual number of glacial earthquakes observed in Greenland continues to increase with time, as new glaciers initiate earthquake activity and already-active glaciers produce more frequent earthquakes. Seismological observations combined with geodetic, meteorological, and glaciological information demonstrate that glacial-earthquake ice-loss events are a primary control on short-term velocity variability at marine-terminating outlet glaciers. Glacial earthquakes provide a ground-based remote-sensing tool for the Greenland Ice Sheet, and allow for the assessment of glacier flow variability driven by surface melt and tidal forcing that would otherwise be obscured by the calving signal.

S105S3.02

S105S3 - Seismology of Polar Regions and Glaciers

Oral

On the spatial-temporal distribution of icequakes on Svalbard

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Using seismic signals to monitor glacier activity has become a popular approach in recent years. In this study we use several years of seismic data recorded on three permanent broadband stations on Svalbard and on the Spitsbergen array to locate and analyze icequakes in the northwestern and southern part of the archipelago. Limited station coverage and weak or ambiguous signal onsets limit the amount of events we can locate using P and S phase arrivals and backazimuths. However, we obtain a sufficiently high number of localizations to study spatial-temporal patterns. For about 400 on-shore events we have clear evidences that they are of glacial origin. We select a number of master events from this group and apply automatic detection methods to the continuous records in order to obtain a more complete catalog. The spatial-temporal distribution of all detected and located events lead to the following results: A clear cluster of events is observed around Kongsfjorden in northwestern Svalbard. Another cluster with similar waveforms is observed in southern Spitsbergen in the Hornsund area. Both clusters show a clear seasonal variability, i.e. much more events are observed from late summer on to end of autumn. Furthermore, seismic signals show a clear peak in the amplitude spectrum between 1 and 3 Hz, a characteristic feature which has been observed at calving glaciers in Alaska and on Greenland. The epicenters of events of the Kongsfjorden and Hornsund cluster are located in areas of active (i.e. calving, fast moving) glaciers. For a third event cluster within the area of the Nathorstbreen system however, almost all events occur within a short time period between February and March 2009 coinciding with a major surging phase of that glacier. These events lack a clear spectral peak what indicates a different source mechanism. Possibly, the first two clusters are more calving dominated, whereas stick-slip and/or crevassing is observed in the third cluster.

S105S3.03

S105S3 - Seismology of Polar Regions and Glaciers

Oral

Tracking icebergs along the Dronning Maud Land shoreline, Antarctica, with the TROLL seismic station

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In February 2012, NORSAR installed a new, permanent, broadband seismic station (TROLL), in the vicinity of the Norwegian research station Troll, situated at a minimum distance of about 230 km from the coast of Dronning Maud Land, Antarctica. Apart from standard seismological research, TROLL data are used to study cryogenic seismic signals. During the first year of the station's operation, signals emitted from icebergs hold a prominent position among the cryoseismicity recorded at TROLL. Such signals were first encountered in TROLL records in April 2012 and by spatiotemporal correlation with satellite imagery could be associated with four large icebergs drifting along the shoreline, carried by the westward cyclonic gyre. The recorded signals, also recorded at other seismic stations in the region (SNAA, the Neumayer seismic stations, NVL), are highly dispersive in character, some of them exhibiting tremor-like features (several harmonics, frequency gliding, etc.) and others being mostly chaotic. Analysis with the application of the short-time Fourier transform and the continuous wavelet transform is used to identify signals, classify them and investigate the possible processes that generate them (iceberg calving, collision with the ice-shelf, scraping on the ocean floor, etc.). Information about the icebergs involved (position in time and space, dimensions, possible calving, etc.) evaluated jointly with bathymetry and tide data is important to constrain the possible scenarios. The progress of this study will be presented, with focus on observations at TROLL.

S105S3.04

S105S3 - Seismology of Polar Regions and Glaciers

Oral

Icequakes, shear-wave anisotropy and deformation in the Rutford ice stream

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Ice streams provide major drainage pathways for the Antarctic ice sheet. The stress distribution and style of flow in such ice streams produces elastic and rheological anisotropy, which informs ice flow modelling as to how ice masses respond to external changes such as global warming. Here we analyse elastic anisotropy in the Rutford ice stream, West Antarctica, using observations of shear wave splitting from three-component icequake seismograms to characterise ice deformation via crystal preferred orientation. Over 110 high quality measurements are made on 41 events recorded at five stations temporarily deployed near the ice stream grounding line. To the best of our knowledge this is the first well-documented observation of shear wave splitting from Antarctic icequakes. The magnitude of the splitting ranges from 2ms to 80ms and suggest a maximum of 6% shear wave splitting. The fast shear wave polarisation direction is roughly perpendicular to ice flow direction. We consider three mechanisms for ice anisotropy: a cluster model (VTI model); a girdle model (and HTI model); and crack-induced anisotropy (an HTI model). Based on the data we can rule out a VTI mechanism as the sole cause of anisotropy - an HTI component is needed, which may be due to ice crystal a-axis alignment in the direction of flow or the alignment of cracks or ice-films in the plane perpendicular to the flow direction. The results may suggest a combination of mechanisms are at play, which represent vertical variations in the symmetry of ice-crystal anisotropy in an ice stream, as predicted by ice fabric models.

S105S3.05

S105S3 - Seismology of Polar Regions and Glaciers

Oral

Using passive seismic observations to study the dynamics of Whillans Ice Stream, Antarctica

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Discharge from Earth's major ice sheets is dominated by fast-flowing glaciers and ice streams. Fast flow is most often associated with regions of rapid basal sliding, enabled by enhanced lubrication at the ice-bed interface. Knowledge of the spatial and temporal variability in bed lubrication is thus essential to understanding the behavior of fast moving sectors of ice sheets. We examine the spatial pattern of basal lubrication on the Whillans Ice Stream in Antarctica using passive seismic emissions that originate from regions of higher basal friction. The majority of motion in the 150 km downstream portion of Whillans Ice Stream occurs via a stick-slip cycle similar to that of earthquakes. The origin of this stick-slip behavior arises from the presence of a large (~10 km radius) asperity at the bed of the ice-stream that inhibits stable motion. Monitoring of naturally occurring seismic events originating from the bed of the ice stream indicate that the large asperity is composed of many smaller (~10 m) asperities. Stable flowing regions outside of the asperity are typically associated with lower levels of seismicity, indicating more efficient basal lubrication in these regions. These results indicate that the large scale variability in the flow of Whillans Ice Stream is driven by meter scale features at the ice-bed interface. Additionally, our results demonstrate the ability of large (> 30 instruments) seismic deployments to investigate spatio-temporal pattern of basal conditions across broad regions (~80 km radius) of ice streams. Future development of instrumentation that enables large seismic deployments on ice streams will help advance our understanding of ice sheet dynamics.

S106aPS.01

S106aPS - Modern macroseismology

Poster

Macroseismic study of Krn Mountains 1998 Mw5.6 earthquake (NW Slovenia) based on effects on natural environment using Environmental Seismic Intensity scale (ESI 2007)

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The 12 April 1998 Mw5.6 Krn Mountains earthquake with a maximum intensity of VII-VIII on the EMS-98 scale caused extensive environmental effects. The application of intensity scales based mainly on damage to buildings was limited in the epicentral area, because it is a sparsely populated high mountains area. On the other hand the effects on the natural environment were prominent and widespread. These facts and the introduction of a new ESI 2007 scale motivated a research aimed to evaluate its applicability to this event. All environmental effects (rockfalls, landslides, fallen boulders, secondary ground cracks and hydrogeological effects) were described, classified and evaluated by a field survey, analysis of aerial images and analysis of macroseismic questionnaires. It was realized that only rockfalls (78 were registered) are widespread enough to be used for intensity assessment, together with the total size of affected area. They were classified in five categories according to their volume. Distribution of very large, large and medium size rockfalls has clearly defined an elliptical zone, elongated parallel to the strike of the seismogenic fault, for which the intensity VII-VIII was assessed. This isoseismal line was compared to the EMS-98 isoseism derived from damage-related macroseismic data and similar shape was obtained. EMS-98 isoseism is slightly larger, but its size is controlled by a single intensity point lying quite far from others, at the location where local amplification is likely. The ESI 2007 scale has proved to be an effective tool for intensity assessment in sparsely populated regions not only for very strong, but for moderate earthquakes as well. This study has shown that the quantitative definition of rockfall size and frequency, which is diagnostic for each intensity, is not very precise in ESI 2007, since the rockfall size is related not only to the level of shaking, but also depends on the vulnerability of rocky slopes.

S106aPS.02

S106aPS - Modern macroseismology

Poster

Comparison of EMS98 intensities estimated by automatic methods and expert analysis using online or communal questionnaires

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The reliability of the automatic intensity estimation is important as they are today used for automatic shakemaps communications and crisis management. The comparison of the different techniques used for assessing macroseismic intensities help estimating uncertainties on the resulting values. In charge of intensity estimations in France, BCSF has collected and analyzed more than 47000 online individual macroseismic questionnaire since 2000. These macroseismic data allow us to estimate one SQI value (Single Questionnaire Intensity) for each form. Several techniques are used : 1) direct use of images selected on a menue by the witnesses (one image per EMS-98 intensity value, allowing us to quickly issue an intensity map of the communal intensity by averaging the SQIs related to each city) «; 2) use of several statistical methods of correlation between a new filled questionnaire and previously analyzed questionnaires ; 3) application of the USGS algorithm (DYFI form); 4) by human «expert analysis» of the questionnaires. The three first methods, are objective independent of expert judgment, the latter one requires expert analysis and can take into account incoherent answers. We compare the SQIs obtained by these methods from our a large database and discuss the coherency and variations between automatic and manual processes. We explain the characteristics of the data, and present a critical analysis of the above techniques by using different statistical approaches. We compare the preliminary communal intensities based on averaged SQIs with the classical intensities based on a complete macroseismic survey applying the EMS-98 rules. Note that beyond intensity VI, on-line questionnaires are useless and a field survey is necessary. In France, BCSF lead a macroseismic intervention group (GIM).

S106aPS.03

S106aPS - Modern macroseismology

Poster

Characterization of the human vibration perception of earthquakes

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The estimation of macroseismic intensity is based on specific effects description which are influenced by some variables as mentioned in the macroseismic scale degree definition. For example, the Mercalli-Cancani-Sieberg (MCS) and the Modified Mercalli Intensity (MMI) scales describe the second degree as “Felt only by a few people, extremely susceptible, in perfectly quiet situations, almost always on the upper floors of buildings.” The European Macroseismic Scale (EMS) describes the fifth degree as “felt indoors by most, outdoors by few. Many sleeping people awake.” We focus on variable “situation” (what were you doing? Sleeping, still or walking) and variable “observer’s location” both referred to people. The last variable is mentioned as “observer floor position” if you were within a building, otherwise to “outdoor”. Both variables have a partial influence on intensity assessment because they are used to give a weight only to the specific question referred to vibration perception. However it is important to find the right weights of the variables, which are not quantified in the macroseismic scales and never experimentally studied, due by the difficulty in the past to overcame the scarcity of data. Today, thanks to internet diffusion and to citizen collaboration (crowdsourcing), the experimental approach is now possible. The present analysis involves the macroseismic questionnaires (now 520000) of the Istituto Nazionale di Geofisica e Vulcanologia (INGV, http://www.haisentitoilterremoto.it), referred to Italian earthquakes and collected shortly after an earthquake occurrence. The results of this analysis show the importance of the situation variable and its rule into the intensity degree definition.

S106aPS.04

S106aPS - Modern macroseismology

Poster

Intensity assessment method for on-line macroseismic questionnaires

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The purpose of our method is providing an easy and efficient tool to collect and elaborate internet-based intensity data of a seismic event in order to carry out the corresponding macroseismic field. The strength of our method stems from results obtained almost in real time and the total large amount of data (more than 520000 compiled questionnaires, collected since June 2007 related to almost 6000 earthquakes) even for small intensity earthquake events. The wide diffusion of Internet connection, in fact, allows us to record, with low costs, information on whole area where the earthquake is felt having, just after few minutes, a preliminary evaluation of earthquake severity, and a reliable macroseismic field after few hours. Our method is based on assigning to each given answer a previously established distribution of scores for all related macroseismic degrees. The scores of all the answers for each municipality are then summed up, in order to find the mode of the total distribution. The assessed degree is that one corresponding to the mode. A particular analysis is dedicated to the relative percentage of not felt, usually underestimated in on-line macroseismology, to improve the low degrees (II, III, IV) determination.

S106aS1.01

S106aS1 - Modern macroseismology

Oral

A database of intensity data for South Africa

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A database of intensity observations from instrumentally-recorded earthquakes in South Africa has been compiled. The database contains just over 1,000 intensity data points (IDPs) that have been assigned from macroseismic observations retrieved from newspaper reports and questionnaires, and also digitised from previously published isoseismal maps. The database includes IDPs from 57 earthquakes with magnitudes in the range of MW 2.2 to 6.4 and based on observations at epicentral distances of up to 1,000 km for the larger events. Sixteen of the events have 20 or more IDPs, with half of these events having more than 80 IDPs. The database is dominated by relatively low intensity values, mostly determined from human perception of shaking rather than structural damage. However, 19 IDPs have intensity values that are greater than VI. For each of the IDPs, the intensity value is reported – generally on the MMI-56 scale or another that may be considered equivalent – together with the epicentral distance and the moment magnitude. Using geological maps of South Africa, the location of macroseismic observations and published IDPs were correlated with surface geology to classify, where possible, IDPs as either on 'rock' or 'soil'. Such classifications were possible for 60% of the IDPs, with the uncertainty in locations precluding such a classification for the remaining data points. A few soil IDPs show a strong influence of site geology. A final subset of the database with 436 'useful' IDPs was created from 15 earthquakes which have a minimum of five 'useful' IDPs. The 'useful' IDPs were identified after removing those IDPs that appeared to have been influenced by site conditions, those with trivial intensity values (MMI = I), and those that were created using a single observation. This subset of the database can be used in further studies, such as selection of suitable attenuation equations.

S106aS1.02

S106aS1 - Modern macroseismology

Oral

Comparison of macroeismic data and ground-motion amplitude spectra for moderate-size earthquakes, evidence for site effects ?

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Analysis of a set of accelerometric and macroseismic data related to three moderate-size earthquakes which occurred in north-eastern France and south-western Germany in 2003-2004 (4.4 <Mw <4.8) has been performed by Lesueur et al. (J. seismol., 2012). Accelerometric stations are located at epicentral distances between 29 and 180 km, and macroseismic intensities vary from II to V (EMS-98). One of the conclusions of this analysis is that averages of macroseismic data in area extending up to10 km away from each accelerometric station are well correlated with the ground motion amplitude spectra at frequencies lower than 10 Hz and above 25 Hz. In contrast, very poor correlation is observed between 10 and 25 Hz. The high correlation observed below 10 Hz is understood as linked with a magnification effect at the free oscillation frequencies of typical building of the region. The lack of correlation between 10 and 25 Hz, together with the rise of correlation above 25 Hz is more difficult to explain. In this presentation, we first review the observed correlation between the spatial variations of amplitude spectra and macroseismic parameters estimated from individual Internet reports for several events. In a second step we discuss the reason why we observe such a puzzling behaviour in the correlation plots above 10 Hz in terms of spectral content and site effects. One possibility for the lack of correlation between 10 Hz and 25 Hz could be a large variability in the ground motion response spectra at frequencies of soil resonance. Indeed, large variability of the soil conditions among the different accelerometric stations could explain why the local ground motion presents no spatial coherency, while the macroseismic observations averaged over 10 km are more related to lower frequency observations. At frequencies higher than 25 Hz, correlation rises and reaches values close to the PGA-macroseismic intensities correlations.

S106aS1.03

S106aS1 - Modern macroseismology

Oral

SISMOTem-Antilles: an innovative pilot of macroseismic data close to seismic sensors

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In order to be efficient during seismic crisis management, authorities need to dispose of rapid assessment of the earthquake impacts. To answer to this need as well as to ensure quick information of the public, one can usually appeal to empirical relations allowing conversion of ground-motion parameters to intensity values and vice-versa: the so-called “GMICEs” (Ground Motion to Intensity Conversion Equations). Now, the problem is that GMICEs are usually derived from instrumental and macroseismic data independently collected within different contexts. These data allow producing only limited correlations as the observed effects of earthquakes are not directly related to a seismic record. In that context, it appears essential to dispose of both types of data (instrumental and macroseismic) for close and homogeneous recording/observation sites in order to reduce uncertainty of GMICEs.

As to do that, BRGM and BCSF are conducting an original and unique experiment allowing acquisition of macroseismic data close to permanent seismic sensors in French West-Indies (Caribbean): the SISMOTem-Antilles project. The innovative proposed approach consists in setting up a network of voluntary witnesses frequently present very close to seismic sensors, coupled to an online testimony process feeding into a database. This approach seems to be particularly well adapted to French West-Indies where many seismic sensors are located in administrative/educational buildings or in the vicinity of habitations. Regular presence of many peoples may facilitate constitution of such a network of witnesses. Theses data will improve research on GMICEs and their utilization.

The SISMOTem-Antilles project takes up two challenges:

- To constitute, sensibilize and make durable a citizen network of witnesses nearby existing seismic stations;
- To offer to the witnesses network a specific testimony process allowing the collect of macroseismic data and further availability to the scientific community

S106aS1.04

S106aS1 - Modern macroseismology

Oral

KF approximation for great earthquakes? --test by the2008 Wenchuan earthquake

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Kinematic Function (KF) approximation is a simplified formulation of earthquake intensity distribution which has been used in retrieving the source parameters of historical earthquakes, and is potentially useful for the rapid estimation of intensity distribution to assist in earthquake emergency response and rescue actions. This approach was mainly based on, and applied to, the study of moderate to major earthquakes. Whether this approach holds for major to great earthquakes is one of the questions with direct practical implications. The May 12, 2008, Wenchuan MS8.0 earthquake of southwest China, being a great inland earthquake with extended rupture, provides an opportunity for testing the KF approach. Using strong motion data and intensity data, we investigate the applicability of KF in explaining the intensity distribution. By a series of numerical simulations, we discuss the uncertainties of the application of KF method to the study of historical great earthquakes.

S106bPS.01

S106bPS - Investigating historical earthquakes from documentary sources

Poster

The autumn 1919 Jacarilla/Torremendo (SE Spain) earthquake series. Macroseismic vs. instrumental studies

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IAG, Universidad de Granada, Spain

On the 10th September 1919 several slightly damaging earthquakes struck the towns of Jacarilla, Torremendo (near Alicante, SE-Spain) and others nearby. Magnitude estimations for the largest two events of the series are M=5 approx, and its epicentral intensity was evaluated as VIII (MSK). On recovering records and documents for an instrumental study of this earthquake, the original macroseismic documentation, thought lost, was found.

This lucky discovery gives us the opportunity to study the main shock and its series from instrumental and macroseismic sources, in this order. New instrumental location and Mw estimates are now available as well as ESM98 reevaluated macroseismic intensities.

Questions about the different macroseismic evaluations existing, and on macroseismic and instrumental location and magnitude for these events, as well as the number of recorded aftershocks are raised.

We are concern about the facts that, in 1919 (and most likely up to 1955) detection and location of small to moderate size earthquakes occurred in the Iberian Peninsula from macroseismic sources look more reliable than instrumental record results.

S106bPS.02

S106bPS - Investigating historical earthquakes from documentary sources

Poster

Reevaluation of the most important earthquakes produced in Romania in 18th century

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The purpose of this paper is to present the new historical documents related to the earthquakes produced in Romania in 18th century. This new information has come from the original documents and compilation of the historical source, such as chronicles and manuscripts on that time, and related books, reports, and searchable publicly available on the internet. In particular, detailed description of damage coming from these documents provides new quantitative information necessary to re-evaluate the historical earthquakes. In some cases, this information contains also data about aftershocks, foreshocks, landslides, etc. The maps with intensity data points are presented for the most important earthquakes of 18th century. All these events were generated at intermediate depth in the Vrancea seismic zone, known as the source generating the most destructive earthquakes in Romania. We followed the approach developed in the SHARE project (SHEEC catalog, Stucchi et al., 2012) in order to integrate the new results into the European database.

S106bPS.03

S106bPS - Investigating historical earthquakes from documentary sources

Poster

Tsunami folklore and potential tsunami risk on the eastern coast of Taiwan

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Taiwan is located at the convergence of the Eurasian and Philippine Sea Plates. It is a complex boundary due to the presence of two subduction zones with opposing polarities with a high convergence rate. However, no large tsunamis are thought to have struck the eastern cost of Taiwan because of the seafloor topography. Nevertheless, folklore tells of a large sea wave that struck an area of Chenggong on the eastern coast of Taiwan. This event is estimated to have occurred in the middle of the 19th century based on the history of the area. Folklore of the Ami tribe, an original Taiwanese tribe, says that big sea waves struck the area, then plants and trees all perished, and afterwards the place was named as Malaulau. The Malaulau tsunami had a run-up of at least 18 m above sea level 400 m inland from the coast. Despite an estimated run-up height of more than 18 m, no other folklore related to the tsunami has been found in areas adjacent to the site, which may be due to several reasons, such as that the tsunami was amplified at Chenggong due local topographic effects or that Ami tribes lived near the feet of mountains at that time, which may have caused the tsunami to not have been recorded elsewhere. Considering the importance of understanding the possible dangers posed to the eastern coast of Taiwan, numerical tsunami simulations were carried out to study localized amplification effects. Three tsunami sources were studied: 1) the westernmost portion of the Ryukyu trench, 2) offshore of Chenggong and 3) the source of the 1771 Yaeyama tsunami along the Ryukyu trench. The numerical simulations using detailed bathymetric maps reveal that the tsunami waves are not significantly amplified around Chenggong; the eastern coast of Taiwan should have been affected by the 19th century tsunami if it was large enough. This study emphasizes the importance of investigation of paleotsunamis on the eastern coast of Taiwan to assess the risk for future tsunami hazards.

S106bS1.01

S106bS1 - Investigating historical earthquakes from documentary sources/Archaeoseismology

Oral

Tools for compiling the Global Earthquake History, a GEM project

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The study of historical earthquakes is of wider interest than just the seismic hazard and risk community. In the scope of the two-year project (October 2010-November 2012) «Global Earthquake History», developed in the framework of GEM, a reassessment of world historical seismicity was made, from available published studies.

The scope of the project is the time window 1000-1903, with magnitudes 7.0 and above. Events with lower magnitudes are included on a case by case, or region by region, basis.

These are the project's main outputs:

- the «Global Historical Earthquake Archive (GHEA)», an online resource that contains the best and most recent information available for each individual earthquake, collected in the framework of the GEH project activity; the Archive is in many respects the most important output. It represents the platform for compiling, collating and comparing studies of historical earthquakes, which can be exploited by future studies.
- the «Global Large Historical Earthquake Catalogue (GLHECAT)» that is a product of GHEA, and represents the best global historical earthquake catalogue that can be compiled today from publically-available materials.

The project fulfilled its goals by establishing an innovative set of methodological and technological tools necessary for facilitating long-term developments in historical seismicity for studies over the next decades.

S106bS1.02

S106bS1 - Investigating historical earthquakes from documentary sources/Archaeoseismology

Oral

AHEAD, the European Archive of Historical Earthquake Data

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AHEAD is the result of a coordinated effort among various European Institutions to establish a distributed archive of historical earthquake data for the Euro-Mediterranean area. AHEAD is driven by a consortium where involved regional archives are encouraged to adopt a set of common procedures and where each of them is made responsible for their own material. Since the late eighties the seismic history of Europe has been defined mostly on a national basis by the use of regional catalogues relying on a huge quantity of macroseismic data, partially available as published material and partially kept in the Institutions archives. This scattered knowledge has been developed adopting different procedures making it difficult to retrieve all the available information, especially while compiling continent-wide catalogues. AHEAD is an attempt to pave the way for the future historical research in the Euro-Mediterranean area by putting together in a critical way the most relevant material. The core is the inventory, where each earthquake has a corresponding list of referenced material. Two types of materials are presented: historical earthquakes studies that may interpret the historical records in terms of Macroseismic Data Points (MDPs) and parametric earthquake catalogues. AHEAD mostly concentrates on publicly available material, discouraging the habit of personal communications. AHEAD can be accessed by means of a website; it contains nearly 5000 earthquakes from 1000 to 1899, and more than 300 published items, some of which cover hundreds of earthquakes. For about 50% of the earthquakes there is at least one study that provides MDPs, also retrieved and available on the website. SHEEC 1000-1899, the SHARE European Earthquake Catalogue, is the first scientific product that fully exploited the Archive potential. SHEEC derived from AHEAD the earthquake list and the most updated historical datasets, and processed them with updated and repeatable procedures.

S106bS1.03

S106bS1 - Investigating historical earthquakes from documentary sources/Archaeoseismology

Oral

Seismic history of Turkey: A compilation for the period 1000 AD to 1903

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The seismic history of Turkey from written sources spans for about two millennia. The distribution of the events however lacks homogeneity both in time and space, tending to cluster around main cities, also changing as a function of the cities' relative importance in time.

The present work is devoted to the recompilation of the historical earthquake data of Turkey for the period 1000 AD to 1903, resulting from the common efforts of the GEH (Global Earthquake History), SHARE (Seismic Hazard Harmonization in Europe) and EMME (Earthquake Model of the Middle-East region), projects. By merging the main current earthquake catalogues with earthquake specific studies based on traditional material, the aim of this compilation is to obtain a revised and updated historical earthquake catalogue for Turkey.

Entries from different sources are collected, stored in a database, and finally carefully compared, in order to retrieve the best available knowledge of each event and select the most reliable parameters. This approach also helps in the identification of false, duplicate or mislocated events. Whenever possible, intensity and damage data are also collected and compiled.

The present study also concentrates on the seismic histories of particular historical centers. We present the seismic history of Istanbul, that of Lake Van region as recently investigated, and the first results obtained focusing on Erzincan and Antioch regions, two of the most important centres in Anatolia throughout history.

S106bS1.04

S106bS1 - Investigating historical earthquakes from documentary sources/Archaeoseismology

Oral

From raw data to seismogenic sources: A case study from the western Gulf of Corinth, Greece

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In the framework of the ANR-SISCOR project on the western part of the Gulf of Corinth, a multidisciplinary investigation is in progress to improve the current knowledge on the seismicity and the characterization of the seismogenic sources. A complete reappraisal of the information on the past earthquakes (1000-1899) is being carried out, first by retrieving the available studies and published data, and then going back to the primary, documentary sources. This will lead to an updated earthquake catalogue for the study area. The research performed thus far has allowed to estimate more than 100 new macroseismic datapoints of the most important events of the 19th century. Based on the new intensity distribution, location and magnitude of these events have been reevaluated with different methods. Results from the investigations of sedimentological analysis of cores that are currently beeing performed in the Gulf of Corinth, between Aigion and Trizonia Island, will also be used to complement the analysis, and to help constrain the link between these historical earthquakes and the active faults that produced them.

S106bS1.06

S106bS1 - Investigating historical earthquakes from documentary sources/Archaeoseismology

Oral

New insight on the earthquake of 26 March 1511

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The earthquake on 26 March 1511 is considered to be the strongest one that happened in Slovenia in the times of written history. Several contemporary reports from Carniola are preserved, and many more from neighboring Friuli and Veneto. The reports describe destroyed churches, castles and towns in numerous localities. Some memorial tables from the restructuring period are preserved as well. It is now clear that the main shock has happened on 26 March in the afternoon. The existing theories about the possible multiple shocks are therefore proven to be wrong.

The most important primary sources for Slovenia give details about the effects of the earthquake in Ljubljana, Škofja Loka, Kamnik, Tolmin, Bovec, Turjak, Piran etc. Although this earthquake was named “Idrija earthquake” in the older seismological literature, there are no contemporary sources for the town of Idrija. The landslide near Idrija that had blocked the river and caused flooding of the town and mercury mine can not be attributed directly to the earthquake, and is therefore considered as a probable secondary effect.

S106bS2.01

S106bS2 - Investigating historical earthquakes from documentary sources/Archaeoseismology

Oral

Seismological evidence for a tsunami earthquake recorded four centuries ago on historical diaries

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Historical documents reveal that a series of large earthquakes occurred in the past 1400 years along the Nankai Trough at an interval of 100-150 years. These documents, combined with recent seismological data, show that the five most recent large earthquakes are megathrust events that occurred on the upper interface of the Philippine Sea Plate. However, the 1605 Keicho earthquake differs from these five events: extensive tsunami damage occurred along the western coast of Japan, despite a relative lack of damage due to strong ground motions. Based on these data, the earthquake is thought to be a tsunami earthquake, which generates a disproportionally large tsunami compared to its seismic waves. In this study, we carefully examined a diary in which the writer described earthquakes felt in Kyoto over 37 years. At present, 17 volumes are preserved. A total of 83 earthquakes were recorded over 17 years in the preserved volumes. Comparing the felt events from 1950 to 1994 at the same site are likely to be comparable to those documented in the diary, written 400 years earlier. The detailed analysis shows that it is extremely unlikely that the writer did not record the event in the diary. Assuming that this event occurred on the shallower plate interface near the trench axis, a tsunami simulation was performed based on the data recorded in historical documents. If the 1605 earthquake is a tsunami earthquake, the 1605 earthquake cannot be considered an ordinary thrusting event on the seismogenic zone of the plate interface that occurs at an interval of 100-150 years along the Nankai Trough. If we exclude this event from such a group, the interseismic interval increases to approximately 200-400 years, which implies that large earthquakes occur with a wide range of interval.

S106bS2.02

S106bS2 - Investigating historical earthquakes from documentary sources/Archaeoseismology

Oral

Japanese historical earthquakes in early modern - the latest result

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The research on historical earthquakes of Japan started very early by Naumann and Hattori in 1878. Sekiya, Omori, Terada, Imamura, Musha, Kawasumi, and Usami piled up the effort to exhume historical materials related to earthquakes. After the tragedy in 1995, Japanese government made the densest network in the world to measuring seismic intensities. The compiled data of it for the known earthquakes allow us to re-examine the intensities obtained from the historical materials and to pursue and to narrow down source regions of old earthquakes. We are now constructing seamless earthquake catalogue of Japan from 1586 to 1922, after that year, JMA catalogue is modestly reliable. For years before 1885, we have to use historical materials. And even after 1885, when the systematic collection of felt intensity reports in Japan was started by the government, the same macro seismic technic is effective. Although we had the knowledge of huge tsunami disaster at the southern part of Tohoku district in 869, we could not warn local people enough in advance before 2011 tragedy. We have to spread the research result even we are still working on the catalogue. In this opportunity, I would like to show our current achievement to seismologists in the world, since it will be worth to share with those, who also do the similar research in various countries.

S107PS.01

S107PS - Array seismology – Status and Perspectives

Poster

Approaches to array and network processing for enhanced nuclear explosion monitoring

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Single and multiple seismic array stations can provide an exquisitely sensitive monitoring capability for nuclear test sites which exceeds significantly that for general seismicity using standard algorithms. We here outline some methods for enhanced seismic monitoring employed at NORSAR. A detection on a single array with parameters consistent with a signal anticipated from a given site can initiate an Alert, followed by an automatic search in specific time-windows for corresponding detections at other global stations. For sites with available waveform templates from previous events, pattern detectors can identify similar signals even at low SNR; correlation detectors recognize wavetrain repetition on single or multi-channel datastreams and matched field detectors recognize the wavefront-specific phase and amplitude relationships between sensors of an array. Both are effective on arrays where scattering and incoherence preclude classical array processing. Spectrogram beamforming may be applied to larger arrays to detect and classify incoherent signals. Site Specific Threshold Monitoring uses data from a network of arrays to produce a continuous “threshold trace” indicating the upper bound of the magnitude of a seismic event which could have occurred at that site at any given time. The above methods are demonstrated for monitoring of the North Korea nuclear test site.

S107PS.02

S107PS - Array seismology – Status and Perspectives

Poster

Enigmatic Rg and Sn observations at the Eskdalemuir seismometer array

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We apply the generalised F detector (Selby, 2013) to data recorded by the seismometer array at Eskdalemuir (Scotland, UK) over a period of six months, to assess the distribution of local and regional seismic signals observed. Phases such as Pg and Lg show clear temporal variations indicating that they are mostly anthropogenic in origin, most likely related to quarrying and mining in northern Britain and Ireland. Surprisingly however, over 20% of the detections observed are Rg (short period Rayleigh wave) arrivals from a single azimuth in the frequency band 2.5-3Hz, and a substantial number of Sn arrivals are also detected at a similar azimuth. The Rg and Sn signals show clear individual arrivals with short duration, and their origin is intriguing. While the Lg detections are typically associated with Pg or Pn arrivals, the Rg and Sn detections show no temporal or azimuthal relationship to other phases, and there appears to be no quarrying or mining in the direction indicated. Initial investigations suggested that the phases might be related to forestry operations in the immediate vicinity of the array. However, close analysis of the arrival times of the Rg and Sn phases revealed a convincing correlation with a particular anthropogenic source, at a distance of about 20km from the array.

S107PS.03

S107PS - Array seismology – Status and Perspectives

Poster

Array analysis of oceanic microseisms at NORSAR

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We investigate variations in the microseismic wavefield at NORSAR between summer and winter months of four years, focusing on 1998/99. Semiannual variations in source locations and energy of microseisms are well known and related to seasonal changes in storm activity over northern and southern oceans. However, similar variations have recently also been observed in H/V ratios within the microseismic band, the causes of which remain unclear. At NORSAR, we observe distinct seasonal differences in the H/V curve for long-period secondary microseisms (135-185 mHz), while outside of this band, the curve stays remarkably constant. High-resolution FK analysis for the primary microseismic frequency band shows a significant transverse component with higher velocities than the vertical and radial components (roughly 3.8 km/s vs. 3.35 km/s), while mean source directions are similar. Using forward calculations for a Fennoscandian velocity model, this signal is identified as fundamental mode Love wave. Within the secondary microseismic frequency band from 100 mHz to 185 mHz, we observe energy travelling with the fundamental mode Rayleigh wave velocity on vertical as well as horizontal components. However, we also find a significant amount of energy with very low slownesses (< 0.1 s/km) on the vertical component during summer, which is absent during winter. This can only be related to body waves and explains the observed lower H/V values during summer at these frequencies. Backprojection of FK results, assuming various P phases, indicates source locations within the southern oceans. Surface wave sources are mainly located in the north-western quadrant from NORSAR for all frequencies between 65 mHz and 250 mHz. During summer, though, the primary microseismic frequency band contains additional sources to the south-west and north-east of the array. Raised velocites observed from the east could be related to propagation effects from more distant sources caused by Indian Ocean monsoon.

S107PS.04

S107PS - Array seismology – Status and Perspectives

Poster

Back-projection analysis of P waves emitted by Maule earthquake (Chile, 27/02/2010, Mw 8.8) using dynamic station corrections

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We have analyzed the time-evolution of the rupture process of Maule earthquake (Chile, 27/02/2010, Mw 8.8) looking at the source location of the seismic energy by back-projection analysis.

We have isolated P phases recorded by three seismic arrays located in USA, Africa and Antarctica filtered in four frequency ranges: 0.05-0.1 Hz, 0.4-3 Hz, 1-4 Hz, 2-8 Hz Time shifts between sensors (inferred by maximizing the cross-correlation function) have been estimated with respect to a 1D global velocity model (ak135) and have been refined by introducing a static correction and a dynamic correction. The former is a constant time shift induced by local effects in the sensor area, whereas the latter is the correction associated with the source-sensor path and is mostly affected by medium properties in the source area. These corrections have been estimated by analyzing the time shifts between stations associated with the waveforms of 23 aftershocks and foreshocks with high magnitude (>5.1). Moreover, dynamic corrections (and hence the complete travel times) have been interpolated over all the source area by Kriging, a spatial interpolation method. The results show that the onset of the energy release occurs south of the epicenter just off the coastline. Afterwards, the source moves towards inland regions, that are deeper areas of the slab interface, up to a distance of about 160 km from the trench. Hereafter, source generally moves towards NNE mostly along the coastline, with a deepening at the northern boundary of the rupture front. This scheme is partially modified for the band 0.4-3 Hz, for which a non-negligible fraction of energy comes from an area south of the epicenter along all the duration of the slip process, reflecting a bi-lateral rupture front.

S107PS.05

S107PS - Array seismology – Status and Perspectives

Poster

Application of array methods to the monitoring of induced and natural seismicity in the northern Upper Rhine Graben

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The seismicity of the northern Upper Rhine Graben and its seismic hazard have recently attracted new attention due to the potential of this region for geothermal power generation. The natural seismicity can be used to determine active fault zones and stress conditions within the crust. It also provides important background information for the estimation of possible induced seismicity. We investigate the feasibility of using array methods for the detection and discrimination of near-surface micro-earthquakes. The planned array will be located in the relatively remote Taunus region at a distance range between 20 km and 50 km with respect to potential target areas for deep geothermal mining. The noise conditions in the Taunus region are favorable and tests show that M = 1 events, located within the target area, can be recorded by a single seismic station. Further tests are performed to determine relevant slowness and frequency ranges for near-surface events, including mining explosions. These measurements are used to generate realistic synthetic waveforms for the array-design studies. It is planned that the proposed array will provide independent information on possible induced and natural seismic events and thus will help to improve the public acceptance of deep geothermal activities in this densely populated area.

S107PS.06

S107PS - Array seismology – Status and Perspectives

Poster

Study of earthquake clusters in the Marmara Sea using pires arrays

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Earthquake clusters in the Marmara Sea are systematically analysed in order to understand the spacial variation of the stress regime and the fault structure across the North Anatolian Fault. Data is provided mainly from two seismic arrays installed on Sivriada and Yassiada Islands that are located within 6 km of the fault zone. Additional data are used from closely located stations installed on neighboring islands. Events occured between 2007 and 2013 that are located within ~15 km distance to the arrays are used for the detailed analysis. The use of dense arrays in close proximity to the epicentres, high sampling rates and high number of observations from various azimuthal angles allowed a high accuracy study of the source properties even for events down to a magnitude of Ml=1.0.

During the cluster detection, larger magnitude events have been used as waveform templates for detecting the similar smaller magnitude ones. We have cross correlated the template with the continuous waveform from the same sensor, then time shifted and stacked the cross correlation traces from all of the stations from the two arrays. With the power of arrays, beam forming has lead to large improvement of the detection of the clusters. Standard location approach is combined with FK to improve the backazimuth estimation.

We have also calculated the seismic moment, source size, stress drop and radiated energy of the template events and events in the clusters both individually and in a relative manner using P and S wave spectra. Comparison of the results of constant Q analysis, spectral amplitude ratio method and stacking of the spectral amplitudes are discussed. Qualitative comparison of scaling properties between individual clusters is obtained.

The use of stations from the two arrays allow us to carry independent estimations of different parameters which permits an overall improvement of the accuracy. We compare the benefits of arrays both to single stations and borehole environment.

S107PS.07

S107PS - Array seismology – Status and Perspectives

Poster

Detection performance of BURAR (Romania) seismic array after its upgrading in 2008

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BURAR seismic array has been operating since 2002 in the north-eastern part of Romania in cooperation between Air Force Technical Application Center (AFTAC) of the United States of America and the National Institute for Earth Physics (NIEP) of Romania. The analysis of array monitoring capability showed a high efficiency in detecting regional and distant signals, while a slightly deficiency in detecting seismic phases belonging to local events (Ghica et al, 2010). To improve the performance of detection and location of local events, the original configuration of the array was supplemented in 2008 with 5 new array sites. The goal of the present study is to test the improving of detection capability of the new array configuration. To this aim, we ran the RONAPP signal analysis software package (Mykkeltveit and Bungum, 1984) for both array systems, and compare the results for a common one-month time interval. It was found an increasing detection for certain seismic phases using the new array configuration, but at the same time, an increase of the fake detections when SNR was below a certain threshold.

S107PS.08

S107PS - Array seismology – Status and Perspectives

Poster

The modernized large-aperture broadband array NOA, Norway

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The large-aperture seismic array NOA had a major instrumental upgrade in 1994 and has been operational with the very same configuration until recently. Over time the instruments became obsolete and spare parts were not longer available. NOA consists of 42 sites grouped into seven subarrays covering a total aperture of about 60 km. It had been equipped with 7 broadband 3C-sensors (one in each subarray) and 42 short-period instruments. In 2008 NORSAR initiated the modernization of NOA. In order to utilize an instrument with the same response for all sites and to optimize the broadband monitoring capabilities of the array, NORSAR specified a hybrid instrument response for the seismometers, which were engineered by Guralp. The upgrade of the NOA array was completed in July 2012 and in the present configuration NOA has seven 3C sensors (360s - 50Hz) and 32 vertical borehole sensors (120s - 50Hz), with identical amplitude responses in the overlapping frequency band. We will report on the characteristics and the capabilities of the new all-broadband array NOA.

S107PS.09

S107PS - Array seismology – Status and Perspectives

Poster

The new Plostina seismic array (Romania)

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Since 2010, a new small-aperture seismic array (PLOR) is operational in the central part of Romania, at Plostina. PLOR has been deployed by the National Institute for Earth Physics near the Vrancea epicentral area. The array consists of 7 three-component broadband seismometers (CMG40T Guralp) distributed over an area of 3.5 km2; inter-element distance varies between 450 m and 2450 m. In 6 sites, infrasound instruments (Chaparral Physics microphones) are collocated. All collected data are continuously recorded and real-time transmitted to the Romanian National Data Centre, in Magurele. The main objective of the PLOR array is to provide high-quality data for research projects aiming at improved detection, location, and identification of weak seismic events at regional and teleseismic distances. Furthermore, by adding acoustic information to the seismic observations, near surface explosions (quarry blasts) can be identified. The process is useful for discrimination purposes and to establish a set of ground-truth events. In this paper, we present a primary evaluation of the detection performance of the array for one year of data (2011). The data analysis was carried out using the RONAPP array processing package developed at NORSAR, and customized to PLOR. The PLOR configuration (3C instruments) allows to detect a larger number of low-velocity seismic phases (S-type), leading to a much better single-array location capability. A preliminary investigation of the PLOR array characteristics was carried out in terms of array transfer function, wavenumber resolution, signal coherency and noise general characteristics. The results will be used to calibrate PLOR observations, in order to improve the capabilities of detection and single-array location, by applying the correction of measured slowness. PLOR data will also be utilized together with BURAR array (Northern Romania) recordings to assess the combined capability of small-aperture arrays in monitoring seismic activity.

S107PS.10

S107PS - Array seismology – Status and Perspectives

Poster

AlpArray – a broad(band) initiative to advance understanding of Alpine geodynamics

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NO COUNTRY SELECTED -

AlpArray is an initiative to study the greater Alpine area with a large-scale broadband seismological network. The interested parties (currently 57 institutes in 16 countries) plan to combine their existing infrastructures into an all-out transnational effort that includes data acquisition, processing, imaging and interpretation. The experiment will encompass the greater Alpine area from the Black Forest and the Bohemian Massif to the Northern Apennines and from the Pannonian Basin to the French Massif Central. We aim to cover this region with a high-quality broadband seismometer backbone by combining the ca. 220 existing permanent stations with additional 300-340 instruments from mobile pools, all of them to be deployed from 2014-2015 until 2017, achieving homogeneous and high resolution coverage (ca. 40 km). Furthermore, we plan to deploy a few densely spaced targeted networks along swaths across key parts of the Alpine chain, and ca. 40-45 OBS in the Mediterranean Sea. We aim to implement the best practice for synchronizing mobile pool operation and data handling: common data centre and data management procedure, free access to data to participants through EIDA. Data will be open to the public 3 years after the experiment ends.

The main scientific goal of AlpArray is to investigate the structure and evolution of the lithosphere and slabs beneath the Alps. Numerous regional questions such as seismic hazard will be tackled. Targets will be imaged at several depths and scales using different methodologies, including array techniques. The geodynamic interpretation of the acquired data will be complemented by other Earth Science disciplines such as state-of-the-art numerical and analogue modelling, gravity and magneto-telluric measurements, and structural geology. In conclusion, we hope to turn the strong community interest into a truly interdisciplinary and collaborative project in the key region for seismotectonic activity and dynamics of Europe.

S107S1.02

S107S1 - Array seismology – Status and Perspectives

Oral

Microseisms from superstorm Sandy recorded in North America by the transportable array

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In this study we report on microseisms created by superstorm Sandy and recorded by over 400 broadband, three-component seismometers of the Transportable Array (TA) that were deployed mostly in central and eastern North America during the period of Oct. 22-31, 2012. Although at its peak Sandy was classified only as Category 2 (out of 5) on the Saffir-Simpson hurricane wind scale, it was the largest Atlantic hurricane on record as measured by spatial extent, and caused enormous damage along the east coast of the United States. We perform continuous, frequency-dependent polarization analysis of the TA data to determine how microseismic waves created by Sandy varied in time, space, power, and polarization. Our approach is based on eigen-decomposition of 3x3 spectral covariance matrices at individual stations (Koper and Hawley, 2010) and does not use cross-spectra from different stations. Although this approach gives weaker angular constraints than conventional beamforming, the seismic energy does not have to be coherent between stations, it does not have to propagate as a plane-wave, and true amplitudes are recovered because there is no beam loss. We find that (1) energy propagated dominantly as Rayleigh waves with peak energy near 5-6 s, though Love waves were dominant at a period near 12 s when the storm passed over the Bahamas; (2) the largest microseisms were generated when Sandy turned sharply west towards New York, and at this time the dominant period shifted to 8-9 s; (3) the major microseismic source region often occurred in Sandy's wake, trailing the hurricane eye; (4) finger-like striations were observed in the amplitude field across the TA that we interpret as a complex pseudo-radiation pattern, possibly created by near-source bathymetry changes; (5) the array-averaged amplitudes of microseismic waves generated by Sandy were not significantly larger than those of normal background microseisms caused by storms in the north Pacific and north Atlantic.

S107S1.03

S107S1 - Array seismology – Status and Perspectives

Oral

Performance comparison of mid-aperture broadband arrays at an ocean island and in the deep ocean

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The aim of the DOCTAR (Deep OCean Test ARray) project is to examine the potential of broadband array methods on the ocean floor in comparison to installations on an ocean island and on the continent. For this purpose, three mid-aperture arrays were deployed on the island of Madeira, in western Portugal and north of the Gloria fault in the western mid Atlantic. Here, we focus on the comparison of the performance of the ocean island array on Madeira and of the deep ocean array. We temporarily deployed 12 broadband (8 Guralp 60s & 4 STS2) and 12 short period stations (LE3D 5s) on Madeira and the neighbouring island of Desertas. If the STS2 sensor on Desertas is excluded, the array has an aperture of about 20 by 40 km on the island of Madeira (else wise 70 km). Additionally, three permanent stations are installed on the island of Madeira (Guralp 120s and 2 LE3D 5s) and two on the nearby island of Porto Santo (Guralp 120s and LE3D 5S). In the deep ocean (4.5 - 5.5 km) north of the Gloria Fault, we deployed 12 ocean bottom stations (OBS) with an aperture of 75 km. The autonomous station consist of an broadband seismometer (Guralp 60s) combined with a HTI hydrophone (DEPAS type instruments). We compare different aspects of the two arrays: (1) the effort during collection and processing of the data (e.g. successful timing correction for the OBS array using ambient noise). The orientation of 3 component stations by waveform comparison and results from measurements with a portable Gyrocompass will be presented. (2) the ambient noise spectra as a function of frequency and time. (3) examples of fk-analysis and its specific problems for installations at the ocean floor and volcanic, oceanic islands (topography and scattering effects). (4) detection thresholds and frequency content of local and regional events. We give some preliminary conclusion from our investigations and observations regarding the potential and performance of seismic broadband arrays in the deep ocean.

S107S2.01

S107S2 - Array seismology – Status and Perspectives

Oral

Improving signal detection at International Monitoring System seismometer arrays

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Seismometer arrays form the backbone of the International Monitoring System (IMS), being set up to monitor compliance with the Comprehensive Nuclear-Test-Ban Treaty. The IMS array network includes newly constructed sites as well as historical stations with decades of recording history. Arrays in the network have widely varying apertures, element spacings, and background noise characteristics. Signals of interest under the Treaty may originate at local, regional or teleseismic distances to an array, and may have a range of frequency content. This variation means that a major challenge is to develop an improved signal detection methodology, which increases the number of events which can be detected, but which also provides a uniform detection criteria across the wide range of arrays and signal types, and so allows more efficient network processing.

Here I briefly review the use of seismometer arrays in Test-Ban monitoring, and describe my recent work to make use of prior knowledge of array geometry, signal and noise spectra, and noise covariance, to develop a generalised signal detection approach based on least-squares signal estimation and the F-statistic. I demonstrate that the new approach increases the number of detections associated with events, while at the same time dramatically decreasing the number of statistically bogus detections. I describe how the approach can be applied to different arrays and signal types by using different approaches to frequency-time analysis and beamforming. Finally, I discuss current and future challenges for both the IMS and seismometer arrays.

S107S2.02

S107S2 - Array seismology – Status and Perspectives

Oral

The role of arrays in the monitoring of seismic events

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The costs and workload associated with the installation of a seismic array are usually very much higher than for a regular three-component station. Consequently, most observational seismic networks consist of three-component stations deployed strategically to provide optimal geographic coverage. However, due to the superior detection and signal classification capabilities, array stations form the core of the global seismic network for monitoring compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT). We will in this presentation give an overview of the advantages and disadvantages of using seismic arrays, as stand-alone elements or as part of larger networks, for continuous seismic event monitoring at various distances and over various magnitude ranges. Some key factors in this regard are the installation costs, data quality and redundancy, signal detectability, determination of phase characteristics, automatic data processing, location uncertainty, and usefulness of the data for fundamental seismological studies. We will also provide examples of recent developments in array processing algorithms for enhanced signal detection, automatic classification of aftershocks, and monitoring of areas of particular interest.

S107S2.03

S107S2 - Array seismology – Status and Perspectives

Oral

Learning f-k image sequences at small-aperture arrays for detection purpose

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The analysis of continuous data streams at arrays allows generally the decomposition of seismic wave field constituents and their corresponding dynamics at the observation point. As most common signal processing tool, f-k techniques have been established to analyze the short-term characteristics of the observed wave field. Here, we apply a sliding window f-k analysis scheme in multiple broad frequency bands to convert the raw observation into a temporal sequence of f-k images at the small-aperture broadband array SPITS (Svalbard, Norway). For signals of interest, like glacier related seismic events occurring frequently at this location, we test whether the f-k sequence may serve as robust characteristic pattern for signal detection. For the purpose of obtaining a seismological meaningful wave field representation from the temporal patterns of (complex) image sequences we try to capture the intrinsic information of the f-k images. We quantify the amount of expected image focusing by statistical estimators and by learning information preserving transformations. Further, we additionally analyze residual f-k images by reducing the original observations by the band-limited array response function given a single plane wave arrival at the most coherent plane wave arrival estimate. We then make use of a stochastic modeling technique called Hidden Markov Modeling (HMM) to describe the temporal patterns. HMMs are conceptually well suited to cope with the expected variability of seismic waveform observations and can handle complex pattern classes by learning from example patterns. In our first tests, we find a good recognition accuracy of the system for small scale events at SPITS. The future target of this system is the automated tagging of glacier related seismicity from the array records with the goal to i) count this kind of activity seeking correlations to data from climate change research and to ii) exclude those events from manual analyst inspection.

S107S2.04

S107S2 - Array seismology – Status and Perspectives

Oral

The automatic classification of extensive aftershock sequences using empirical matched field processing

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Aftershock sequences following large earthquakes create significant problems for data centers attempting to produce event bulletins in near real-time. The greatly increased number of events requiring processing can overwhelm analyst resources and reduce the capacity for examining events of monitoring interest. Waveform correlation methods have shown promise for automatically identifying groups of events belonging to the same source region, allowing the more efficient analysis of event ensembles rather than individual events. However, signals from very large earthquakes often correlate too poorly with the signals from smaller aftershocks for correlation detectors to produce statistically meaningful triggers at the correct times. Empirical Matched Field Processing (EMFP) is a quasi-frequency-domain technique that recognizes signal patterns by calibrating the spatial structure of wavefronts crossing a seismic array in a collection of narrow frequency bands. It is a highly promising method for detecting pertinent arrivals with both high sensitivity and a low false alarm rate and is here demonstrated to perform exceptionally in detecting aftershocks from the 2005 Kashmir and 2011 Van earthquakes. EMFP has the potential to produce reliable triggers of aftershocks in an evolving sequence such that correlation and subspace detectors can be created automatically, with well-chosen parameter specifications, to identify and classify clusters of very closely-spaced aftershocks.

S107S2.05

S107S2 - Array seismology – Status and Perspectives

Oral

A tool for automatic real-time seismic bulletin at regional scale using array processing

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We present an automatic algorithm applied to seismic arrays and designed for automatic detection and location of regional events. The detection is achieved using PMCC method (Progressive Multi-Channel Correlation). PMCC algorithm is based on a study of the cross-correlation functions between each stations of the array, which leads to a consistent set of time-delays when a seismic phase is present. The set of time-delays allows calculation of horizontal velocity and azimuth of arrival wavefront. This algorithm allows a very low level of detection even for poor signal to noise ratios. A first identification of regional seismic waves is obtained using those propagation parameters, providing the estimation of a pre-location. The second step consists in the integration of additional data from regional seismic stations, in order to build a consolidated location. The identification of the nature of seismic phases is based on a direct method using a large search-grid covering PMCC pre-location area. This algorithm has been applied to Songino seismic array in Mongolia, completed by Ulan Bator seismic network data. The results constitute an automatic seismic bulletin characterized by a low completeness magnitude. We present also an on-going study focusing on the automatic identification of seismic phases using different classification algorithms.

S107S2.06

S107S2 - Array seismology – Status and Perspectives

Oral

Seismic arrays in earthquake early warning systems

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Seismic arrays are well established tools to monitor the seismic activity worldwide and also to monitor specific target areas of interest. Due to the huge data volume recorded with seismic arrays, the usage of seismic arrays implies the application of quite advanced and specifically tuned analysis tools, which are usually running in a fully automated mode. NORSAR was during the last 40 years one of the leading institutions to develop such (near) real-time analysis software. In this contribution an overview will be given on how on-line processing of seismic array data and array data based event location can contribute to Earthquake Early Warning Systems. As examples of earthquake alert systems based on single or multiple seismic array installations, partly in combination with additional data from seismic 3C stations, the FEIS and NEWS algorithms will be presented and explained. Finally, possible applications and their limitations will be discussed.

S108PS.01

S108PS - Real-time seismology

Poster

PRESTo Earthquake Early Warning system: Feasibility study for a nation-wide deployment using an integrated regional and on-site

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PRESTo (PRobabilistic and Evolutionary early warning SysTem) is a highly configurable and easily portable platform for Earthquake Early Warning (EEW) that integrates algorithms for real-time probabilistic earthquake location, magnitude estimation and damage assessment. The system processes the live accelerometric streams from the stations of a seismic network and provides location and magnitude estimations, as well as shaking prediction at the regional scale. The earthquake location and magnitude are obtained by an evolutionary, probabilistic approach combining triggered and not-yet-triggered stations. Peak ground motion is estimated at target sites by GMPEs using location and magnitude. The regional approach is integrated with a threshold-based early warning method for the definition of alert levels at stations and the estimation of the Potential Damaged Zone (PDZ), in which the highest intensity levels are expected. At each station the characteristic P-waves period (τc) and the peak displacement (Pd) are measured on the initial P-waves signal. They are compared with threshold values in order to produce an alert level at each station, that can be finally correlated to the expected local damage. Integrating the measured on-site parameters at stations (Pd, τc) and the estimated regional parameters (hypocenter), PRESTo can identify the damage area in few seconds and send an alarm message containing the evolutionary estimates before the destructive waves can reach target sites. Since late 2009, PRESTo has been under continuous real-time experimentation in Southern Italy, on the data streams of the Irpinia Seismic Network (ISNet). Since June, 2012 similar deployment is implemented at KIGAM accelerometer network, in South Korea. Likewise, PRESTo has been off-line tested on the Mw >= 4 deep earthquakes recorded since 2005 by the Romanian Seismic Network, on off-shore earthquakes of the Iberian Peninsula and on a database of M >3 Japanese earthquakes.

S108PS.02

S108PS - Real-time seismology

Poster

Automatic real time and near real time analysis @ ISNet (Irpinia Seismic Network)

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The Irpinia Seismic Network (ISNet) is deployed in Southern Apennines along the active fault system responsible for the 1980, November 23, M 6.9 Campania-Lucania earthquake. It is constituted by 30 stations, each of which is equipped with both an accelerometer and a velocimeter, to catch a broad set of seismic signals, from micro-seismicity and ambient noise to strong motion. Real-time (within 1-2 minutes) data analysis is performed through the Earthworm software package, that also provides the automatic earthquake location and local magnitude. In near real-time (within 4minutes) the custom software INERTIA provides moment magnitude, source parameters, focal mechanism and shaking maps. Moment magnitude and source parameters are obtained by an automatic inversion of displacement spectra, that accounts for site, propagation, window selection and signal-to-noise ratio. Focal mechanisms are instead computed using polarities and data-fitting at low frequencies.

During seismic sequences, which sometimes occur in localized places inside ISNet, the helicorder at the closest stations is also scanned with a master trace to extract smaller magnitude events, which are not individuated by the binder of the network because of the small number/poor quality of the pickings.

In real-time, data-streaming from seismic stations are also collected by the software PRESTo (PRobabilistic Evolutionary early warning SysTem), which provides an earthquake early warning for events occurring inside the network with moment magnitude larger than 2.5.

S108PS.03

S108PS - Real-time seismology

Poster

The Virtual Seismologist in SeisComp3: System architecture and performance

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The Virtual Seismologist (VS) method is a Bayesian approach to regional network-based earthquake early warning (EEW) originally formulated by Cua and Heaton (2007). Implementation of VS into real-time EEW codes has been an on-going effort of the Swiss Seismological Service (SED) at ETH Zürich since 2006 (Fischer et al., 2009), with support from ETH Zürich, various European projects, and the United States Geological Survey (USGS). VS is one of three EEW algorithms that form the basis of the California Integrated Seismic Network (CISN) ShakeAlert system, a USGS-funded prototype end-to-end EEW system that could potentially be implemented in California.

To enable the transition of VS from this Earthworm-based prototype to a more stable and standardized production type system, it is a necessary step to fully embed EEW codes in the hardened, robust and well-programmed real-time processing software that is used by the respective network operators. In California efforts are therefore underway to deeply integrate the current ShakeAlert system in Earthworm/AQMS. For use in Switzerland and other European Centers, VS modules are being included in the SeisComp3 (SC3) system that is now operational at the SED. SC3 is becoming widely used in Europe as well as globally.

In Switzerland, the Earthworm-based version of VS has been running in real-time on stations monitored by the Swiss Seismological Service (including stations from Austria, France, Germany, and Italy) since 2010 and the SC3-based version of VS since March 2013. We present the architecture of the new SC3 version and compare its results from off-line tests with the real-time performance of VS in Switzerland over the past two years. We further demonstrate that the empirical relationships used by VS to estimate magnitudes and ground motion, originally derived from southern California data, perform well in Switzerland.

S108PS.04

S108PS - Real-time seismology

Poster

Suggestion for a system to achieve rapid hypocentre location using tabular data

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This paper is to suggest a possibility for finding hypocentre locations by rapid table-scanning, the method here being an interpolative scan (currently four 2-space interpolation regimes are provided). These tables are formed from sets of tripartite two dimensional tables delineating: arrival times; take-off angles and error calibration data. These tables are general. The use of point-to-point ray tracers in their construction is key. The procedure for finding hypocentre foci, using such tables requires first the epicentral coordinates of the object event. Given this, a procedure can be put in place, which in the present instance, will locate to a depth of 1000 km within a time of < 0.25 s (with a scanning granularity of 2000 points) using a 3.2 Giga-Hertz machine. Five alternative algorithms for the location of epicentres are also here considered. This software structure can, in principle, be used to try out and validate sets of combinations of ray tracing techniques and Earth velocity models.

S108PS.05

S108PS - Real-time seismology

Poster

Development of earthquake early warning system using low cost accelerometer in Taiwan

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The earthquake early warning (EEW) research group at the National Taiwan University (NTU) and one technology company have been developing a Micro Electro Mechanical Systems (MEMS) type of accelerometer (the Palert EEW sensor) specifically designed for EEW purpose. The main advantage of the MEMS accelerometer comparing to the other seismometers is that it is a relatively very low-cost seismic sensor. Currently, a total of 350 Palert devices are installed in Taiwan region for onsite and regional EEW purposes. When P wave triggers Palert will determine peak amplitude of the filtered vertical displacement (Pd) as an indicator for onsite EEW. Most of the Palerts are installed in the elementary schools with internet connection. Real-time signals from local Palert device transfer to servers in NTU and Academia Sinica Grid Center via internet for regional EEW purpose. Real-time signals are recorded using the Earthwarm system. Twenty-one events with magnitude large than 4.0 were recorded by the Palert network from June 2012 to January 2013. This system could report the earthquake location and magnitude within 20 seconds. The uncertainty of magnitude and location are about 0.2 and 30 km, respectively. Results of the Palert network encourage the further implementations for the MEMS-type of seismometer in the EEW application. Now the Palert device has been installed in Taiwan, China, Indonesia, and Mexico. India, Korea and Philippine are also planning to install the Palert device for EEW purpose.

S108PS.06

S108PS - Real-time seismology

Poster

Feedback about Earthquake Early Warning: Questionnaire survey after the 2011 Tohoku Earthquake (Mw9.0)

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We will report results of a questionnaire survey and feedback about Earthquake Early Warning, EEW, from general residents, based on the 5-year operation of its practical stage. The Japan Meteorological Agency, JMA, conducted questionnaire surveys in the Tohoku district and nationwide in February 2012, that is approximately 1 year after the 2011 Tohoku Earthquake(Mw9.0). Respondents numbered 817 in the Tohoku district survey and 2,000 in the nationwide survey. Most respondents received EEW messages from TV or cell phone broadcast mail service. Most respondents took some actions in the Tohoku district (74 percent) and nationwide (54 percent); 16 and 17 percent, respectively, tried to take action but could not; and 10 and 29 percent, respectively, did nothing. More than 90 and 80 percent of respondents think EEW is useful (or, useful on balance) in the Tohoku district and nationwide, respectively. Among the reasons why EEW was considered useful, primary was that EEW can be served as a trigger for taking safety measures against strong shaking. Many people state that EEW helps them prepare for strong shaking, even if they do not actually take specific actions. Psychological relief is a major factor.

The percentage of respondents evaluating EEW to be useful was larger among Tohoku than nationwide. Likewise, the percentage of people who were able to take useful actions was larger in Tohoku. The regional difference may be the results of repeated experience, as is the more positive evaluation of EEW in Tohoku. The perceived value of the EEW system is its usefulness both as a trigger of actual actions and as an aid to mental preparedness before strong shaking begins. Most people considered the EEW system useful despite some false alarms. Although it is necessary to improve the EEW system to reduce false alarms and make the predictions more precise, the results of this survey should be encouraging to the community of EEW researchers.

S108PS.07

S108PS - Real-time seismology

Poster

A study of the planned earthquake early warning system in Israel

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In June 2012 Israel Government legislated building the Earthquake Early Warning System (EEWS) in the country. The system would be on the first stage designed to provide the early warning for schools. Most important characteristics of such a system are warning times Tw=Ts-Talarm, i.e. time between the alarm signal and arrival time of the damaging S waves Ts, and the false alarms rate. Network configuration (on the first stage) was chosen as a staggered line of 50 stations along the regional main faults: the Dead Sea fault and the Carmel fault. For such a network the S wave travel time Ts and the alarm time Talarm were calculated using the standard 1D velocities model and certain assumptions regarding the EEWS algorithm and the data latencies. The false alarms, true alarms and missed alarms rates are computed for different EEWS algorithms and thresholds using the «real-time hazard assessment» approach (Iervolino et al., 2006), where epicenter and magnitude are randomly generated according to the given seismicity characteristics. Peak-ground acceleration PGA at a station is obtained according to the magnitude-distance prediction law. For more realistic simulation of the EEWS performance we used synthetic and real strong earthquake seismograms on the basis of the PRESTO EWS algorithm. The algorithm is developed and now tested at the ISNet (University of Naples,Italy). It utilizes P wave arrivals to the closest stations (at least 3) and the 3 first seconds of the waveform data for prompt location and magnitude estimation. In Israel the hybrid approach is suggested, where P-wave based system will be combined with the S-threshold approach. The latter is defined as the method which issues an alarm when the surface shaking (velocity or acceleration) exceeds the relatively high threshold corresponding to a magnitude 5 earthquake at a short distance (5-10 km) at least for the two neighboring stations.

S108PS.08

S108PS - Real-time seismology

Poster

ShakeMap in Portugal

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ShakeMap, a software package developed by Wald *et al*. (1999) and provided by U.S. Geological Survey (USGS), generates maps of ground motion after an earthquake, automatically and in real-time. These maps provide to the population, scientists, civil protection authorities and media, useful information about the affected areas. In Portugal, this software is currently implemented at IPMA (*Instituto Português do Mar e da Atmosfera*), the institution responsible for seismic monitoring in the country. In this work we will present an optimization of ShakeMap for Portugal. Our current implementation of ShakeMap produces not only one map of each estimated ground motion parameter, but rather a collection of possible maps that are obtained assuming different attenuation laws and proxies for site effects proposed for the region. We also generate maps of maximum and minimum expected ground motion considering the previous shakemaps. This implementation is particularly important for Portugal because the regional collection of strong ground motion records is very limited, not allowing for a proper evaluation of attenuation laws. However, historical records indicate the occurrence of moderate to large earthquakes in and around Portugal, highlighting the need to prepare for potentially destructive events. Our most recent work focuses on testing attenuation laws proposed in the international literature for Portugal's mainland, following the work of Vilanova *et al*. (2012). This research is supported by European and Portuguese funding (FP7-PEOPLE-IRG-2008, PTDC/CTE-GIX/116819/2010).

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S108PS.09

S108PS - Real-time seismology

Poster

Real-time moment tensor monitoring system (RMT) applied for rapid source parameter determination in Taiwan

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We have developed a Real-time Moment Tensor monitoring system (RMT), which takes advantage of a grid-based moment tensor inversion technique and long-period broadband seismic recordings, to automatically monitor the earthquake activities in the vicinity of Taiwan. The centroid moment tensor (CMT) inversion technique and a grid search scheme are applied to obtain the information of earthquake source parameters, including the event origin time, hypocentral location, moment magnitude and focal mechanism. All of these source parameters can be determined simultaneously within 117 seconds after the occurrence of earthquake. The monitoring area involves the whole Taiwan Island and the offshore region, which covers the area of 119.3°E to 123.0°E, 21.0°N to 26.0°N, and the depth to 136 km. A 3D grid system is implemented with an average grid spacing of 10 km in all dimensions. This inversion procedure is based on a 1D Green's function database calculated by the frequency-wavenumber (fk) method. We compare our results with the CWB catalog data for earthquakes occurred between 2010 and 2012. The average differences of event origin time and hypocentral location are less than 2 seconds and 10 km, respectively. The focal mechanisms determined by RMT are also comparable with the BATS CMT solutions. These results indicate that the RMT system is realizable and efficient to be applied to monitor the local seismic activities. In addition, the time needed to obtain all the point source parameters is reduced substantially compared to the routine CWB and BATS CMT reports. The RMT has been operating online for more than one year from January 2012 to present at the Institute of Earth Sciences (IES), Academia Sinica (http://rmt.earth.sinica.edu.tw). The long term goal of this RMT monitoring system is to provide real-time source information for rapid seismic hazard assessment during large earthquakes.

S108PS.10

S108PS - Real-time seismology

Poster

Determination of Epicentral Distances and Magnitude using P waveform of the small earthquake(2.0 < M < 5.2) around Korean Peninsula

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This dissertation demonstrates the methods to estimate earthquake magnitudes quickly and statistical assessments on results to show that the methods are applicable to the seismic environment in Korean Peninsula.
A method proposed in a previous study is used to estimate the epicentral distance using the first arrival of P wave recorded at a single station and to quantify the accuracy of the estimation at many stations across the peninsula. In order to quantitatively evaluate seismic waveforms, a simple fitting function of Bte-At is used where A and B are calculated using the least-squares method and a linear relationship between log(B) and log(Δ) is found. This result is applied to the local magnitude equation of KMA and to the equation proposed by Park (2002), giving a new magnitude equation by which the magnitude can be estimated by using maximum absolute amplitude of P wave. A new magnitude equation (MP) is suggested by modifying the term of the epicentral distance using a term of B value. The results shows that 62% of the calculated epicentral distances using the B values can be estimated within ±50km. The difference between logarithmic epicentral distances calculated by this study and KMA is ±0.5, which means 83% of magnitudes estimated in this study are located in the range of ±0.5.
This study shows that the epicentral distance, local magnitude, and moment magnitude can be quickly determined only by using P waves. The error presented in this study can be reduced by improving the observation enviroments and by additional studies to improve these methods.

S108PS.11

S108PS - Real-time seismology

Poster

Utilizing time-frequency polarization filtering to automated extraction of S phase on seismic records

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Rapid progress in data acquisition provides plenty of digital records. Automated phase identification for these records is of paramount importance. In this paper we present an automated algorithm to recognize the arrival time of S phase based on instantaneous polarization attributes of analytic traces. We enjoyed the recent progress in the field of pattern recognition and the procedures of advance feature extraction. To achieve this desire, deriving S phase characteristics is performed within time-frequency framework. This analysis executes by exploiting an adaptive windows to extract polarities.

S108PS.12

S108PS - Real-time seismology

Poster

Test of the GMPE obtained for South Iberia

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South Iberia is an area where potential large or damaging earthquakes may occur such as the 1755 (Lisbon I_{max}=X), 1969 (S. Vicente Cape Ms=8,1) or 1964 (Gulf of C ádiz Ms=6.5) shocks at the coast or more recently in 2011 Lorca´s Earthquake (Mw=5.1).

During development the ALERT-ES project (CGL2010-19803-C03) we have estimated the peak displacement (P_d), the mean period (τ_c) and the maximum predominant period (τ_P^{max}) for a rapid estimation of the potential damage of earthquakes occurring in this region. From the first seconds of the beginning of P-waves, we have obtained these parameters and different scaling laws with magnitude and the peak ground velocity (PGV) for this area. The P_d has been correlated with the PGV to obtain the Instrumental Intensity (I_{MM}) at the site. We have also studied the relation between P_d the epicentral distance (R) and magnitude (M) obtaining a ground motion prediction equation (GMPE) for the region. The GMPE developed has some differences from those obtained by different authors for other regions.

In order to check our relationship we have estimated the Theoretical P_d from Mw values (epicentral distances from 10 to 500 km) for the 1969 and 2011 shocks. From these P_d values using the scaling law we have obtained the PGV and its corresponding I_{MM}. Comparing these I_{MM} with the available observed intensities, we can test the robustness of this method for future damaging earthquakes in the area and it´s suitability for an earthquake early warning system.

S108PS.13

S108PS - Real-time seismology

Poster

Crustal models and localization procedures in Northwestern Italy

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The real-time localization procedures adopted by the regional seismic network of Northwestern Italy (RSNI) are based on iterative methods of the linearized problem near the solution, theorized by Geiger, with crustal models linked to stations (Hypo71). Northern Italy area, surrounded by Alps and Northern Apennine, presents a complex system of lithospheric structures, characterized by strong heterogeneities of various physical parameters. Several studies conducted in the area, as well as technological improvements of monitoring networks, have greatly increased the amount and detail of the available data and knowledge. In this work we developed new localization procedures for the area through a different algorithm, suitable for real time localization in a strongly heterogeneous context (Hypoinverse2000).

In the first step we built some new sets of multiple models of crustal velocities for the entire area. The geometries and the velocity values of crustal models were built through integration of several geophysical (firstly tomographic) and geological data.

In the second step we developed a methodology for analyze and evaluate the localization system performance, handling and combining varying sets of input data, crustal models and algorithm parameters, through the integration of DB, GIS, statistical and graphical capabilities.

Elaboration processes have been highly automated and parameterized, allowing to store and organize data of each set of localizations, creating a flexible tool for the algorithm execution with different configurations and for the comparison of the relative results obtained.

Compared to current routine localizations, in terms of hypocentral parameters accuracy and of time residuals distribution, improvements are shown in the outcomes achieved through the implementation of the most refined crustal models with the most advanced features of the analyzed algorithm (multiple models linked to epicentral area, model-station corrections).

S108S1.01

S108S1 - Real-time seismology

Oral

Real-time prediction of seismic ground motion (Part 1): real-time estimation of wavefield using data assimilation and time evolutional prediction using Kirchhoff integral

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In this presentation, I propose a new approach for real-time prediction of seismic ground motion which is applicable to Earthquake Early Waning (EEW). Many methods of EEW are based on a network method in which hypocenter and magnitude (source parameters) are quickly determined, and then the ground motions are predicted, and warnings are issued depending on the strength of the predicted ground motion. In this method, it is necessary to determine the hypocenter and magnitude at first, and error of the source parameters leads directly to the error of the prediction. It is not easy to take the effects of rupture directivity and source extent into account, and it is impossible to fully reproduce the current wavefield from the interpreted source parameters.

Time evolutional prediction is a method in which future wavefield is iteratively predicted from the wavefield at the certain time, that is $u(x, t+\Delta t)=P(u(x, t))$, where u is the wave motion at location x at lapse time t, and P is the prediction operator. Future wave motion, $u(x, t+\Delta t)$, is predicted from the distribution of the current wave motion $u(x, t)$ using P. For P, finite difference technique or boundary integral equation method, such as Kirchhoff integral, is used.

In the time evolutional prediction, determination of detailed distribution of current wave motion is a key, so that dense seismic observation network is required. Data assimilation is a technique to produce artificially denser network, which is widely used for numerical weather prediction and oceanography. Distribution of current wave motion is estimated from not only the current real observation of $u(x, t)$, but also the prediction of one step before, $P(u(x, t-\Delta t))$. Combination of them produces denser artificial network than the real one.

In Part 2, real-time correction of frequency dependent site amplification factors will be discussed.

S108S1.02

S108S1 - Real-time seismology

Oral

Real-time prediction of seismic ground motion (Part 2): real-time correction of frequency-dependent site amplification factors

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In Part 1, real-time estimation of wavefield using data assimilation and time evolutional prediction using Kirchhoff integral are discussed. For actual application of them in Earthquake Early Warning (EEW), site amplification factor should be corrected in real time. Site amplification is an important factor as well as source and propagation factors which control the amplitude of seismic waves.

Data assimilation and Kirchhoff integral are powerful techniques for time evolutional prediction. For the application in EEW, frequency-dependent site amplification factors should be corrected beforehand, and then for evaluation at ground surface. A method is proposed in which the frequency dependent site factor can be corrected in real time. The frequency-dependent site factor is modeled by the linear system of the first and second order low-pass and high-pass filters. A causal recursive IIR filter in time domain is estimated from the linear system using bilinear transform and pre-warping methods of digital filtering technique. Using the causal filter, the site amplification factor is corrected in real time manner even when the site factor has strong frequency dependence.

Instead of rapid estimation of hypocentral location and M, time evolutional prediction is a powerful method for real-time prediction of ground motion for EEW, which is applicable even for cases of strong rupture directivity and large source extent. Techniques of data assimilation and real time correction of site amplification factors will be applied for the time evolutional prediction. An example of the real time correction of the frequency-dependent site factors is presented using data from borehole seismometer (depth: 504m) in the Kanto region, Japan.

S108S1.03

S108S1 - Real-time seismology

Oral

Expanding the P-wave time window: Insights from observations and implications for earthquake Early Warning

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For the real-time magnitude estimate two Early Warning (EW) parameters are usually measured within 3 seconds of P-wave signal. These are the initial peak displacement (P_d) and the average period (τ_c). The scaling laws between EW parameters and magnitude are robust and effective up to magnitude 6.5-7 but a well known saturation problem for both parameters is evident for larger earthquakes. The saturation is likely due to the use of only a few seconds of the P-wave which cannot capture the entire rupture process of a large event.

In a previous work we proposed an evolutionary approach for the magnitude estimate, based on the progressive expansion of the P-wave time window, until the expected arrival of the S-waves. The application of this methodology to the 2011, Mw 9.0 Tohoku-Oki earthquake records showed that when a 3 second window is used to measure P_d and τ_c the result is an obvious underestimation of the event size. However, as the time window increases up to 27-30 seconds, the measured values of P_d and τ_c become stable and comparable with those expected for a magnitude Mw 8.5 earthquake. Here we extend the analysis to a larger data set of Japanese earthquakes with magnitude from 4 to 9 and explore the proposed approach for the magnitude estimate based on the expansion of the P-wave time window. We analyze the relationship between the observed saturation time of EW parameters and the earthquake magnitude itself. Our purpose is to understand the role of this time during the rupture process and to develop and validate a theoretical scaling model for both small and large events.

S108S1.04

S108S1 - Real-time seismology

Oral

Earthquake rupture details by the back projection method using data from the Swedish National Seismic Network (SNSN)

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The initial portion of P-waves trains at teleseismic distances (30°–90°) contain valuable information about the source characteristics of moderate to large earthquakes. Rapid and robust images of the source rupture including the initiation of rupture and propagation of the earthquake rupture front can be obtained by back projecting high-quality teleseismic P-wave trains recorded by large arrays. Such results are interesting in relation to the issuing of warnings and assessments immediately after the occurrence the events. The analysis can provide detailed knowledge on the earthquake rupture propagation from the high-frequency radiated seismic energy in the P-wave trains. We apply the method to 66 three-component broadband (CMG-3TD) seismic stations of the Swedish National Seismic Network (SNSN) operated by Uppsala University since 1998. The SNSN array covers an area about 450 km by 1450 km with the high concentration of stations along the Baltic Coast. Well-correlated and uniform recorded waveforms of moderate to large earthquakes at teleseismic distances provide a high quality dataset with insignificant site effects suitable for back-projection application. It is especially significant that SNSN stations record clear signals even at relatively high frequencies. We present an application of the method to a number of large earthquakes including the April 11, 2012, Mw 8.7 northern Sumatra earthquake - one of the largest intraplate strike-slip earthquakes ever recorded. The high-frequency (0.2-1.0 Hz) data reveal the extent and magnitude of the fault slip and the progression of slip along the fault.

S108S1.05

S108S1 - Real-time seismology

Oral

Exploring the feasibility of an early warning system in a moderate seismicity context: case study of Pyrenees

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Pyrenees presents a moderate seismicity responsible of many destructive earthquakes over history, which maximum magnitude could probably reach 6.5. This seismicity has led to the development of seismological forecasting networks around the massif. In this context, a feasibility study of a Pyrenean earthquake early warning system (EEW) had been performed within the framework of the SISPyr project.

We first focused on «technical» feasibility aspects. Then, the SISPyr seismic network had been examined in order to assess its adaptability to early warning purposes in terms of network coverage, latency of the existing real-time system... Then different rapid magnitude determination methodologies have been tested in order to check their adaptability to the Pyrenean context and to establish empirical relationships usable in Pyrenees. To that end, a waveform catalog had been constituted, gathering more than 2.400 records from 193 Pyrenean seismic events. The analysis of these records has allowed us to bringing to light clear correlations between earthquakes' magnitudes and four waveforms indicators calculated from first seconds of the P wave.

We also considered question of the opportunity to put in place EEW in Pyrenees. As to do that, an analysis of theoretical performances of the system had been performed: this exercise allowed us to establish approximate levels, for different types of earthquakes, of expected warning delays in the Pyrenees, thus providing a basis to underlie a reflection on how appropriate such a system may be in the zone. Furthermore, this simplified approach can guide definition of potential uses of Pyrenean early-warnings, since they are closely dependant to the time separating warning arrival to the one of destructive seismic-waves. Finally, we carried through a survey bound to Pyrenean potential end-users in order to evaluate their wishes in terms of earthquake early warning

S108S1.06

S108S1 - Real-time seismology

Oral

Anatomy of an Earthquake Early Warning (EEW) alert: analysis of time delays for an end-to-end EEW system in Switzerland

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The speed at which an EEW system can estimate earthquake source parameters is determined not only by the EEW algorithm but also by the seismic network monitoring the relevant source seismicity. Key factors include the network geometry and proximity to hypocenters; station and hub hardware and software; and communications.

We present a detailed analysis of the time delays we observe in an end-to-end EEW system operated by the Swiss Seismological Service (SED) in Switzerland. The EEW algorithm we use to estimate the epicenter and magnitude is the Virtual Seismologist (VS) (Cua and Heaton, 2007; Fischer et al. 2009). VS provides a Bayesian approach to regional network-based earthquake early warning. It has been implemented as a real-time product at the SED since 2006, and since 2008 has been running in real-time as one of the three EEW algorithms which comprise the CISN ShakeAlert demonstration system in California. In its original operational form VS uses the Earthworm binder algorithm for event association; in 2013, VS will be made available as a SeisComp3 module, taking advantage of SeisComp3's event association capabilities.

Our study presents 1) the theoretical alert times for hypothetical earthquakes occurring at any point around the Swiss Seismic Network taking into account variable network geometries; and 2) the observed delays associated with network latencies, data pre-processing, event association and magnitude estimation, and the final dissemination of an alert. Based on the observed performance of the VS system in Switzerland during the past three years we can also assign uncertainties to magnitude estimates at different times after an event. If combined with information on regional seismicity our study can provide a valuable tool to analyze the potential benefits of EEW in Switzerland.

S108S2.01

S108S2 - Real-time seismology

Oral

Application of real-time seismograms: Landslide detection

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There are various types of vibration signals in the world, which are able to be recorded by high-sensitive seismometers. We observed seismic signals recording deep-seated landslides caused by Typhoon Talas, passing Japan Island on September 3-4, 2011.

The long-period surface waves are recorded by broadband seismic network (F-net) all over Japan (NIED, 2011), and short-period ground motions are recorded by the high-sensitive seismic network (Hi-net) as much as a few hundred km away. The landslide signals are usually tens of seconds long and have smooth onset, thus it is easy to distinguish to records of small earthquakes with couple of seconds duration. We applied back-projection technique to the records and determined the timing and location of each landslide signal.

We successfully detected several landslides in the continuous seismic recordings, and large events with volume more than 1 million m3 were located by the back-projection method. The seismic waveforms are very characteristic, and composed of high-frequency ground motion (frequency > 1Hz) and low-frequency ground motion (frequency < 0.1Hz). This complicated waveforms reflects the actual mechanism of landslides, and helps to understand the mass movement in time series.

The sequence of the landslides caused by Typhoon Talas can be located by the conventional source relocation technique in seismology. The seismic signal can tell the snapshot of the process of the landslides, which is rarely observed in visual. This is one of the most well-recorded landslide sequences all over the world. This seismic network is originally designed for locating seismic activities, but continuous records are very important to understand the mechanisms of the natural phenomenon as shown in this presentation.

S108S2.02

S108S2 - Real-time seismology

Oral

Toward constructing an automated source inversion system

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Source rupture process has now become a fundamental information to be released as soon as possible if a large and/or damaging earthquake occurs. The National Research Institute for Earth Science and Disaster Prevention (NIED), Japan, has conducted the source inversion for damaging earthquakes in Japan using strong-motion data recorded by their strong-motion seismograph networks, K-NET and KiK-net. It takes at least about one day to derive and publish a preliminary but plausible result on Website. Now that the strong-motion data can be retrieved just after earthquakes and the hypocenter information is estimated automatically by NIED, it has become realistic to perform the source inversion automatically using these real-time data, which could accelerate the first release of the information on the source rupture process.

We have developed a prototype system for the automated source inversion analysis. Triggered by the seismic intensity data, the system collects the K-NET and KiK-net acceleration, and F-net velocity strong-motion data. The system also obtains the hypocenter location and the moment tensor solution automatically determined by AQUA system using the Hi-net and F-net data. The fault models are constructed using this source information for the two nodal planes with several cases of the relative location of the hypocenter in the fault plane. An algorithm to select strong-motion data used for the inversion considers the epicentral distances, azimuthal coverage and the site response data of each station evaluated by Morikawa et al. (2007). The inversion method follows Sekiguchi et al. (2000, 2002). We test the automated analysis procedure for the previous damaging earthquake data. For the 2008 Iwate-Miyagi Nairiku earthquake (Mw6.9), the best-waveform-fit model is in fairly good agreement with the result we derived in the previous study (Suzuki et al., 2010), except for the relatively larger total seismic moment.

S108S2.03

S108S2 - Real-time seismology

Oral

Real-time automatic seismic monitoring system

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Traditional approaches to the localization of seismic events are based on the detection and identification of a number of specific phases of seismic signals. At that, modern computer analysis methods practically do not use capabilities of the multichannel data processing. These methods inherited the traditional approaches. Usually, geophysicists are mostly concentrated on developing better ways to automatically detect and estimate the parameters of individual phases in single-channel records. However, the automatic procedures based on the ideology of manual processing are extremely inefficient because it is difficult to create algorithms adequate to the actions of an experienced geophysicist.

In this study, a new approach to the automatic real-time detection and location of seismic events is proposed. It is based on our previous investigations in emission tomography. To solve the problems of seismic event detection, we scan a medium by a beam formed by a seismic recording group and subsequently evaluate the energy of weak emissions from different points of the medium.

Scanning is carried out at the nodes of a uniform 3D grid covering the medium under study. When scanning, each node is assigned the experimental evaluation of signal-to-noise ratio (SNR) for signals coming from the vicinity of the given node. A set of the energy evaluations forms a SNR-matrix that reflects the spatial distribution of seismic sources in the medium under study. Implementation of this approach will vary, depending on the ratio of the epicentral distance to the recording group aperture.

The method was successfully applied for detection of weak local earthquakes and quarry explosions and evaluation of coordinates of their epicenters and hypocenters. It could be useful for aftershock activity analysis, seismic monitoring of hydrocarbon fields development, etc.

S108S2.04

S108S2 - Real-time seismology

Oral

Continuous strong motion observation and *'Kyoshin monitor'*

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Owning to the drastic progress of information technologies, continuous strong motion observation has become technically and economically feasible and thus has directly contributed to the mitigation of ongoing seismic disasters. Basically, time history of the ground motions of K-NET and KiK-net, which are nation-wide strong motion seismograph networks operated by NIED, is recoded by an event triggering system and the data are sent to the DMC (Data Management Center at Tsukuba) by non-continues telephone line which is connected only after the earthquake. KiK-net stations share the observatory with Hi-net, which performs a continuous telemetric observation using a high-sensitivity seismograph through a continuous line, EarthLAN. Some K-NET stations are experimentally equipped with a continuous line. For these stations, several kinds of strong motion indexes such as peak values of acceleration, velocity and displacement, real-time seismic intensity, and response spectra are continuously calculated at stations and immediately transmitted through the continuous line to the DMC every second. From these observed strong-motion indexes, the current ground motion of Japan Island is visualized and released as a Web site, 'Kyoshin monitor', the realtime ground-motion monitoring system (http://www.kyoshin.bosai.go.jp). 'Kyoshin' means strong motion in Japanese. The Kyoshin monitor provides realtime ground-motion map every two seconds. If an earthquake occurs, visitors can see the shaking area expanding as the seismic wave propagates from the source area and intuitively understand the earthquake occurrence. The web site always has thousands of visitors, and in particular just after some felt earthquakes the number of visitors exceeded ten thousands.

S108S2.05

S108S2 - Real-time seismology

Oral

A new Bayesian inference-based phase associator for earthquake early warning

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Network-based Early Warning systems can provide warnings for M7+ earthquakes as event characterization is available before the destructive S-waves arrive across much of the strongly affected region. In contrast, for more frequent moderate events, providing warning to the smaller damage zone is more difficult - the 'blind zone' of current systems (e.g. CISN ShakeAlert in California) is similar in size to the severely damaged zone. We propose a faster more robust Bayesian inference-based event associator that, in contrast to current standard associators, is tailored to EEW and exploits more than just pick times. The associator could allow for event association with two observations, which, compared to ShakeAlert, could save ten seconds and reduce the blind zone area by up to 80%.

We compile a dataset of regional and teleseismic earthquake and noise waveforms. Using a causal real--time filterbank with passband filters between 0.1 and 50Hz, updating every second, we extract the maximum amplitudes in each frequency band. We define distributions of amplitude maxima in each passband as a function of epicentral distance and magnitude.

In real-time, we use the maximum amplitude distributions to check whether incoming waveforms are consistent with amplitude frequency patterns of local earthquakes using a maximum likelihood approach. If a single-station likelihood is larger than a threshold value for at least 2 neighboring stations, we evaluate whether the arrival times are in agreement with a common earthquake origin (using an Equal Differential Time location scheme). Single-station likelihood functions and the location likelihood function constitute the multi-station event likelihood function that can be combined with prior information (station noise, preceding seismicity, fault proximity, etc.) to obtain a Bayesian posterior distribution, representing the degree of belief that current real-time observations correspond to a local earthquake.

S108S2.06

S108S2 - Real-time seismology

Oral

Continuous kurtosis-based migration for seismic event detection and location, with application to Piton de la Fournaise volcano

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We present an automatic earthquake detection and location technique based on migration of continuous waveform data. Data are pre-processed using a kurtosis estimator in order to enhance the first arrival information, then migrated onto a pre-defined search grid, using pre-calculated P-wave travel-times, and finally stacked. Local maxima in the resulting 4-D space-time grid indicate the locations and origin times of seismic events. We have applied our technique to earthquake swarms occurring before eruptions and during intrusive events on Piton de la Fournaise volcano, Reunion Island, France, and have located 5000 events from 12 different swarms that occurred between 2009 and 2011. Our automated locations are consistent with those performed using manual picks where available, and indicate that the seismicity clusters around sea-level for both types of volcanic events. Multiplet analysis of the detected events and subsequent double-difference relocation produce sharper images of earthquake swarms. Our code, named WaveLoc, is released in open-source and is in the process of being adapted to real-time operation.

S201bPS.01

S201bPS - Ground Motion Prediction Equations

Poster

The variation and scaling of strong motion in near source region

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Current engineering application, strong motion attenuation models are often scaled by moment magnitude (M_W) instead of local magnitude (M_L). In this study, we shall examine its appropriation by analyzing some strong motion recordings collected in Taiwan. The strong motion data that belong to the earthquakes with about the same local magnitude and greater than 6.0 are selected. The peak ground acceleration (PGA) and spectral intensities defined in different period ranges (SI_a in period range and SI_a in long period range) are adopted as model parameters to represent ground motion characteristics.

First of all, the distributions of PGA are compared with those of SI_a. The results reveal that the pattern and area of PGA and SI_a distributions are about the same for each earthquake and may respond the earthquake source geometry and M_W. The PGA and SI_a attenuations are better scaled by ML than by M_W while the attenuations of $SI_a$are better scaled by M_W. These are actually reasonable results since M_L is defined by scaling the amplitude of short period waves and M_W is scaled by DC or the amplitudes of very long period waves. The attenuation and variations of strong motions in near source region show that the strong motion parameters of earthquake with large magnitude and complicated source rupture have larger deviations to their regreesion average values. More detailed results will be presented in the conference.

S201bPS.02

S201bPS - Ground Motion Prediction Equations

Poster

A new PGA attenuation prediction model by employing genetic optimization techniques for Iran's plateau database

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A new Peak Ground Acceleration (PGA) model, by means of evolutionary algorithms such as genetic programming and genetic algorithm, has been proposed in this paper. The first step toward obtaining the attenuation model is gathering an Iranian database which includes 179 ground motion records obtained from 36 earthquake events in Iran with magnitudes ranging from 5.0-7.4 and distances ranging less than 200 km. After finding the new model, it is compared with a set of candidate models. The candidate ground motion equations are comprised of three groups: (1) the local models which have been developed based on the Iranian data, (2) the regional models corresponding to Europe and Middle East data sets and (3) the Next Generation Attenuation (NGA) models. Based on the traditional hypothesis test such as Z-test and Lilliefors-test the results show that all the residuals have normal distribution but majority of the models do not have zero mean residuals. Other results from different statistical and mathematical methods such as Error terms (RMSE & MAE), coefficient of determination (R-squared) and a new approach of information-theoretical method (LLH) indicate that the obtained model by genetic programming and improved by genetic algorithm (GP Model), based on Iranian database, have the best predictions compared with the others. Another important test which is applied in this paper is checking for no bias on residuals. In this case GP model is not heavily biased between the other models. And finally the results based on the new approach in this study for evaluating stability of models by re-sampling indicate GP model is more stable in comparison to the other selected models.

S201bS1.01

S201bS1 - Ground Motion Prediction Equations

Oral

The future of ground motion prediction equations: what to expect in the next 5-10 years

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The development of ground motion prediction equations (GMPEs) has changed from simple curve fitting excises to model building with analytical model constrains on the extrapolation of the GMPE outside the range that is well constrained by empirical data. In this presentation, I present the main changes to expect in GMPEs in the next 5-10- years: rock site classification, regionalization, single-path sigma, and use of finite-fault simulations as constraints. For rock sites, GMPEs will include kappa, or a similar parameter, as an additional site parameter to capture the high frequency site and region effects. The site classification has been based on simple site categories or simple parameters, such as VS30 or site period, that are correlated with the shear-wave velocity profile. The GMPEs will include regional differences in the large distance attenuation (Q) and in the VS30 scaling that account for differences in the correlations between the simple parameters used in the GMPEs and the physical parameters related to the ground motion scaling. The regionalization will then be extended to capture effects of specific source-path geometries within a region thought the use of single-path sigma and single-path medians terms in the GMPEs. Finite-fault simulations that have been adequately validated will gain wider use, particularly for large magnitudes and complex rupture geometries that are not captured in empirical data sets. Validations need to address both the median prediction from the simulations and the aleatory variability. While the results of the finite-fault simulations can be used directly in hazard studies, there will still be a need to have simplified parameterized models (GMPEs) that capture the main features of the simulations. Future GMPEs will be developed that include both empirical data and numerical simulations; initially, the finite-fault simulations will be used for the median only, and later for the aleatory variability.

S201bS1.02

S201bS1 - Ground Motion Prediction Equations

Oral

New concepts in ground-motion modeling for Switzerland

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We present a stochastic ground-motion model for Switzerland, constrained by ground-motions observed from small local- and regional-earthquakes in addition to macroseismic intensities observed from large damaging events in Switzerland. We use this model in a stochastic simulation to generate predictions of PGA, PGV and 5% damped response pseudo-spectral acceleration. We facilitate the prediction of ground-motions from finite-fault sources through the use of the REFF distance metric and show that magnitude and distance scaling-behavior of events up to Mw=7.5. Ground-motion prediction uncertainty is described in terms of between- and within-event uncertainties. Single-station sigma is derived, accounting for the prediction uncertainty at a given site without the ergodic assumption. The model is referenced to a generic rock-profile that was developed by utilizing measured velocity profiles of the sites of seismic stations and is calibrated at higher magnitudes to the Swiss regional macroseismic intensity prediction model. The model is based on moment magnitudes from the recently developed Earthquake Catalogue of Switzerland 2009 (ECOS09). The well-defined reference for the model means that it can be adapted for a site specific application through the use of site-specific quarter-wavelength velocity profiles, quarter-wavelength velocity contrasts and kappa values. We have investigated the scaling of the stochastic model and other GMPEs with respect to Japanese strong-motion data. A rock reference profile has been defined for the Japanese network which allows an adjustment of the model to different rock profiles. After accounting for site-specific differences in Japan and Switzerland, it was shown that the Swiss model was successful in predicting strong-ground motion of large earthquakes in Japan. The comparison of Japanese data with other GMPEs also brought to light an issue with their applicability to sites not typical to the dataset used in their derivation.

S201bS1.03

S201bS1 - Ground Motion Prediction Equations

Oral

Updated empirical ground motion models for active tectonic regimes developed under the NGA-West2 Program

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The Pacific Earthquake Engineering Research Center (PEER) has completed a 5-year program, called NGA-West2, to update the NGA ground motion models (GMMs) for PGA, PGV and 5%-damped pseudo-absolute response-spectral acceleration (PSA). Part of the original NGA program's success is that subsequent studies have shown that the NGA models are generally consistent with recordings from shallow tectonically active regions around the world. However, as successful as the NGA program was, there were several topics that could not be incorporated because of time constraints, which have now been addressed in the new PEER NGA-West2 project. These topics include the incorporation of new or improved modeling of source directivity (i.e., focusing), directionality (e.g., median vs. maximum rotated components), hanging wall geometry, shallow site response, deep basin response, and anelastic attenuation terms. In addition, new models were developed for vertical ground motions, response-spectral damping ratios (0.5% to 30%), intra-model epistemic uncertainty, and classification of mainshocks versus aftershocks. The PEER uniformly processed strong-motion database was expanded to include around 13,000 small-magnitude (3.0 ≤ M < 5.0) recordings from 400 earthquakes in California and 8,500 moderate-to-large magnitude (5.0 ≤ M ≤ 7.9) recordings from 250 worldwide earthquakes. This has provided much stronger constraints on magnitude and distance scaling, thus eliminating the previous overestimation of ground motions at small magnitudes and large distances by the original NGA models. Significant additional earthquakes include 2003 Bam, Iran (M6.6), 2004 Parkfield, CA (M6.0), 2008 Wenchuan, China (M7.9), 2009 L¡'Aquila, Italy (M6.3), 2010 El Mayor-Cucapah, Mexico (M7.0), 2010 Darfield, New Zealand (M7.0), and 2011 Christchurch, New Zealand (M6.2). We summarize the project components and show comparisons among the new NGA-West2 GMMs as well as between the NGA-West2 and the previous NGA GMMs.

S201bS1.04

S201bS1 - Ground Motion Prediction Equations

Oral

Ground motion for complex multi-fault ruptures and incorporation in hazard analysis

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It is becoming more common to consider complex multi-segment fault rupture scenarios as part of the source characterization (SSC) in seismic hazard analyses. These complex ruptures not only lead to larger magnitudes, but also can include large changes in the rupture geometry and rake in a single rupture scenario. In addition, there may be overlapping rupture segments or splay faults that add to the rupture complexity. The occurrence of complicated multi-fault ruptures is postulated by the most recent Uniform California Earthquake Rupture Forecast (UCERF) model. SSC needs to capture the complexity of fault geometry at intersections or where a single fault branches into multiple segments and splays. Ground motion prediction equations (GMPEs) used in hazard studies need to be applicable to all cases in the source characterization, including these complex ruptures. The GMPEs use explanatory parameters such as magnitude, mechanism, dip, and top of rupture to describe the source and distance metrics to account for the wave propagation. Simple rules need to be defined for estimating these explanatory parameters for complex ruptures. For example, source geometry parameters could be computed as average values over the entire source or using local values based on the closest rupture segment to the site. In the presentation, we review the state-of-the-practice criteria for appropriate use of predictive parameters in complex multi-fault scenarios. The complex ruptures encountered along coastal California considered in the Southwestern US (SWUS) Ground Motion Characterization (GMC) SSHAC Level 3 project are used as examples. We also discuss future improvement on how complex kinematic and dynamic rupture simulations can help constraining the strong ground motion for those cases.

S201bS2.01

S201bS2 - Ground Motion Prediction Equations

Oral

Evaluation of nonlinear site amplification ratios for ground motion prediction equations for Japan

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Ground motion prediction equation (GMPE) is an important tool in earthquake engineering. The site terms in a GMPE for soil sites need to accommodate the nonlinear soil response in a plausible manner but the number of strong-motion records that contain significant nonlinear soil response is too small to constrain nonlinear soil site terms. Usually 1-D nonlinear or equivalent linear modeling is used to obtain these nonlinear soil site terms. In the present study, the elastic soil profiles of 272 soil sites from the Kik-Net strong-motion sites in Japan were used to construct 1-D models. Six nonlinear models for clay, sand and soft rock were assigned to the soil profile according to soil shear-wave velocity and depth while some random variation was allowed in the process so as to capture the variability in real soil sites. The models were subjected to 530 components of rock site strong-motion records that were selected from earthquakes in a wide range of magnitudes, depths and source distances. An equivalent linear computer code SHAKE was used to compute the site response spectral amplification ratios. A surprising result was that impedance ratio appeared to be a very important site parameter. A high impedance ratio not only increased the amplification ratios in low level motions, but also enhanced the nonlinear responses of the soil sites. A simple model to account for all site parameters is proposed and a number of ways to diminish the limitations of 1-D modeling when it is used for GMPE will be described. The main site parameters that are used to model near-surface site effects in a GMPE are site-period based site classes, site period, V_{S30} - travel time-averaged shear-wave velocity of the top 30 meters, and a combination of V_{S30} for short-period sites and $4H_{bedrock}/ V_{S30}$ for long-period sites where $H_{bedrock}$ is bedrock depth.

S201bS2.02

S201bS2 - Ground Motion Prediction Equations

Oral

Ranking of suitable GMPEs for northern Italy, based on residual analysis

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The selection of the Ground Motion Prediction Equations (hereinafter GMPEs) appropriate to a specific regional geologic context is one of the crucial issues of any seismic hazard evaluation. The Emilia dataset, together with the strong motion data available from past events occurred in northern Italy, offers the opportunity of investigating in detail the characteristic of the ground motion in this region, with special emphasis on the Po plain area. The strong motion dataset for northern Italy (DBN) is composed by 1440 strong-motion records from 224 stations, relative to seismic events from 1976 (Friuli sequence) to 2012 (Emilia sequence) in the magnitude range 3.5 – 6.4. In the framework of the Sigma-Project we exploited the DBN to select and rank a set of 5 candidate GMPEs, which are developed from global datasets or specifically derived for Italy. We adopted the data-driven method recently developed by Scherbaum et al. (2009) to quantitatively judge the applicability of GMPEs in this region. We subsequently carried out a residual analysis in order to evaluate the features of ground motion attenuation in terms of magnitude and distance scaling. We found that, in general, all the considered models are not able to represent high-frequency motion, predicting values which are larger than the observations and that the global models should not be applied outside their range of applicability, without introducing appropriate corrective factors. Furthermore, we identified some peculiar features of DBN, that can be highlighted independently from the GMPES adopted: i) low amplitudes at short periods, ii) attenuation with distance strongly dependent on frequency; iii) amplification of spectral ordinates in the distance range from 80 to 100km, particularly evident at short periods (0.1 s)

S201bS2.03

S201bS2 - Ground Motion Prediction Equations

Oral

New Ground Motion Prediction Models for Caucasus region

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The Caucasus is a region of numerous natural hazards and ensuing disasters. In this study new GMP models are obtained based on new data from Georgian seismic network and also from neighboring countries. Estimation of models are obtained by classical, statistical way, regression analysis. Also site ground conditions are considered because the same earthquake recorded at the same distance may cause different damage according to ground conditions. Apart, GMP models will be obtained not only for entire Caucasus region but for specific seismically active areas. Finally, Seismic Hazard are assessed using GIS based on updated GMP models obtained in this study.

S201cPS.01

S201cPS - Earthquake scenarios

Poster

Spectral ground motion characteristics of the Canterbury earthquake sequence, New Zealand

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The Canterbury earthquake sequence beginning with the 2010 Mw 7.1 Darfield earthquake is one of the most notable and well-recorded crustal earthquake sequences in a low-strain-rate region worldwide. Ground motions in Canterbury during the aftershock sequence were partially severe, in particular during the 2011 Mw 6.2 Christchurch event, and a range of contributing factors are invoked in the explanations of these ground motions, such as high stress drop sources, regional geological structures and variable site effects (including strong liquefaction effects). A clearer understanding of these particular influences on the observed ground motions is crucial in assessing on-going seismic hazard in the region and informing the rebuild process.

We present preliminary observations from a generalized spectral inversion approach that allows us to separate and quantify ground motion characteristics specific to the Canterbury region. Results were obtained utilizing a subset of the rich GeoNet accelerogram database composed of more than 200 earthquakes (Mw 3.4–7.1) and more than 2300 source-stations paths.

The results of this study allow, among others, the determination of stress drop and its variability in the Canterbury region. The source spectra indicate overall higher than average stress drops (median value ~4.1 MPa) and on average close to self-similar behaviour. Moreover, significant lateral stress drop variations are observable. Non-parametric attenuation functions derived from the inversion illustrate regional characteristics, including strong high-frequency attenuation and what we infer to be the influence of strong ancient subducted crust at mid-crustal depths. Linear site response factors spanning a range of rock and soil conditions show that local amplification effects also played a significant role in the variations in ground motion observed within Christchurch city, although nonlinear/liquefaction effects dominated at deep soil sites during the strongest shaking.

S201cPS.02

S201cPS - Earthquake scenarios

Poster

Near–source strong ground motion field for the 2011 May 11, M5.2 Lorca (Spain) Earthquake from regional and local distance data

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The telemetered broad band displacement data registered from the National Seismic Network of Spain for the 2011 May 11, Lorca (Spain) earthquake has been inverted for the seismic moment tensor determination using a pre-calculated library of the corresponding Green Functions. With the obtained moment magnitude value, the dual geometric fault plane solutions together with an estimation of the rupture velocity over both planes an inversion of the planar slip over the selected fault plane is obtained. The proposed model is a 15x15 km centered at the hypocenter considering subfractures of 0.6x0.6 km. The result is that plane (230°, 64°, 37°) is our candidate with a velocity rupture of 1.8 km/s. The inversion of these data provides us with the slip distribution over the fault plane, with a maximum slip of 19.3 cm and an average displacement of 4.5 cm.

Starting with the slip distribution we simulate the near strong ground motion (acceleration field) over the epicentral area. To produce such field a local Green functions calculation is needed using a local velocity structure in order to obtain the acceleration field referred to a soil type C of amplification factor equal to 1. Afterwards the acceleration field obtained is multiplied by the amplification map to get the filtered field. This calculated strong-ground motion in the vicinity of the source is checked against an accelerograph recording at less than 5 km from the epicenter, showing a reasonable fit.

This near-source synthetic strong ground motion field is obtained in almost real time (30-45 minutes after origin time) and may be considered in earthquake scenarios in order to advance future damages.

S201cPS.03

S201cPS - Earthquake scenarios

Poster

Rupture process of the 2011 Tohoku-Oki earthquake inferred by a full waveform inversion with 3D Green's tensor synthetics

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The March 11, 2011 Tohoku-Oki earthquake (GCMT Mw9.1) generated strong ground motions and large tsunamis, and caused devastating damages in the northeastern Japan. Estimating the rupture process of this event is very important for understanding the geophysical condition of the generation of magnitude-9-sized earthquake and the mechanism of the excitation of the large tsunamis. We present the rupture process analysis of the 2011 Tohoku-Oki earthquake by using a non-linear full-waveform inversion method in which the teleseismic and the strong motion seismograms are jointly used. We incorporate the effect of the near-source laterally heterogeneous structure on the synthetic Green's tensor waveforms because the solution can be erroneous one if the effect is not considered (e.g., if only a flat layered structure is used) [1]. For the teleseismic P-wave synthetics we use a 2.5-dimensional finite-difference method [2]. For the strong motion synthetics we use full three-dimensional finite-difference method that incorporates topography, oceanic water layer, three-dimensional heterogeneity and attenuation. Our simulation is accelerated by the use of several hundreds of GPUs used in parallel [3]. We use a GPU supercomputer, the TSUBAME-2.0 in Tokyo Institute of Technology, Japan. The preliminary analysis with 31 teleseismic and 15 strong motion waveforms results in large slips near and around the JMA epicenter: the major rupture apparently migrate toward the north of the epicenter and the maximum slip is about 40 m. We will present results by incorporating more strong ground motion records and discuss the effect of the choice of the Green's tensor waveforms on the solutions. (References: [1] Okamoto and Takenaka, Earth Planets Space, 61, e17-e20, 2009. [2] Takenaka and Okamoto, in Seismic Waves, Research and Analysis, ed. Kanao Masaki, Intech, 2012. [3] Okamoto et al, in GPU Solutions to Multi-scale Problems in Science and Engineering, ed. D.A. Yuen et al., Springer, 2013.)

S201cPS.04

S201cPS - Earthquake scenarios

Poster

Estimating rupture process of 2003 Bam, Iran, earthquake: A bilateral rupture and combination of two focal mechanisms

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The 2003 Bam, Iran, earthquake (Mw=6.6) was recorded by accelerograph of BAM station. As causative fault was placed under the city, the accelerograph recorded mainshock, a foreshock, and many aftershocks closely. To study scenario of rupturing, we simulated all components of observed waveform of mainshock via Empirical Green's Function method (EGFm). We used 28 selected aftershocks and a foreshock to simulate the mainshock in frequency range of 0.5 to 5 Hz. As hypocenters were utterly close to the station, some small events were corrected to reduce difference of path effect. Confirming the result by Sadeghi et al. (2012), starting point of rupturing is found in the middle of strong motion generation area. Horizontal components of simulations show Bam earthquake was occurred in western side of BAM station. Considerable variation in the ratio of amplitude in the EW and NS components may be used to discuss the possibility of variation in the focal mechanism of the aftershocks. Although the EGF simulations are generally successful for the vertical components, however most aftershocks which have similar mechanisms to the mainshock, i.e. similar EW/NS ratio, have capacity to simulate some peaks of the both horizontal components, and on the other hand, some small events with different mechanism are able to simulate peaks of just one horizontal component. Following the combined fault model in the EGFm by Fukuyama and Irikura (1986) and Sadeghi et al. (2012), we make some changes to Irikura (1986) to combine two small events. While two aftershocks have different mechanisms, some combinations improve simulations. The rupture initiating point at the middle of the fault plane and improved simulations by combination of two fault surfaces with different focal mechanisms may suggest a bilateral rupture and combination of two focal mechanisms for the mainshock of the Bam earthquake.

S201cPS.05

S201cPS - Earthquake scenarios

Poster

Frequency distribution of JMA Seismic Intensity between 1950 and 2009

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When seismologists communicate with the public and discuss hazard assessment and risk management, JMA Seismic Intensity is commonly used in Japan. With the introduction on JMA Instrumental Intensity in 1996, the number of seismic intensity observation sites has substantially increased and the spatial coverage has improved vastly. While it is always difficult to represent complex ground motion with one index, these intensity data represent characteristics of the seismic ground motion in Japan. We investigate statistics of JMA Seismic Intensity between 1950 and 2009. Specifically we focus on the frequency distribution of intensity recordings. Observations of large intensity are rare compared to those of small intensity, and previous studies demonstrated that the frequency distribution of observed intensity can be expressed as an exponential law, or the Ishimoto-Iida law [Ishimoto & Iida, 1939]. Such behavior could be used to empirically construct probabilistic seismic hazard maps [e.g., Kawasumi, 1951]. For the recent instrumental intensity data as well as pre-instrumental data, we are able to confirm that Ishimoto-Iida law explains the observations of JMA Intensity. Exponents of the Ishimoto-Iida law is approximately 0.5. At stations with long recordings, there is no apparent difference between pre-instrumental and instrumental intensities when Ishimoto-Iida law is used as a measure. Numbers of average intensity reports per year and exponents of the frequency distribution curve vary regionally both of which are controlled by local seismicity. The observed numbers of large intensity is slightly less than extrapolated and predicted from those of small intensity assuming the exponential relation.

S201cPS.06

S201cPS - Earthquake scenarios

Poster

Strong ground motion simulations in Port-au-Prince (Haiti)

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Haiti was struck by a strong earthquake in January 2010 that had a moment magnitude of 7.0. Very few seismological stations were existing at the time in Haiti and the one that recorded the main shock was saturated. Thus, there were no direct measurements of the ground motion produced by this large event. Quickly after the event, however, multiple stations were installed by the USGS, the CGS and the BME. These stations have been recording aftershocks, allowing us to study the site response in several locations in Port-au-Prince and to simulate the ground motion due to larger events. From these networks we have used the recordings of several tens of earthquakes with a magnitude of larger than 3.0 at 14 stations: 3 stations of the Canadian Broad-band network, 2 stations of the educational French network and 9 stations of the BME accelerometric network. Seismic response of the studied sites were estimated from the classical SSR and H-over-V ratio computation. The estimated site responses present a large variability, depending on the site and the earthquake recordings. We then used the same earthquake recordings as Empirical Green's Functions in order to simulate the ground motion generated by a virtual earthquake. For this simulation a stochastic EGF summation method was used. This work included the simulation of a magnitude Mw=6.8 using two successively smaller events that occurred on the Leogane fault as EGF. The results obtained using the two events are surprisingly very different. Using the first EGF, nearly the same ground motion was obtained at each station in Port-au-Prince, whereas with the second EGF, the results highlight large differences. Finally, the estimated site response was used in combination with a direct estimation of the rock site motion in order to reproduce the ground motion which were compared to the EGF simulation method. The comparison confirms the large variability in the modeled ground shaking which can be due to both site and source effects.

S201cPS.07

S201cPS - Earthquake scenarios

Poster

Earthquake scenarios and probabilistic ground shaking maps for the Tehran region, Iran

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Tehran region is an area encompassed by 49.5°-54° E longitudes and 34°-37° N latitudes, which covers central part of the Alborz Mountains in the north, and the northern Central Iranian microcontinent in the south. This region has experienced intense seismic activities with surface deformation. The most recent catastrophic events occured in 1962 with Ms 7.2 in Buyin Zahra and 1990 with Ms 7.4 in Manjil. A uniform catalogue of earthquakes is provided and a total of 20 potential area seismic sources are delineated in the region. Seismicity parameters are evaluated considering magnitude uncertainty and incompleteness of earthquake data. Inhomogeneity of seismicity in time and space is properly portrayed in annual mean occurrence rate of earthquakes of each potential seismic source.

Probabilistic seismic hazard assessment (PSHA) is performed for Tehran region. Seismic hazard maps in terms of spectral acceleration (Sa) are prepared for periods of 0.2 and 2.0 sec, and mean return periods of 475 and 2475 yr (10% and 2% probability of exceedance in 50 yr). In order to identify distribution of earthquake scenarios that contribute to exceedance of a given Sa level, probabilistic seismic hazard deaggregation is carried out for selected cities in the region in terms of magnitude (M), source-to-site distance (R) and the deviation parameter in the attenuation equation (ε). For example the results indicate that scenario earthquake of Ms=6.8, R=35 km, and ε=1.3 for Sa(2.0 sec) represents the relatively likely ground motion with 10% chance of being exceeded in 50 yr for Tehran city. Deaggregation results can provide useful information on better defining the design scenario and selecting corresponding time histories for seismic design. The results show that in most cases, as the Sa period increase, the contribution of larger and more distant scenario earthquakes to the overall seismic hazard increase.

S201cPS.08

S201cPS - Earthquake scenarios

Poster

Ground motion scenario based on multi-scale mapping of fault heterogeneity

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It has been proposed that earthquake complexity can be described by multi-scale heterogeneity in fracture energy of the fault interface (Ide and Aochi, JGR, 2005). The 2011 Tohoku earthquake revealed us such multi-scalability of the fault heterogeneity, seemingly a cascade-rupture mode (Aochi and Ide, EPS, 2011; Ide and Aochi, accepted in Tectonophysics, 2013). We are then interested in the effect on the ground motion through systematic works on the model parameters. This study presents the ground motion simulations based on the multi-scale dynamic rupture simulations in the regional scales for both shallow moderate earthquakes and subduction large earthquakes. In all cases, the synthetic seismograms in time vary according to the variation in dynamic rupture process (rupture directivity, rupture directivity, and slip distribution, source time function). The frequency content changes significantly in the near field, while it is quite homogeneous for a receiver located far away.

S201cPS.09

S201cPS - Earthquake scenarios

Poster

Deterministic high-frequency ground motions from simulations of dynamic rupture along rough faults

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The accuracy of earthquake source descriptions is a major limitation in high-frequency (~>1 Hz) deterministic ground motion prediction, which is critical for performance-based design by building engineers. We address this issue by an attempt to quantify the contributions to high-frequency ground motion from both small-scale fault geometry and media complexity and perform validation against recent Next Generation Attenuation (NGA) relations. Specifically, we compute the ground motion synthetics using dynamic rupture propagation along a rough fault imbedded in a velocity structure with heterogeneities described by a statistical model. First, simulations of dynamic rupture are carried out using a support operator method (SORD, Shi and Day [2013]), in which the assumed fault roughness follows a self-similar fractal distribution with wavelength scales spanning three orders of magnitude from ~10^2 m to ~10^5 m. The rupture irregularity caused by fault roughness generates high-frequency accelerations with near-flat power spectra up to almost 10 Hz. Next, we perform wave propagation simulations using the moment-rate time histories from the dynamic rupture simulation as a kinematic source to extend the ground motions out to farther distances from the fault with a highly scalable fourth-order staggered-grid finite difference method. The latter wave propagation simulations use a characteristic 1D rock model with and without small-scale heterogeneities. We then compare our ground motion results (e.g., distance and period dependence of peak ground accelerations and peak spectral accelerations) with the empirical curves given by recent NGA relations, for both the median and the standard deviation. Finally, the high-frequency ground motions from the rough-fault simulations are compared to those obtained by a hybrid deterministic–stochastic technique (Mai et al, 2010) in order to understand the limitations of high-frequency generation using the latter method.

S201cPS.10

S201cPS - Earthquake scenarios

Poster

How geometry and structure control the rupture dynamics of the Mw 9.0 Tohoku earthquake

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The giant Tohoku earthquake had an unexpected size for that region and triggered a huge tsunami wave.

Inversion of local and teleseismic data, indicated a complex frequency dependent rupture. Low frequency signals (f<0.1 Hz) evidenced an extremely compact region of large slip extending along-dip over about 100 km, between the hypocenter and the trench. This slip asperity was likely the cause of the localized tsunami source. High-frequency signals were instead generated closer to the coast in the deeper part of the subduction zone and are likely the cause of most of the ground shaking felt along the Japanese coast. Additionally, during its first stage the rupture was almost confined in a small stripe containing the hypocenter before propagating southward along the strike.

To study the influence of geometry and structure on the rupture propagation, we fixed the geometry of the fault plane and the velocity properties and we studied the effects of the stress and the friction on the rupture behavior by producing a large number of 2D spectral elements simulations.

We used a regional stress field and we explored the effect of its variability on the rupture dynamics by decreasing the stress close to the surface, mimicking the large pore pressure under the ocean bottom.

In our «best» model, we obtained an asymmetric rupture, which travels faster in the up-dip direction. Localized asperities with large slip occur close to the trench as an effect of the interaction of stationary Rayleigh waves with the propagation rupture, Downwards, the mantle wedge behaves as an accelerator of the rupture producing a slip patch. In all models, up-dip rupture is strongly sensitive to the orientation of the stress field and in some cases it stops and restarts boosted by positive interference of surface waves. Along the down-dip direction, high-frequency radiation has an asymmetric pattern, with most of the energy confined in the oceanic layers.

S201cPS.11

S201cPS - Earthquake scenarios

Poster

Dynamic rupture scenarios of anticipated Nankai-Tonankai earthquakes, southwest Japan

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We investigated dynamic rupture scenarios of anticipated megathrust earthquakes on the Nankai-Tonankai subduction zone, southwest Japan. To improve the scenario reliability, the model parameters should be constrained by available data, or derived from their analysis. We employed the three-dimensional plate interface geometry and the slip-deficit rate on the interface. Accumulated slip-deficit was used to obtain the stress drop distribution of anticipated earthquakes. The estimated stress drop distribution is consistent with the seismogenic asperity locations known from the analysis of past earthquakes. Fault friction constitutive parameters, however, had to be assumed from indirect observations because they cannot be constrained directly by the data. Based on various geophysical observations, we defined three regions where larger fracture energy is required. These are the eastern edge of the Tonankai area, the western edge of the Nankai area, and the region between the Tonankai and Nankai areas (beneath the Kii peninsula). Such lateral heterogeneity promoted the segmented rupture along the Nankai trough. With predefined stress drop and constitutive parameters, various rupture scenarios for Tonankai and Nankai asperities were obtained for different initiation locations. In some cases, a single segment is ruptured, while in other cases, all the segments are broken due to dynamic linkage at the segment boundary, causing a giant earthquake. The initiation location is a critical parameter that controls the rupture propagation across the segment boundary. These scenarios will be extremely useful to evaluate deterministically the strong ground motions and tsunami hazards caused by the next major earthquakes in southwest Japan.

S201cS1.01

S201cS1 - Earthquake scenarios

Oral

Reconsiderations for seismic hazard assessment after the 2011 Great Tohoku earthquake

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The 2011 Great Tohoku earthquake was the largest event in the history of Japan. This earthquake was not considered in the National Seismic Hazard Maps for Japan that were published by the headquarters for earthquake research promotion of Japan. Based on the lessons learned from this earthquake disaster, we consider problems and issues to be resolved for seismic hazard assessment.

(1) Modeling of seismic activity with no oversight to low-probability earthquakes. For earthquakes occurring both in subduction zones and in active faults, it is necessary to model seismic activity that can be considered to large events in a return period of 10,000 or 100,000 years.

(2) Preparation of strong-motion evaluation considering low-probability earthquakes. In addition to emphasize the urgency of the earthquake occurrence by showing the seismic hazard probability, we should prepare the maps that show the strong-motion level for earthquake preparedness. For example, based on the averaged long-term seismic hazard assessment, we should show the strong-motion level for 10,000 or 100,000 years return period.

(3) Development of methodology for selecting appropriate scenario earthquakes from probabilistic seismic activity model. It is necessary for purposes of earthquake preparedness to establish a methodology that appropriate scenario earthquakes can be selected from probabilistic seismic activity models.

(4) Sophistication of techniques for prediction of strong-motion for mega earthquakes.

In order to perform seismic hazard assessment considering the low-probability events, it is necessary to predict strong-motion for large earthquakes. For the “Recipe” for prediction of strong-motion, which is currently being used in Japan, the subduction zone earthquakes up to about M8 and earthquakes on active fault up to about 80km in length are only verified its scope. The sophistication of techniques that can be applied to super large earthquakes is required.

S201cS1.02

S201cS1 - Earthquake scenarios

Oral

Earthquake scenarios for predicting strong ground motions from subduction mega-thrust earthquakes

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Source models related to strong ground motions have been integrated in the waveform inversion analysis to better characterize rupture processes of inland crustal earthquakes and subduction mega-thrust earthquakes. Generation of strong ground motion is related to slip heterogeneity inside source areas, i.e. strong motion generation areas (SMGAs). High frequency motions are generated from SMGAs which are almost coincident with large slip area for inland crustal earthquakes. However, ground motions from subduction earthquakes clearly show differences in wave radiation at various frequencies. The short-period generations of the subduction ones obtained from the backprojection method using short-period teleseismic arrays are located on deeper down-dip areas, while most of slip distribution inverted from long-period records such as geodetic and tsunami data are placed at shallower depths near the trench. We estimate a source model for generating strong ground motions from the 2011 Tohoku earthquake by comparing the observed records from the mainshock with synthesized motions based on a characterized source model and the empirical Green's function method. We obtained a short-period source model consisting of five SMGAs with large slip velocity or high stress drop. The SMGSs distributed in dip direction west of the hypocenter and in strike direction north and south of the hypocenter, along the down-dip portion of the source fault of this earthquake. These results indicate that great earthquakes on inland active faults and on subduction earthquakes have different source characteristics, especially in the short-period range related to strong ground motions. A recipe for predicting strong ground motions was proposed for inland crustal earthquakes. We have confirmed earthquake scenarios based on the recipe successfully estimate ground motions from the inland ones. Then, we propose an improved idea for recipe of predicting strong ground motions for the subduction earthquakes.

S201cS2.01

S201cS2 - Earthquake scenarios

Oral

3-D modelling of wave propagation in the Marmara sea region resulting from M7+ events

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Wave propagation in the Marmara region (Turkey) due to the rupture of the Marmara Sea segments of North Anatolian Fault is modeled in 3-D. We make use of the detailed data about the fault geometry and a velocity model created earlier, improving it by incorporating information and data that became recently available. We validate the improved velocity model by regional events. Using extended source models available for the Kocaeli earthquake we simulate the strong motion records from the earthquake and look at the differences caused by them. We also focus on the Northern Marmara that includes Istanbul and vicinity, since it is there, where a future earthquake is expected to cause most of the damage. Seismic wave propagation around the fault is modeled using a 4th order staggered grid finite difference method. The effective frequency range of the simulation is 0-0.8Hz We consider several plausible fault geometry and rupture scenarios and look at the effect of the basin structure on wave propagation and on surface ground motion. We study the variability of ground motion in the area resulting from different models of rupture propagation and from amplification due to basin response.

Consideration of 3D structures beneath the Marmara Sea yields interesting results in terms of spatial distribution of regional ground motion. Basin structures particularly beneath the Cýnarcýk basin play an important role in channeling the waves away from Istanbul if the rupture propagation is from west to east. If we assume a 1D velocity structure then the directivity effect is clearly observed to effect larger parts of Istanbul. When the 3D velocity model is used, the deep 3D structures effectively reduce or direct the destructive waves away from Istanbul. However we observe significantly enhanced ground motion levels in the Armutlu peninsula.

S201cS2.02

S201cS2 - Earthquake scenarios

Oral

Rupture directivity during the 2009 L'Aquila earthquakes sequence: A key parameter for seismic scenarios

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During the 2009 L’Aquila seismic sequence, ground motion showed variations as large as a factor of 10 at same sites for earthquakes with similar moment-magnitude, focal mechanism and hypocenters. Much of these variations can be ascribed to effects of rupture directivity. A method based on the EGF deconvolution in the frequency domain is applied to quantify the strength of rupture directivity in the magnitude range 3.3 < Mw < 6.1. The spectral ratio of event pairs with different magnitudes at individual stations shows large azimuthal variations above the corner frequency in spite of the consistent focal mechanism and source distance. A systematic analysis indicates that strong along-strike source directivity characterized all three Mw > 5.0 shocks. Source directivity was also persistent for smaller events: 68% of the examined earthquakes showed evidence of unilateral directivity toward SE, whereas only one (Mw 3.7) event showed clear rupture propagation in the opposite direction. The spatial distribution of the events suggests that the probability of unilateral rupture is higher for events close to the main faults, whereas weak directivity or bilateral ruptures are observed more frequently for events in the volume around the faults ruptured by the main (Mw > 5) shocks of the seismic sequence. To clarify further the origin of the strong directivity for events near the main faults, we analyze P waveforms generated by small events. The results indicate, for some source-receiver configurations, head waves propagating along fault bimaterial interfaces. Our study highlights the role of source directivity on observed large motion variability, with significant implications for ground shaking hazard associated even with moderate earthquakes. If the propensity for and direction of unilateral ruptures are controlled by the local velocity structure, seismic imaging studies can provide crucial information for improved estimates of earthquake shaking scenarios.

S201cS2.03

S201cS2 - Earthquake scenarios

Oral

Ground motion prediction in 3D velocity models including statistical models of inhomogeneities

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As ever-increasing computational resources allow earthquake scientists to push the frequency limits of deterministic ground motion estimates higher, understanding small-scale, near-surface heterogeneities becomes paramount. These small-scale heterogeneities may significantly affect ground motion in geologic basins, and are not included in state-of-the-art Community Velocity Models (CVMs). Toward characterizing the variability of shallow sediment amplification, we have collected readily available near-surface velocity data, including several datasets of direct and indirect Vs30 values and downhole sonic logs from oil exploration surveys in the Los Angeles area. We have prepared semi-variograms of the near-surface heterogeneities in an effort to quantify statistical parameters characterizing the existing shear-wave velocities in Los Angeles Basin. Our preliminary analysis suggests that the data are conforming to a fractal distribution with fractal dimensions of 1.5-1.8 and related Hurst exponents of 0.2-0.5. We then generate statistical models of seismic velocities and densities in agreement with the results of the data analysis and integrate these models into the most recent SCEC CVMs. The effects of the near-surface heterogeneities on ground motion and scattering are tested using simulations of the 2008 Mw 5.4 Chino Hills, CA earthquake in a subset of the SCEC CVM 4.0, with frequencies up to 5 Hz. We assume a minimum Vs of 200 m/s using a highly scalable finite-difference code (AWP-ODC). Preliminary results indicate a trade-off between the statistical model (in terms of scattering Q) with anelastic attenuation, and that the currently employed sediment Q models may need to be tuned for models including the near-surface heterogeneities. The ratios of peak ground velocities between models with and without the near-surface heterogeneities (both including the Q model) vary between ~0.5 and 2.

S201cS2.04

S201cS2 - Earthquake scenarios

Oral

Deterministic generation of high-frequency ground motion with dynamic rupture simulations

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We present a deterministic methodology for the generation of high-frequency ground motion through numerical simulations of 3-D dynamic ruptures on rough faults. As suggested by recent observational studies of fault topology, the model fault geometry is assumed to follow a self-similar roughness distribution with wavelength scales spanning three orders of magnitude, from ~102 m to ~105 m. Motivated by recent high-speed rock sliding experiment, we employ a rate- and state-dependent (RSD) friction with a strongly rate-weakening feature to characterize the fault frictional behavior. We also adopt Drucker-Prager viscoplasticity allowing off-fault plastic strain to relax unphysically high stress concentrations in the dynamic process around the rupture tip and the roughness slopes. The rupture simulations resolve wavefield spectral components up to greater than 10 Hz, permitting comparisons with empirical ground-motion intensity measures over much of the frequency range of engineering interest. Our simulation results show that dynamic rupture propagation on rough faults results in rupture irregularities that lead to ground motions with complex spatial patterns and extensive high-frequency content. The simulated ground accelerations have near-flat power spectra from a few tenths of a Hz to slightly less than 10 Hz. Our initial studies with simple 1-D velocity structures produced site-averaged synthetic response spectra having characteristics, including the distance and period dependence of the median values, absolute level and intra-event standard deviation, comparable to appropriate empirical estimates, throughout the period range 0.1-3.0 sec. We extend this initial validation study by incorporating more realistic media, different realizations of fault roughness, and a range of target event sizes, with the goal of elucidating generic aspects of ground motion that are still not well defined by existing data.

S201cS2.05

S201cS2 - Earthquake scenarios

Oral

Slip reactivation: 3D dynamic rupture simulation of the 2011 Mw 9.0 Tohoku earthquake

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Near-source ground motion observations and kinematic source inversions suggest that the rupture process of the 2011 Mw 9.0 Tohoku earthquake has experienced slip reactivation. This unusual rupture is characterized by an additional second push of the rupture after the initial slip is close to cease. Various explanations have been proposed. Ide et al (2011) consider that the additional push comes from the rupture front back propagating from the free-surface after rupturing the trench of the fault, a phenomena usually observed in dynamic rupture simulations of dipping faults (e.g. Dalguer et al. 2001). Goto et al (2012) shows that it can results from heterogeneous stress distribution. Grabriel et al (2012) suggest that it results from a self-healing pulse of slip due to an additional stress concentration, behind the healing front, that overcomes the fault strength by a second time and reactivate the slip. Here we propose that slip reactivation may also take place in a crack-like rupture under slip-weakening friction. This type of friction models has been first proposed by Kanamori and Heaton (2000) in which frictional strength drops initially to certain value, but then at large slips there is a second drop in frictional strength. The slip velocity caused by this mechanism is a sharp pulse capable to radiate stronger ground motion. Our simulations show that this mechanism produces synthetic ground motion pattern along the Japanese cost of the Tohoku event consistent with the observed ground motion. In addition, the rupture pattern with slip reactivation is also consistent with kinematic source inversion models in which slip reactivation is observed. Therefore we propose that the slip reactivation observed in this earthquake is results of strong frictional strength drop, maybe caused by fault melting, pressurization, lubrication or other thermal weakening mechanisms that reduces further the frictional strength to lower levels due to the extremely high slip.

S201cS2.06

S201cS2 - Earthquake scenarios

Oral

Developing a physics-based rupture model generator (RMG) with 1-point and 2-point statistics of source parameters

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We develop a physics-based rupture model generator (RMG) with 1-point and 2-point statistics of key kinematic source parameters such as final slip, rupture velocity, and peak slip velocity. The rupture model generator can also be considered a stochastic model that governs the finite faulting process with a spatial random field assigned to each source parameter. 1-point statistics is a marginal probability density function (mPDF) that controls the physical variation of each source parameter at any given point on the fault. For example, 1-point statistics controls the mean and variance of final slip and variations in rupture speed (e.g., the occurrence of supershear rupture), while 2-point statistics is composed of both auto- and cross-correlations of the source parameters. Autocorrelation governs the spatial heterogeneity of each source parameter by quantifying the correlation of the same parameter between two points on the fault. Cross-correlation governs physics-based coupling between different source parameters by considering both zero- and nonzero-offset correlations. Both 1-point and 2-point statistics of kinematic source parameters are extracted from spontaneous dynamic rupture models simulated with the slip weakening friction law. Given the extracted 1-point and 2-point statistics, we perform Monte Carlo sampling with the Cholesky factorization method to generate rupture models that reproduce the target 1-point and 2-point statistics, and compute ground motions by combining them with synthetic Green's functions. Our preliminary results in source and ground motion modeling show the potential that the newly developed rupture model generator will help us to quantify the characteristics of finite faulting processes for future scenario events, and thus it may lead to improved simulation-based ground motion prediction methods

S201dPS.01

S201dPS - Site effects

Poster

Non-linear stress-strain response of carbonate rocks to ground motion

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The ground motion due to earthquake leads to change in distribution of stress concentration in rock mass. In particular, there are deformation zones where compression of rock mass increases until its failure occurs. In this study, non-linear stress-strain responses and axial failure strains of different carbonate rock formations (limestones, dolomites and chalks) under compression are measured in the experimental laboratory. The failure strain is strain at which material breaks or fails (endpoint of the pre-failure stress-strain curve). Failure strain is an important parameter needed for the prediction of squeezing potential of rocks around large-size underground structures. It is observed that axial failure strain of studied carbonate rocks subjected to compression can achieve 3 %, and semi-analytical equation for the modeling of stress-strain relationship for heterogeneous carbonate rocks exhibiting large axial strains (> 1 %) is formulated. This exponential equation is derived by modifying the stress-strain model based on Haldane's distribution proposed for carbonate rocks exhibiting small (< 0.5 %) and intermediate (<1 %) axial strains. In contrast to stress-strain model based on Haldane's distribution function, the value of pre-calculated free parameter is not constant, but dependent on the failure strain value. This parameter decreases according to a power law with increasing failure strain. The developed exponential model relates normalized axial stress over the whole pre-failure strain range to current axial strain and failure strain. The model allows one to calculate the failure strain in terms of compressive strength and stress-strain measurement at one point only.

S201dPS.02

S201dPS - Site effects

Poster

2D site effect investigation and modelisation in Nice, France

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The quantitative assessment of site effects--the local surface geology impact on ground motion, is a major player in seismic hazard and engineering seismology studies. Frequency dependent site amplifications are known to be caused mainly by reverberations and the resonance effects of S-waves within either unconsolidated sediments overlaying stiffer formations or within topography. In 2008 we installed a temporary array throughout the city of Nice, France. The stations, composed of an Le3D velocimeter coupled with a Kephren digitizer, have been continuously recording the ground movement. More than 30 local earthquakes (with an epicentral distance of less than 100 km) with an Mw of up to 4.3 have been recorded. To analyze the site response at lower frequencies, we also studied several tele-seismic recordings. Among the 12 equipped stations, six stations form a cross section in the Var valley. Although this valley is less than 1 km wide, previous geophysical and geotechnical studies show a possibility that the bedrock reaches a maximum depth of about 200 m. In the studied area, the sediments are mainly composed of sand and gravel layers overlaying Pliocene marl. The seismic profile helps us to follow the evolution of the resonance frequency across the Var valley. A 2D numerical modeling of the waves propagation in the basin shows good agreement with the collected data and confirms the role of the basin geometry on the seismic amplification at the surface.

S201dPS.03

S201dPS - Site effects

Poster

Landslides of Palestinian region

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Natural disasters are extreme sudden events caused by environmental and natural actors that take away the lives of many thousands of people each year and damage large amount of properties. They strike anywhere on earth, often without any warning.

A risk maps of natural disaster are very useful to identify the places that might be adversely affected in the event of natural disaster. The earthquakes are one of natural disaster that have the greatest hazards and will cause loss of life and properties due to damaging the structures of building, dams, bridges. In addition, it will affect local geology and soil conditions. The site effects play an important role in earthquake risk because of its amplification or damping simulation. Another parameter in developing risk map is landslide, which is also one of the most important topics in site effect hazards.

Palestine region has been suffering landslide hazards because of the topographical and geological conditions of this region. Most Palestine consists of mountainous area, which has great steep slopes and the type of soil is mainly grayish to yellowish silty clay (Marl Soil). Due to the above mentioned factors many landslides have been occurred from Negev south to the northern borders of Palestine. An example of huge and destruction landslide in a Palestine authority is the landslide in the White Mountain area in the city of Nablus, which occurred in 1997.

There are many things that can be used to mitigate landslides disaster. The most important one is the control of the landslides by establishing landslide maps. Other methods such as geometrical, hydrological, mechanical and chemical methods would also be effective in mitigate landslides.

Recently, due to the development of the technology in all aspects, a safe and economical design for slopes can be achieved easily.

S201dPS.04

S201dPS - Site effects

Poster

Testing the use of local slope as a proxy to site conditions in GMPEs : The RESORCE case

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In the past few years it has been proposed to use the topographic slope from digital elevation models (DEMs) constructed through remote sensing to give first-order estimates of National Earthquake Hazards Reduction Program (NEHRP) site classes based on the average shear-wave velocity in the top 30 m, VS30. The direct testing of the correspondence between local slope and VS30 has already been done with variable success on different data sets. Here, we take advantage of the Reference database for Seismic grOund-motion pRediction in Europe (RESORCE) to compare the relative decrease in aleatory variability brought by the consideration of VS30 and/or local slope as a proxy to site conditions. A subset of the RESORCE data base consisting of shallow crustal events recorded on sites with actually measured VS30 values and available slopes (i.e., close to 1000 recordings) is considered. The Artificial Neural Network approach and a random effects like procedure have been used for the derivation for GMPEs setting the relationship between simple ground motion parameters (PGA, PGV and 5% damped pseudo-spectral acceleration PSA from 0.01 s to 4 s), and simple event / station parameters (moment magnitude MW, the Joyner-Boore distance RJB, the focal mechanism, the hypocentral depth, and the site proxies VS30 and/or slope). The presentation will outline the effects of the considered proxy on the total, between-event and within-event variabilities for the various ground motion parameters, and will discuss the relevance of the slope as a proxy to site conditions.

S201dPS.05

S201dPS - Site effects

Poster

Low frequency amplification in the southern part of the Quito basin (Ecuador) inferred by spectral ratio analysis

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In this study, the soil response at 16 sites of the permanent Quito Accelerometer Network, QAN (equipped with Guralp CMG-5TD stations) has been characterized by using the Standard Spectral Ratio (SSR), Receiver Functions (RF) and H/V Noise Spectral Ratio (HVSR) methods.

We used signals of earthquakes having magnitudes between 2.9 and 5.9 and epicentral distances from 1 km to 381 km, with a signal to noise ratio greater than 3. For the SSR technique an average of two sites is used as a reference site. In order to be able to work on ambient vibrations (HVSR) with a good resolution in a large frequency band, we measured 40 min of noise using a seismometer Lenartz LE- 3D/5s at the location of all stations of the ANQ.

We found that the spectral shape and frequency of the peaks encountered by the HVSR for ambient vibrations at any given site is very similar to the results of the techniques SSR and RF using earthquakes. These results validate the use of the HSVR technique in Quito. However, in some of the sites studied it is very difficult to determine the fundamental frequency, because none of the methods show a clear amplification peak.

The important and new result of this analysis is that we found, for all the stations in the south of the basin, a clear peak of amplification at a rather low frequency of about 0.4 Hz. This peak can be identified with the three methods and was not observed in the northern part of the basin and in previous studies.

In a second part of the study, we have selected two of the best earthquakes recorded by the accelerometer network as empirical Green’s functions and have simulated earthquakes with magnitudes 6.4 and 7.1 in the city. The effect of the low frequency amplification in the southern part of the city is very clear, especially for the larger event. Further analysis is now necessary to better understand the origin of this low frequency amplification and to link it with underground velocity model of the basin.

S201dPS.06

S201dPS - Site effects

Poster

Site characterisrics of the hwacheon borehole seismic station in Korea using microtremor

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The Korea Meteorological Administration operates borehole stations to record good quality seismic data by minimizing surface noises. To evaluate how much the surface noise is reduced by borehole recording, we observed tremors continuously for 29 days at the Hwacheon seismic station on the surface and at a depth of 100 m in a borehole. As the recorded data included a regional earthquake, we analyzed both microtremor and the earthquake in the time and frequency domains. For microtremor data the surface-to-borehole energy ratio varied greatly with the time of day and between weekdays and weekends. For the horizontal component of motion, these ratios were approximately 11 times greater during the day than during the night and 1.5 times greater during the weekdays than on the weekends. The surface-to-borehole ratios of spectral amplitudes peaked at 46 Hz for the microtremors. Differences between the day and night ratios are attributed to the greater amount of cultural noise during daylight hours. For earthquake data amplitude spectra and dominant frequency were computed of surface and borehole data. As a result, for the surface-recorded data, frequency spectra were amplificated in 7~8Hz as compared with borehole-recorded data. To understand the site amplification, the H/V ratio was calculated using microtremor and the peak frequency was 7.3Hz. The thickness of the surface layer was estimated at 8.9m using average shear-wave velocity of the Korea Peninsula. Coherence between surface and borehole-recorded data was calculated by cross-correlation of FF Tto study interference effect of surface reflection, . Consequentially, Surface-recorded data includes background noise and amplification of site compared with borehole-recorded data. According to theses result of the microtremor and earthquake data provide strong evidence for the superior recording of earthquakes using borehole seismometers instead of surface seismometers.

S201dPS.08

S201dPS - Site effects

Poster

Vs30 estimation using ambient vibrations and seismic refraction experiments - Application to the lower Tagus Valley (Portugal)

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The town of Lisbon has been affected by several strong earthquakes in the past originated either offshore or inland. The main inland seismogenic zone is the Lower Tagus Valley (LTV) region oriented NNE-SSW and reaching the northern part of Lisbon at its southern end. It is composed by a system of faults mainly oriented according to the valley trend, but the identification of the particular seismogenic structures able to produce large earthquakes are still under debate. The strongest reported event was the January 31st, 1531 earthquake (Mw = 7.0) that produced large damage in the southern part of the valley, in particular in Lisbon. In recent years the seismic activity in the LTV is characterised by several small earthquakes. The last strong earthquake occurred on April 23rd, 1909 (Mw = 6.1) and destroyed several small towns located in the valley. Due to the concentration of economic and industrial facilities and population density, this region presents high seismic risk in the Portuguese context. Besides, this region can be also affected by large offshore earthquakes, as the 1755 earthquake which source is located southern of Portugal mainland, in the Atlantic Ocean, about 250 km far from Lisbon.

In order to estimate soil ground motion associated to different seismic sources, a map of Vs30 is need. We present here a methodology to estimate Vs30 based on ambient vibrations surveys (single-station and arrays measurements), seismic refraction experiments and geologic and geotechnical information.

This work was partially financed by the Portuguese project PTDC/CTE-GIX/102245/2008 NEFITAG - Strong ground motion and near field effects in the Lower Tagus Valley Region, and the Spanish funded Complementary Action CGL2010-11831-E Identificacion de efectos de sitio en los registros de intensidad sismica en Iberia.

S201dPS.09

S201dPS - Site effects

Poster

Shaking evaluation and seismic code: implication for the post-seismic actions after the 2012 Emilia (Italy) earthquakes

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After the May 20 and 29, 2012, Emilia (Italy) mainshocks (Ml 5.9 and 5.8, respectively), the ground motion ShakeMaps were mentioned in a law on urgent measures of post seismic actions to secure the buildings in the area. In particular, the law states that no safety check is needed if the construction experienced a shaking greater than 70% of the design acceleration expected at the site (NO-CHECK area), without abandoning the elastic behavior. The ground motion values are evaluated from the shakemaps available when the law was approved (http://shakemap.rm.ingv.it) and the design accelerations derive from the Building Code (NTC08), which is based on the reference Italian seismic hazard model. Both estimates account for soil conditions: the first uses specific amplifications factors, the latter applies the NTC08 coefficients to modify the expected acceleration originally computed on rock.

We compare the design accelerations with several shakemaps determined with an increasing number of temporary stations, to evaluate the possible errors resulting from the incomplete estimation of the shaking. The NO-CHECK area increases when the ground motion is better constrained by the highest density of stations: if the complete dataset was available for the law prescriptions, the NO-CHECK areas would have been larger respect to what can be inferred by the on-line shakemaps, and the number of buildings for which the safety check is required would probably decrease.

The underestimation of the shaking is due to the smaller values provided by the used GMPE, not accounting properly for the near source and local site effects. The recordings from the very dense temporary networks in the epicentral region are strongly controlled by the alluvial basin of the Po River (depth varying from 150m to more than 2km), which is defined as soil class C according to EC8 but largely affects the waveforms.

S201dPS.10

S201dPS - Site effects

Poster

Site seismic amplification analysis and seismic protection of industrial activities

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This research deals with the local seismic amplification analysis in the industrial district of the Sulmona basin (Central Italy) using both the Nakamura's HVSR technique and the 1-D numerical simulation computed with Shake91 code. An extensive geognostic database allowed to make out the geometries of the subsurface layers up to a depth of 50 m and cross-hole tests led to characterize the dynamic proprieties of terrenes, namely the shear waves velocities values. Noise measurements were collected in the 0.1-10 Hz frequency domain and data were used to calibrate the 1-D simulations, performed using as source a seismic record of M=5.5. The results obtained point out that local site effects are present in the central and eastern part of the basin, an area which is likely to be interested by a major industrial development in the future. Moreover, the comparison between the 1-D simulation spectra and the spectra of project provided in the Italian normative, enhances that in these areas the expected response is underestimated in the frequencies range of building interest.

The seismic protection of structures by means of seismic isolation and energy dissipation systems is by now a practice frequently used in civil engineering field. The applications to industrial plants, however are still few, in spite of their high seismic vulnerability.

For this reason INAIL ex ISPESL, which operates in industrial safety field, has promoted and developed research activity, which aim is the study of the applicability of seismic isolation and energy dissipation to industrial plants subjected to site seismic risk and site amplification phenomena.

S201dPS.11

S201dPS - Site effects

Poster

Influence of spatial heterogeneity on the 2D PSV wave propagation in linear and nonlinear media

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Basin response depends on the site geometry, impedance contrast, material properties and their constitutive model, and on the complexity and strength of the input solicitation. Numerical modeling is a useful tool to understand the role and the influence of these different parameters governing site effects. In this study we focus on the 2D P-SV seismic wave propagation in a simple-shaped asymmetric model whose properties are derived from Alpine basins. We consider that nonlinear properties vary as a function of depth following the curves defined by EPRI (1993): nonlinear soil properties are defined for different depth ranges and on the whole, superficial soils are more nonlinear than deep soils. We consider different velocity models such as a homogenous one basin. The basin may as well be composed of distinct geological layers whose properties are considered as homogeneous with velocities regularly increasing with depth. Finally, we see the effect of velocity reversals as well. We assess the influence of these assumptions on the wave propagation while taking into account linear and nonlinear constitutive models. We use different input wavefields allowing to propagating different dominant wavelengths that must be compared with the basin size and layers thicknesses.

S201dPS.12

S201dPS - Site effects

Poster

The effect of coupled motion on site effect estimation

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Soil amplification characteristics are investigated using data from the Miyagi-Ken-Nanbu earthquake recorded with array network at Sendai, Japan. The frequency dependent amplification function of soil is calculated using uphole-to-downhole spectral ratio analysis, considering the horizontal components of shear wave. The identified spectral ratios demonstrate the splitting of peaks in their resonance frequencies and low amplification values in comparison with a 1D model. Numerical analysis indicate that the site amplification characteristics in the high frequency range (>1 HZ) could be influenced by the 2D effect of a small-scale basin, which is a consequence of the shear wave coupling around the basin edge. Furthermore, it was shown that this coupling effect could produce large torsional motion due to lateral variation of soil in two sides of the small-basin. Finally, the outcome provides first field evidence on the effect of shear wave coupling and induced torsional motion on site amplification characteristics.

S201dPS.13

S201dPS - Site effects

Poster

Characterization of subsurface structure for some urban sites in Iran using passive seismic interferometry

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Many cities of Iran have been constructed over alluvial basins; vary severely in thickness and extent. The susceptibility of ground motion amplification resulted from the local geological and geotechnical condition over this alluvial basin affect increasingly the seismic hazard in this country, having a well known active tectonic regime. Recognition of these alluvial basins structure is one the important factors required for a real seismic hazard assessment. The application of the methods based on active source for these urban areas suffered from many limitations, especially in the case of existence of deep alluvial basins. These limitations are partly come from the operational difficulties as well as the high cost of the direct borehole drilling. The utilisation of the methods based on passive sources could be a suitable alternative to overcome this problem. One of the most recent techniques proposed in this purpose is the passive seismic interferometry. This method use the ambient noise cross correlation to drive the Green's Function between local seismological stations, installed on the ground surface. In the present paper we are going to show the results obtained, using this method for some localities in Iran comparing them with the result of other observations. Due to high level of local noise near the stations for high frequencies (>1 Hz) the Green function could not be well constructed in these range of frequencies. As a result we can consider this method a technique for deeper investigation of ground profile and for investigation of shallow depths we need closer interstation distances.

S201dPS.14

S201dPS - Site effects

Poster

Application of seismic interferometry to extract dynamic soil properties from downhole records

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Recently, three geotechnical downhole arrays are deployed in the west European side of Istanbul, Turkey with efforts of Kandilli Observatory and Earthquake Research Institute. Existing high seismic activity of the region increases the scientific importance of these arrays. Each array is composed of one accelerometer on the ground surface and three or four borehole accelerometers at various depths along the soil profile with the deepest sensor located at the engineering bedrock level (VS>750m/s). The borehole data is analyzed using a technique referred as seismic interferometry. This technique is based on the correlation of waves recorded by different receivers and allows for extraction of soil properties from time-histories. Here, deconvolution is used instead of cross-correlation and in contrast to customary; waveforms are deconvolved by the surface record instead of motion recorded at the bedrock level. Wave travel times between the receivers are then calculated to obtain propagation velocities. Next, envelope functions of the waveforms are calculated. The travel times obtained from the envelope functions are smaller; the difference representing the phase shift due to damping. Analysis of weak motion borehole records from Istanbul arrays shows that wave velocity profiles obtained using seismic interferometry are in agreement with those determined from in-hole seismic measurements.

S201dPS.15

S201dPS - Site effects

Poster

Experimental site response evaluation in Karaj (Iran) using ambient noise considering the effect of the underground openings

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The effect of underground cavities on seismic ground motion has been discussed by some authors using numerical and analytical solution (ex. Wang and Lee, 1979; Sanchez-Sesma et al.2006 & 2008). The experimental studies in this topic are very limited; from these rare researches the work of Sgarlato et al (2010) can be referred. With this purpose a series of ambient noise measurements (single station and array measurements) have been carried out in the city of Karaj (west of Tehran) on the area around an under-construction subway tunnel in order to assess its effect on ground seismic response. The measurements have been carried out as part of a comprehensive research project on earthquake geotechnical microzonation of this city with the aim of evaluation the effect of local geological and geotechnical condition on the ground surface seismic motion. The horizontal to vertical spectral ratio as well as the spectral ratio in respect to the in-tunnel measurement were calculated. The result shows clearly some modification of the site response due to the presence of the tunnel, for the localities over and around the underground opening. The amplification ratio decrease for the area located just on the top of the tunnel and increase for the neighboring areas located at a distance up to a few ten meters from the tunnel. For the area located at a longer distance from the tunnel the amplification ratio return to the value of the natural ground without underground cavities. The results also compared to some numerical modelling previously have been done by some authors and numerical modelling, carried out during the present research. This paper shows some results obtained of the experimental measurement as well as numerical modelling.

S201dPS.16

S201dPS - Site effects

Poster

A review on performance of modified equivalent linear versus nonlinear site response analysis models

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There are two main groups of soil models to account for the soil nonlinearity: equivalent linear models, and nonlinear models. This study proposes a modification to account for confining stress and frequency dependence of modulus reduction and damping in equivalent linear site response analysis program Shake91 and yields a comparison of results with modified Shake91 and two nonlinear site response analysis models (DeepSoil, Dyneq) based on selected borings. The performance of modified equivalent linear versus nonlinear site response analysis models were reviewed based on vertical array soil profiles that have recorded ground motion under a range of moderate to intense shaking levels. Site response analysis carried out to evaluate the effect of confining pressure dependency on predicted ground motions show that using confining pressure dependent curves results in higher amplitude ground motions than those predicted with average generic curves because of the fact that modulus degradation and material damping curves become increasingly linear as confining pressure increases. Analyses based on stress dependent dynamic properties were rerun adopting frequency dependent characteristics into Shake91. This modification by taking frequency dependent behaviour into account improved lower amplification in high frequency range disadvantage of the equivalent linear analysis. The improvement was more pronounced as the soil profile gets deeper. The common observation is that while both methods give similar response spectra, the equivalent linear method underestimates displacements and overestimates accelerations.

S201dPS.17

S201dPS - Site effects

Poster

Seismic characteristics and structural response of ground of Rajshahi District, Bangladesh

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Spectral response in-terms of ground amplification of Rajshahi area due a number of earthquakes felt in and around the study area have been estimated with semi-empirical formulation. Absolute amplitudes, normal and predominant periods of the earthquake motion were estimated from the recorded seismic waves and were used for determining the seismic characteristics of the multiple layered ground of Rajshahi area. The present study finally estimated the amplification of ground vibration for the study area and correlated with local lithological strata of the ground, damage ratio and building structures.

S201dS1.01

S201dS1 - Site effects

Oral

Developments in local hazard assessment in alpine environments

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Since 2007, site characterization of all newly installed seismic stations of the Swiss seismic networks has been systematically performed. In particular, between 2009 and 2013, 30 modern strong motion stations have been deployed at risk-oriented sites. The procedure includes ambient vibration array measurements, MASW and active seismics, CPT measurements and the analysis of geotechnical lab tests, as well as the collection of information related to geology, the geometry of the underground structure (layering, basin effects, etc) and surface topography. The large amount of data collected from typical alpine environments will allow developments in the assessed seismic hazard. Passive seismic surveying methods have been developed to include tools that allow the combined analysis of multiple components of ground-motion (including rotational) from ambient vibration array recordings. New methodologies have been developed to retrieve Rayleigh-wave ellipticity, including the sense of rotation; combining active seismic acquisition with passive methods to optimize the use of available instruments; and the identification of 2D resonances in Alpine valleys and in instable rock slopes. Shear-wave velocity profiles resulting from analyses at the stations of the Swiss and Japanese Networks have been used to develop new tools for seismic hazard assessment. The models facilitate the prediction of site-specific anelastic amplification (including the kappa parameter) and H/V ratios from the Vs profile. Observed amplification at seismic installations is automatically assessed and is utilized for validation of models developed within the site characterization phase. Finally, at selected sites the soil parameters required for advanced constitutive models have been calibrated from field and laboratory measurements in order to predict nonlinear soil behavior and the effects of pore water pressure during strong shaking.

S201dS1.02

S201dS1 - Site effects

Oral

1D velocity structure of the Po river valley from six-channel temporary seismic stations installed for site effects studies

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Strong ground motions recorded on the sedimentary deposits of the Po river alluvial plain during the Emilia Romagna (Northern Italy) Mw 5.7 earthquake of May 29, 2012 are used to assess the shear waves velocity structure of the sediment layers. The time histories show very distinctive, large-amplitude low frequency dispersive wave trains on the vertical component of ground motion after the records are converted to displacement. Wavelet analysis yields group velocity and dispersion curve in the 0.2-0.7 Hz frequency band for three stations that are part of a linear array installed for site effect studies after the Mw 5.9 mainshock of May 20, 2012. The array stations are aligned in the South-North direction, at a distance between 1 and 26 kilometers from the epicenter. Stations were equipped with both strong and weak motion sensors, this also allows to use ambient noise to estimate the resonance frequency of sites and to verify its stability among stations. The joint inversion of earthquake dispersion and noise H/V ellipticity curves allows extending investigations down to the alluvial plain basement, at a depth of about 5000 meters. Our results add new information about the velocity structure at a scale that is intermediate between the local scale already investigated in literature with small-aperture arrays using ambient noise and the regional scale already derived from modeling of seismogram waveforms recorded at hundreds of kilometers from the source.

S201dS1.03

S201dS1 - Site effects

Oral

Local geology, Vsz and site characterization for ground motion prediction in Greece

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Improved knowledge of the shallow subsurface structure beneath accelerometric stations is critically needed for improving seismic hazard assessment, loss estimation and earthquake parameters characterization. Differences in geotechnical site conditions, such as shear wave velocity in the top 30m or even deeper, or local topography, can result in drastic differences in the amplitudes and frequency content of seismic recordings. Thus, it is important to optimize the use of existing and future strong motion recordings, since without a reliable knowledge of the subsurface structure, they are not usable to their full potential and use them for NGA predictive models evaluation in Greece and surrounding area. To this aim, a dataset including more than three hundred sites in Greece (strong motion stations and others) where shear wave velocity profiles with depth, Vsz, were available along with information of local geology, in scale 1:50.000, and topography has been constructed. Classification of local geology in groups according to criteria such as: geologic age, depositional environment and material gradation, among others, is undertaken to correlate them with Vs30. Interrelation between Vs30 and Vsz (z=5, 10, 20m and greater than 30m depth down to bedrock) profiles is also examined and compared with similar studies from Japan and California. We recommend a relation between VS30 and VSz for sites with profiles shallower than 30 m. We also recommend correlations between VS30 and local geology that allows for estimation of the former to sites where only surface geology is known. In addition, we consider correlations of VS30 with other proxies descriptive of topography and terrain, to investigate their relative effectiveness for VS30 estimation.

S201dS1.04

S201dS1 - Site effects

Oral

Large ground motions at a high-rate (10-Hz) GPS station: can topography explain observations?

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The ground motion of the April 6th 2009 Mw 6.3 L'Aquila (central Italy) earthquake, which ruptured a SW-dipping normal fault, was recorded at a very high sampling frequency (10 Hz) by one of the GPS stations (CADO) installed before the seismic event near L'Aquila. The data provide valuable ground displacement time histories in the near source that, jointly with the available strong motion data, allow a reliable reconstruction of the source rupture. Interestingly, a low-frequency (about 1 Hz) nearly-harmonic large oscillation (more than 40 cm peak-to-peak) was recorded at CADO 5s after the beginning of the coseismic dynamic deformation. This signal spans about 6.5s and is not predicted by the inferred source models. Nearly-harmonic 1 Hz oscillations at that site are also observed during the aftershocks by a co-located seismological station installed ~1 year later, and in the seismic ambient noise recorded in the area during temporary measurements. The GPS and the co-located seismic station are situated at the edge of a cliff, a few tens of meters near the slope break, with a variation of elevation by 350 m and a sharp (about 30°) slope. Numerical modeling using a uniform rock block yields negligible effects. Geological evidence of a wide damaged zone adjacent to the station suggests a mechanism involving wave propagation in a low velocity subvertical channel. A model is constructed where the large-amplitude nearly-harmonic wavetrain is generated by energy trapped in the damage zone. Synthetic calculations using a source in a structure consisting in two quarter-spaces separated by a vertical fault layer provide a satisfactory fit to the observed waveforms. The best fitting parameters are a damage zone width of ~650 m, velocity reduction with respect to the host rock around 50% and low Q value (~20).

S201dS1.05

S201dS1 - Site effects

Oral

A source-controlled experiment to investigate the origin of wavefield polarization in fault zones

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In the damage zone of the Pernicana Fault on Mt. Etna, Italy, ground motion is strongly polarized in the horizontal plane. Dense measurements of ambient noise provide H/V spectral ratios that exceed a factor of 10 around 1 Hz near the fault trace and decrease away from the fault. Across the fault, polarization azimuth varies approximately from N140E to N170E. In principle, both locally radiated energy due to fault creeping and a propagation effect could be invoked to explain observations. Earthquake recordings in the fault zone show a similar behavior suggesting a fault-related site effect, as the polarization direction is independent of azimuth, distance and depth of different sources.

In order to investigate the directional amplification mechanism, we performed a source-controlled experiment using a high-resolution Vibroseis machine (Ivi-MiniVib). The machine was operating about fifty meters from the fault scarp, where the natural site polarization was oriented N150E. Ground motion was produced through a iron plate vibrating in the horizontal plane with fixed azimuths of motion, parallel and transversal to the observed site polarization. Three-component seismological stations were installed along profiles in the two orthogonal directions with a 50-m spacing. When shear excitation is parallel to the site polarization, the seismic signal propagates efficiently maintaining the same horizontal polarization of the source and is well recorded up to distances as large as 300 m. When shear excitation is orthogonal to the site polarization, the ground excitation looses the initial source polarization in less than 50 m. At larger distances, transmitted energy propagates with the natural site polarization independently of the source polarization. These experimental results suggest a shallow origin of the wavefield polarization in fault zones, probably due to scattering and mode conversion related to heterogeneities of the predominantly oriented fractures.

S201dS1.06

S201dS1 - Site effects

Oral

New advances in the discontinuous Galerkin method for seismic waves: application to site-effects studies

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In the last years, the use of flexible and accurate methods for seismic waves propagation has increased due to impressive advances in computing power. Among them, the discontinuous Galerkin method has been established as a relevant tool in computational seismology, albeit the challenge of reducing its relatively high computational cost. We address here the possibility of non-constant material properties within the elements, in order to simplify the mesh generation process of complex geological media. We present an extension of the discontinuous Galerkin method (nodal approach) for seismic waves in arbitrary heterogeneous media (e.g. sedimentary basins with soft soil layers near the surface). The method consists of a multivariate (high-order) lagrangian interpolation based on an adequate nodal set, and accurate quadrature formulae based on another set of points within the standard element. We then apply centred fluxes between neighbouring elements and a leap-frog time stepping scheme to solve the elastodynamics problem. Our main result shows that it may be not necessary to honour the interfaces between superficial (thin) layers in order to obtain accurate results for the amplification factors at the free surface. Moreover, we show the spectral convergence of the method in arbitrary heterogeneous media, and we study the effect of interpolation/quadrature orders, mesh size and associated time step for a specific canonical problem. Realistic examples in 2D sedimentary basins are analyzed. The extension to 3D media is straightforward and is the subject of current development.

S201dS1.07

S201dS1 - Site effects

Oral

Spatial variation of long-period (3 to 10 s) spectral amplification factors in the Los Angeles basin observed during the Mw7.2 El Mayor-Cucapah earthquake of April 4, 2010

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We presented the observation-based spatial variation in long-period (3 to 10 s) spectral amplification factors of ground motions in the Los Angeles (LA) basin by computing Fourier spectral ratios of the basin sites with respect to the surrounding reference hard-rock sites from the Mw7.2 April 4, 2010 El Mayor-Cucapah earthquake records. This earthquake was the first event providing many (236) high-quality recordings to study spatial variation of long-period amplification in the LA basin. We also tried numerical wave propagation simulations for two of the recent 3D seismic-velocity models for south California: SCEC (Southern California Earthquake Center) CVM (Community Velocity Model)-4.0 and CVM-H 6.2 to examine how these models account for the observed long-period amplification factors. For the period of 8 and 10 s, the largest amplification factors of 5 were observed in the central part of the LA basin. These observations are well simulated by both of the two velocity models that assume the basement to be the deepest in the central part of the LA basin. For 6 s, the largest amplification factor of 10 was observed in the western part of the basin (Manhattan Beach). This observation cannot be simulated by either of the two velocity models. The 1D S-wave velocity profile estimated from the microtremor measurements indicates that relatively soft and thick sediments are deposited in the shallow part beneath the ground surface at Manhattan Beach, suggesting that the 6-s amplification is controlled not by the basement depth but by the sediments in the shallow part. The above observations demonstrate that the spatial variation pattern of long-period spectral amplification factors in sedimentary basins is significantly dependent on periods and imply the necessity of more detailed data on the underground part that controls the amplification at target periods for a better prediction of long-period ground motion.

S201dS1.08

S201dS1 - Site effects

Oral

Seismic wavefield, ground-motion amplification and spatial variability in the small-size Argostoli basin (Cephalonia, Greece)

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In order to understand the key parameters that locally control the ground motion spatial variability and amplification in basin environments, a large seismological experiment took place in the high seismicity area of Cephalonia Island (Ionian Sea, Western Greece) within the EU-NERA project (ww.nera-eu.org). From September 2011 to April 2012, 62 seismological stations (mid-band velocimeters and accelerometers) were deployed in the 1.5 x 2.2 km small-size shallow sedimentary basin of Argostoli. Stations were distributed along a cross-section of the basin with inter-station distance of about 50 meters, and included two very dense arrays (minimum interstation distance of 5 meters, maximum aperture 160 m) located close to the basin edge and in the basin center. This network recorded about 700 local and regional earthquakes with magnitudes and epicentral distances ranging from 2 to 7 and from 4 to 2000 km, respectively. Preliminary analysis of the recordings from a few, selected events along the valley cross section indicates large multidimensional site effects inside the basin (amplification from 5 to 10 over the 1.5-8 Hz frequency range) together with a large spatial variability of ground motion within few tens of meters inside the basin. A still preliminary array analysis performed on the central 21-station array with various array processing techniques (coherencies, MUSIQUE) indicates complex wave patterns for frequencies around and above the fundamental frequency of the basin. This complexity leads in turn to large amplitude variability and significant loss of correlation of the motions even at the short distances spanned by the central dense array stations.

S201dS2.01

S201dS2 - Site effects

Oral

Nonlinear seismology the actual one in this century

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The question is: how many cities, villages, metropolitan areas etc. in seismic regions are constructed on rock sites? Most of them are located on alluvial deposits/ sediments, on Quaternary layers or in river valleys. Professor Shearer, California Univ. in last book wrote(2009):(i)-Strong ground accelerations from large earthquakes can produce a non-linear response in shallow soils; (ii)-When a non-linear site response is present, then the shaking from large earthquakes cannot be predicted by simple scaling of records from small earthquakes; (iii)-This is an active area of research in strong motion and engineering seismology. Aki(1993):Nonlinear amplification at sediments sites appears to be more pervasive than seismologists used to think. Any attempt at seismic zonation must take into account the local site condition and this nonlinear amplification. To find the actual influence of nonlinearity of the whole system (seismic source-path propagation-local geological structure) the authors used to study the response spectra because they are the last in this chain and, of course, that they are the ones who are taken into account in seismic design of structures. There is a strong nonlinear dependence of the spectral amplification factors(SAF) on earthquake magnitude for all seismic stations on Romanian territory on extra-Carpathian area. Median values of SAF for last strong and deep Vrancea earthquakes are decreasing from 4.16 (May 31,1990;Mw=6.4), to 3.63 (May 30, 1990; Mw = 6.9) and to 3.26 (Aug. 30,1986;Mw=7.1). In last “STRESS TEST” for NPP Cernavoda asked by IAEA Vienna after Japan earthquake (2011) and for same strong earthquakes, SAF have values: 5.74 ; 4.76, respectively, 4.07. The authors are coming with new data which will open up a new challenge for seismologists studying nonlinear site effects in 2-D and 3-D irregular geological structures, leading them to a fascinating research subject in earth physics, in nonlinear seismology.

S201dS2.02

S201dS2 - Site effects

Oral

Occurrence depth of non-linear soil behaviour and influence on seismic site response.

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Robust evaluation of site effects that include evaluation of the mean and associated uncertainties is a high stake for seismic risk mitigation. In one site, site-effect can be variable from one event to another. This inter-event variability is mainly caused by (1) site configuration complexity associated to different seismic sources when considering similar couple magnitude/epicentral distance earthquakes or (2) non-linear soil behaviour when considering similar seismic sources but different incident motion intensity. Laboratory measurements have shocn that, usually, soil layers are more elastic with depth. Furthermore, comparison of linear and non-linear empirical site response at the KiK-net (Japan) sites showed that the non-linear soil behaviour seems to mostly occur in the superficial soil layers. The main challenge is to find the depths where most of the soil non-linear behaviour takes place and affect the seismic site response. We inverted the empirical Borehole Fourier Spectral Ratio (BFSR) to (1) obtain the elastic soil properties (the Vs and Q profiles) from the weak-motion data and (2) compare these with those obtained from the inversion of strong-motion data. We selected 4 KiK-net sites and analyzed the global sensitivity of the site response to each soil parameter to determine which ones can be constrained during inversion. Difficulties arises when interpreting the inversion results mostly because (1) the numerical simulations cannot reproduce the low pseudo-resonance peak amplitudes observed, and (2) the selected sites may not have a simple site configuration (1-D). At FKSH14 site, we performed inversion of the non-linear BFSR. We found that at this site at least, the non-linear soil behaviour mostly takes place in the subsurface soil layers, although the depth where the non-linear soil behaviour occurs and influences the site response also depends on the amplitude of the incident motion.

S201dS2.03

S201dS2 - Site effects

Oral

High peak ground accelerations in strong ground motion: Observations and physical mechanisms (Tohoku earthquake as an example)

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Progress in understanding the nonlinear soil behavior in strong ground motion was due to the development of strong motion networks in Japan, such as, Kik-net, K-net, and others, when records of strong earthquakes (1995 Kobe earthquake (Mw=6.8), 2000 Tottori earthquake (Mw=6.7), etc.) obtained in near-fault zones were analyzed. Vertical array records allowed a simulation of the strong motion step-by-step in small time intervals (down to 1.5 s), at the same time obtaining vertical distributions of stresses and strains induced in the soil layers. We found that in the near-fault zones, soil behavior was substantially nonlinear, shear moduli reduced, and rheological properties of the upper softer layers changed in time due to the strong motion. As a whole, nonlinearity of soil behavior lead to the decrease of peak ground accelerations (because of nonlinear damping); however, the presence of underground water in the upper layers increased peak ground accelerations, because of the hard-type nonlinear stress-strain relations (stresses sharply increase starting from some level of strains).

Records of the Tohoku earthquake (March 11, 2011, Mw=9.1) show extremely high accelerations, up to 1 g at some stations, and the mechanism of their occurrence is quite different. Soil behavior in the upper 100-200 m at Kik-net stations during the Tohoku earthquake was studied, and it was found that shear moduli of the upper softer layers gradually increase with the beginning of the strong motion, and they become maximal when maximum accelerations are achieved. After that, shear moduli reduce. The nonlinearity of the soil behavior is weak, though seismic stations are rather close to the fault plane. Similar behavior is observed for sandy and clayey soils, and the influence of underground water is not noticed. These features of soil behavior are discussed from the viewpoints of soil mechanics and engineering geology.

S201dS2.04

S201dS2 - Site effects

Oral

Site classification and determination of dynamic soil properties using acceleration records of the 2012 Ahar-Varzeqan earthquake

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The horizontal-to-vertical component (H/V) spectral ratio of the August 11, 2012 Ahar-Varzeqan twin earthquakes (M 6.4 and M 6.3) ground motions for the shear-wave window was used as an estimation of the site response in northwestern Iran. The database used in this study consisted of three-component accelerograms recorded on 25 stations in Iranian Strong Motion Network (ISMN), operated by Building and Housing Research Center (BHRC). The stations are located at epicentral distances less than 100 kilometers. Considering obtained amplification functions, predominant frequency was determined at each site and the stations under study were classified in view of estimated dominant frequencies. Site classification was performed based on a new classification system provided by Ghayamghamian and Nojavan (2008), and NEHRP guidelines (2003). Moreover, according to non-linear response of the soil at high ground acceleration levels, local sites that experienced peak ground acceleration (PGA) values more than 90 cm/s/s were considered and amplification factors and predominant frequencies were estimated for these stations. Amplification functions and corresponding dominant frequencies were determined for main part of main shock, coda window of main shock, and main part of aftershocks. These different time windows represent various loading levels. A decrease in dominant frequency with increase in ground acceleration (loading level) is an indication of the non-linear behavior of the soil in some of studied stations. Dynamic soil properties at sites with non-linear response were evaluated using inverse analysis.

S201dS2.05

S201dS2 - Site effects

Oral

Empirical site response in the Taipei basin from the stochastic point-source modeling

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The site response is not easy to consider for ground motion estimation especially in the basin area. Where 1D, 2D, or 3D basin responses need to be considered in the simulation. In this study, we try to use empirical site correction term for the ground motion simulation in the Taipei basin. The method of the stochastic point-source modeling is used to simulate the rock site ground motion in the Taipei basin area. Empirical site corrections are calculated by the spectral ratios between observed earthquake record and stochastic point-source modeled for basement rock. The empirical site correction model is then used to simulate target earthquake ground motions on the soft soil sites within the Taipei basin. Residual between the observed and simulated ground motions are discussed in the time and frequency domains, and also compared with that from the ground motion prediction equation method which engineer application usually used.

S201dS2.06

S201dS2 - Site effects

Oral

Site specific design earthquake characteristics

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Assessment of site-specific design earthquake characteristics for performance levels of Collapse Prevention, Life Safety, and Immediate Occupancy requires seismic hazard analyses to estimate earthquake characteristics on the ground surface for 2475, 475, and 72 year return periods. The analysis may be conducted as composed of statistically independent two consecutive stages. The first stage involves the seismic hazard study to assess the design earthquake characteristics on rock outcrop for three exceedance levels. The second stage involves site response analysis to estimate design earthquake characteristics on the ground surface based on the geotechnical and geological site conditions. A probabilistic approach may be adopted to evaluate the uncertainties in both stages and to determine the overall exceedance probability for the design earthquake characteristics on the ground surface. Thus, site-specific peak ground acceleration and acceleration design spectrum may be calculated for the three exceedance probability levels. The uncertainties arising from the differences in the source characteristics are taken into account by using large number of seismic hazard compatible (i.e. fault mechanism, earthquake magnitude, and fault distance) real acceleration time histories for site response analyses. The uniform hazard spectra estimated by the earthquake hazard study on rock outcrop were used for scaling input motions for site response analysis. One dimensional site response analysis were conducted for the investigated site using slightly modified version of Shake91 and DeepSoil site response analysis codes to evaluate design earthquake characteristics with respect to return periods of 2475, 475, and 72 years. A probabilistic approach based on total probability theory is proposed to determine site specific earthquake characteristics on the ground surface, with respect to acceleration response spectra corresponding to return periods of 2475, 475, and 72 years.

S201PS.01

S201PS - Strong ground motion

Poster

Strong ground motion simulation and source modeling of the March 4, 2010 Jiaxian, Taiwan earthquake using empirical Green's function method

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The Jiaxian earthquake (M_L 6.4) occurred at the southwestern part of Taiwan on March 4, 2010. We examine the source model of this event using the observed seismograms by CWBSN at some stations surrounding the source area. An objective estimation method is used to obtain the parameters N and C which are needed for the empirical Green's function method by Irikura (1986). This method is called «source spectral ratio fitting method» which gives estimate of seismic moment ratio between a large and a small event and their corner frequencies by fitting the observed source spectral ratio with the ratio of source spectra which obeys the ω^{-2}model (Miyake et al., 1999). This method has an advantage of removing site effects in evaluating the parameters. The best source model of the Jiaxian mainshock in 2010 is estimated by comparing the observed waveforms with the synthetic ones using empirical Green's function method. The size of the asperity is about 2.2 km length along the strike direction by 2.6 km width along the dip direction. The rupture started at the left-bottom of the asperity and extended radially to the right-upper direction.

S201PS.02

S201PS - Strong ground motion

Poster

Dominant period distribution of micro-tremor H/V spectra observed in Kochi Plain, Shikoku, Japan

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Kochi is placed in Shikoku, Japan. Kochi Plain has been formed in E-W trending linear mountains and extends 20km for east-west, 5-10km for north-south. Some rivers provides sediments into Kochi Plain. Typical geographic feature of this plain is that the plain is no directly faced to the Pacific Sea, but connected through narrow Urado Bay. In this area, great Nankai Earthquake(M8 - 8.8) occurs repeatedly. Evaluation of strong ground motion and Tsunami hazard are important issues. We investigated soil structure of Kochi Plain using micro- tremor observation. H/V spectrum method is convenient to derive dominant period formed by structural origin such as soil structure. In addition dominant period of H/V spectrum is closely related to that of strong ground motion of giant Earthquake. To derive soil structure and dominant period of ground motion, we observed micro-tremor at many places in Kochi plain by single station. Obtained data was analyzed by H/V spectrum method. In Kochi -Plain. Dominant period of the H/V spectra show the values between 0.2 and 1.6s. Locations with longer periods correspond to around Bay of Urado. In case of Nankai Earthquake, strong ground motion is suggested in and around Urado-Bay area, in addition to flooded disaster by subsidence and/or Tsunami.

S201S1.01

S201S1 - Strong motion monitoring & Record selection for engineering design

Oral

Time-Frequency Domain Based Intensity Measure for SDOF systems due to Pulse-Like Near-Fault Ground Motions

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One of the challenges in assessing structural response is the selection of proper ground motion records to be used in the analysis. How to select a limited number of ground motion records (GMRs) is an important part of the nonlinear analysis of structures. It is evident that presenting a proper criterion as an «Intensity Measure» (IM) to select ground motions can reduce the errors in the structural analysis remarkably. Experiences from previous earthquakes show that pulse-like near-fault ground motions indicated by a velocity pulse, have caused large responses in the structures, and their effects cannot be well described by traditional intensity measures such as spectral acceleration at the structure's first-mode period, Sa (T1).

This paper introduces a new IM for the selection of the strong ground motions for structural dynamic analysis due to pulse-like near-fault ground motions based on incorporation of time and frequency domain characteristics. GA optimization is used to find the best linear combination of time and frequency domain parameters such as spectral shape at first mode εSa(T1) and time parameters like εPGA , εPGV , εPGD beside the directivity pulse characteristics such as pulse amplitude AP, pulse period TP and the number of half pulses NP. Different combination of parameters for a bunch of SDOF systems were tried to achieve the best correlation. According to the results, the most correlation can be seen between εPGA and the response of the system. Moreover, the results show that the directivity pulse characteristics contrary to initial expectation do not have noticeable effects.

S201S1.02

S201S1 - Strong motion monitoring & Record selection for engineering design

Oral

Fuzzy clustering of attenuation relationships for seismic hazard analysis

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Attenuation relationship models are the key elements within the seismic hazard analysis (SHA). As the results of SHA can significantly be changed by using different attenuation models, it is necessary to select an appropriate attenuation model for SHA. The selection of appropriate attenuation model for the regions, which suffer from the lack of available attenuation models, is usually a serious challenge. Therefore a fuzzy clustering approach is employed in this study in order to classify the available well-known attenuation models into groups. Each group is defined based on the criterion to have the most dissimilarity with the other groups. The results show that some of the available models for similar tectonic regions are placed into a same group. Additionally the clustering results can be used in the areas which the appropriate attenuation models are not available or they are not reliable.

S201S1.03

S201S1 - Strong motion monitoring & Record selection for engineering design

Oral

A monitoring system for a quasi early warning in a localized area in Bulgaria

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A moderate earthquake with magnitude of 5.8 struck the city of Pernik, near Sofia, Bulgaria on 22 May 2012 at 3 AM (LT). More then 8 000 houses have been reported with different levels of damages. The macroseismic intensity was estimated at VIII EMS. The earthquake was a straight normal fault with NW-SE direction. The activated fault was unknown to the scientists up to now. Not a single instrument has been deployed before and/or after the quake in the area. Serious concerns have been expressed by the local population about a potential Studena dam wall damages and rushing flood waters from this dam, located about 10 km from the epicenter. The recorded strong motions in Sofia, shows spectral peculiarities at both low and high frequencies. The city of Pernik with more than 30 000 inhabitants is the oldest coal mining town in Bulgaria. The intensive underground mining activities and the abandoned mining structures generate local subsidence and sliding. After the quake, the damages have been located at the week soils and many houses have assessed as too dangerous to live in. A complex geophysical study of the area of Pernik is reported here. The local geology and tectonics have been revised. Full spectrum of geophysical field data will be performed to assess the seismogenic faults structures. A new project named SIMORA is proposed for the establishment of a local, real time strong motion network. The monitoring is targeted mainly towards the city industrial facilities, the dam and the surrounding villages. A quasi early warning system is planned to provide sound and light signals to the local administration and the population in advance warning of a felt earthquakes occurring. The respective triaxial strong motion records will be consequently used to perform a follow up detailed (PGA) assessment. Further analysis and forward modeling of the vulnerability and seismic hazard/risk will allow planning for improved construction practices and population protection measures.

S201S1.04

S201S1 - Strong motion monitoring & Record selection for engineering design

Oral

Source parameters of the 2012 Mw5.9 Emilia (Northern Italy) earthquake by jointly using High-rate GPS and Strong Motion data

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The estimation of the Peak Ground Displacement (PGD) is useful for studies on earthquake processes, seismic design and structural monitoring. However, using conventional seismological records this estimation is still challenging. On the other hand, displacements correspond to basic observations for the Global Positioning System (GPS) and do not suffer from drift, clipping or instrument tilting. Furthermore, using high sampling rates and a kinematic approach ("High-rate GPS", HRGPS), it provides a new promising technique for studying earthquake processes ("GPS Seismology").

In this work, we used HRGPS and strong ground motion data to investigate earthquake radiation pattern and source directivity of the Mw 5.9, 20 May 2012 Emilia-Romagna (Italy) earthquake, estimating the PGD distribution around the seismic source.

The horizontal time series are rotated to the azimuth direction and the GPS-related and the SM-related PGD are retrieved in the transverse component. To more properly compare these PGD estimates, we used the response spectrum, the asymptotic value of the displacement response spectrum being the PGD. Thus, for each HRGPS and SM site, we computed the value of this asymptotic trend. This method allows simple automatic procedures.

The consistency of the PGDs derived from HRGPS and SM with the two methods is also evaluated for sites where the two instruments are collocated.

The spatial PGD pattern obtained for each studied earthquake is interpreted as the result of source effects (focal mechanism, directivity) as at low frequencies, the propagation effects are nearly absent. We used simple grid search method in order to retrieve basic source parameters such as the faulting style, the rupture velocity and the relative position of the hypocenter on the fault.

The PGDs obtained by the two different methods and the two different data types suggest a source directivity effect in the ESE (~120°-130°N) direction.

S201S1.05

S201S1 - Strong motion monitoring & Record selection for engineering design

Oral

Source parameters and rupture characteristics of the 2007 Kahak earthquake in Qom region, Iran

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On June 18, 2008, at 14 h, 29 m, 50 s (GMT), a shallow destructive earthquake with a magnitude 5.7 occurred in Kahak , in Qom region , central Iran .The epicenter was calculated 34.50N and 50.86E . This earthquake was perceptible in Qom , Tehran , Isfahan , Markazi , Semnan ,Yazd , Mazandaran , Ghazvin , Hamedan and Lorestan provinces . The mainshock was recorded by 56 digital SSA-2 near source strong motion stations ; furthermore , More than 10 aftershocks are recorded with maximum magnitude of 4.4 . In this study , in order to predict strong ground motion , the empirical Green function (EGF) method is used for strong ground motion simulation . This technique permits estimation of source parameters (seismic moment, corner frequency, rise time, source duration) and rupture characteristics of the earthquake . One of the prominently recorded aftershocks with a magnitude of 4.4 is used as an empirical Green function , then a deconvolution is performed to remove the path , site and instrumental effects from the main event signals . The size of the main fault was about 15km in length and 10 km in width . The rupture initiated at depth of 14 km and propagated from hypocenter in unilateral manner . The duration of rupture was about more than 6 s . Strike , dip and rake of causative fault are determined as 14, 49 and 126 degrees , respectively. the stress drop is 182 bars, which is higher than stress drops of events in Alborz and Zagros ; in addition , the estimated fault plane solution shows the mechanism was reverse with strike-slip components and is in agreement with the trend of faults in the region .

S201S1.06

S201S1 - Strong motion monitoring & Record selection for engineering design

Oral

Attenuation relationships of engineering ground-motion parameters for S shallow crustal earthquakes of Iran

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Engineering ground-motion parameters can be used to describe damage potential of an earthquake which depends on the amplitude, frequency content and time duration of motion, the energy absorption capacity of structure or equipment, number of strain cycles, and the energy content of the earthquake. Therefore, for engineering purposes, parameters that capture the effects of these characteristics in their definition are more reliable predictors of the earthquake's damage potential than peak and spectral accelerations.

The objective of this study is to propose new empirical attenuation relationships for the prediction of peak ground acceleration and velocity, spectral acceleration, Arias intensity, root-mean-square acceleration, characteristic intensity, Fajfar index, cumulative absolute velocity, and a few other engineering parameters.

The strong ground motion data provided by the Iran Strong Motion Network (ISMN) during more than 20 years of accelerometric recording are employed in nonlinear two-step least squares regression analyses in order to decipher the dependence of all the preceding parameters on moment magnitude, distance to the surface projection of rupture, local site condition and faulting mechanism. The validity of the proposed relations is assessed using the analysis of residuals by proving that the model is unbiased. The residuals have insignificant averages and are uncorrelated with respect to the predictor variables in the regression and the predicted values.

These engineering parameters have been incorporated for the first time in the empirical attenuation relations for Iran. The proposed attenuation relationships could provide an improvement criterion for the selection of earthquake scenarios in terms of engineering ground-motion parameters that are most representative of earthquake damage potential.

S201S1.07

S201S1 - Strong motion monitoring & Record selection for engineering design

Oral

Estimation of source parameters and path effects by using two main events occurred in NW Iran in 2012

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In this study, the strong motion records are used to obtain an estimate of the source parameters and attenuation of high-frequency waves. The records of two earthquakes that occurred in Azarbaijan-Sharghi region with 11 minute time interval, in 11 August 2012 with magnitudes of Mw=6.5 and Mw=6.4, respectively. These events were recorded at hypocentral distances between 15 to 217 km which those are occurred in focal depth around 30 km. Source parameters are determined by manipulation of S spectra in the frequency domain using individually determined time window lengths for arrivals on each accelerogram. The frequency-independent quality factor, Q, corner frequency, fc, and seismic moment, M0 are obtained from inversion. A frequency-dependent attenuation model, Q(f), is calculated by using Amplitude spectral decay Method by using observed acceleration. The source parameters were estimated for first event and second event are (M0 = 8.6e+026, 8.2e+026 dyn-cm, sec, fc = 0.21, 0.24 Hz), respectively. We used linear inversion approach to explore source parameters and independent Q values. By using the estimated results the observed source spectra is compared at various stations with the theoretical spectra. The estimated parameters are compared with reported values by Harvard and USGS (Mw= 6.5, 6.2) that shows well agreement. The estimated path-averaged crustal shear-wave quality factors gives results in range Q =85.979 to 1107 which is comparable with Qs- dependent values which is estimated by using spectra decay methods.

S202PS.01

S202PS - Rotational seismology

Poster

A propagation seismic waves in layered anisotropic media

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The use of the matrix method of Thomson - Haskell for constructing wave fields on the free surface is proposed. The mathematic modeling for the anisotropic medium simulated by homogeneous anisotropic layers with parallel boundaries is developed here. The condition of the hard contact is performed at the boundaries between the layers. A free surface is stressless. Wave source is located inside an anisotropic layer at a certain depth z=zs. The radiation condition also is performed (the waves of the lower half space (n+1) do not return). The solution is shown here for the direct problem when on an arbitrary boundary of a layered anisotropic medium a spatial point source, which is represented by a randomly oriented force or a seismic moment tensor, is preset. The theory of the matrix propagator in a homogeneous anisotropic medium by introducing a «wave propagator» is presented. It is shown that for anisotropic layered medium the matrix propagator can be represented by a «wave propagator» in each layer. The matrix propagator P(z,z0=0) acts on the free surface of the layered medium and generates stress-displacement vector at depth z. The basic expressions for the stress-displacement field using the matrix propagator and the radiation condition is got. In fact, the direct problem is reduced to the determination of the propagator P(z,z0). The displacement field on the free surface of an anisotropic medium is obtained from the received system of equations considering the radiation condition and that the free surface is stressless. The approbation of the matrix method for anisotropic media with TI symmetry is done. A comparative analysis of our results with the synthetic seismic records obtained by other methods and published in foreign papers is executed.

S202S1.01

S202S1 - Rotational seismology

Oral

Rotational seismology applications in earthquake engineering

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Seismic loading of structures has been always one of the most challenging problems in earthquake engineering. During the past four decades, in spite of the fact that different types of seismic waves are required to describe the strong ground motions, most researches have only considered the effects of shear waves in earthquake excitations of structures. This paper tries to make a discussion on the information obtained from rotational seismology and its engineering applications in defining reliable and accurate loading patterns for structural analyses. To achieve this, after reviewing common methods for the evaluation of rotational components, a discussion on the importance of recording these components accompany with translational ones in near-field zone is made. The results of this study indicate that the cognition of the sources of rotational motions can prepare a platform for new strategies in structural and geotechnical engineering problems such as spatial variation of strong ground motions and multiple-support excitation of structures, foundation input motions and soil-structure interaction, structural control and health monitoring, and system identification.

S202S1.02

S202S1 - Rotational seismology

Oral

Joint processing of translational and rotational motions of seismic surface waves: Performance analysis and applications

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The analysis of rotational seismic motions has received considerable attention in the last years. Recent advances in sensor technologies allow us to measure directly the rotational components of the seismic wavefield. Today this is achieved with improved accuracy and at an affordable cost. The analysis and the study of rotational motions are, to a certain extent, less developed than other aspects of seismology. This fact is due to the historical lack of recordings of the rotational part of ground motion. In this work, we aim at offering a quantitative description of the potential performance gain brought from the joint processing of rotational motions and translational motions. Our attention focuses on the analysis of motions of both Rayleigh waves and Love waves from recordings of single sensors and from an array of sensors. A method for the joint processing of rotational and translational recordings to perform maximum likelihood (ML) estimation is presented. Analysis of Fisher information (FI) allows us to understand how the different measurement types contribute to the estimation of quantities of geophysical interest. In addition, we show how rotational measurements resolve ambiguity on parameter estimation in the single sensor setting. We quantify the achievable estimation accuracy by means of Cramer-Rao bound (CRB). We support and illustrate our findings with a comprehensive collection of numerical examples. Applications to real recordings are also shown.

S202S1.03

S202S1 - Rotational seismology

Oral

Asymmetric continuum theories of solids and fluids; the combined system of strains and transport motions

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We present the Asymmetric Continuum Theory with the axial, shear and rotation strains and with the transport processes which are a common theoretical basis for solids and fluids; the related differences between solids and fluids are as follows: - in solids we consider the asymmetric strains and we include, moreover, the molecular transport processes, - in fluids we consider, reversely, the transport motions and molecular strains. Such combined system permits to understand the fracture nucleation processes and propagation of the shear and rotation strains due to the related common interactions in solids. The molecular transport field permits to understand some nucleation processes leading to a fracture. We note that the real displacements, even very weak, do not exist in a solid continuum, but appear there due to integration processes of the introduced molecular transport motions. However, we use the displacements as the reference motions to describe a full system of strain fields. For fluids, we present a new approach to the vortex processes; instead of the classic definition of vorticity, we consider the vortex motion system based on the transport motion with a variable arm and rotation flow in the cylindrical coordinates (vortex axis along z-line). This new definition leads to the full degrees of freedom desired in a vortex motion.

S202S1.04

S202S1 - Rotational seismology

Oral

A note on earthquake rotational acceleration components

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This paper presents that state-of-the art report on the characteristics of the rotational components and the common method for its estimation, as well as the need for for their consideration and their influences on the seismic loading of resistant structures against strong ground motions (SGMs) for reliable analysis and design. A new method for estimating the rotational acceleration components in near to far distances from the source is proposed; and an approximate formula for evaluating the phase velocities in the middle-field is derived. Further, a simple relation to evaluate the spectral density function of the rotational components in order to use as seismic input motions in random vibration analysis is presented. Finally, a discussion on the engineering applications of the presented method for rotational loading of structures is made.

S202S1.05

S202S1 - Rotational seismology

Oral

The relationship between peak values of rotational and translational motions

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A robust relationship between peak values of rotational and translational motions has been identified for small to moderate earthquakes. Understanding this relationship might provide a first-order estimate of the rotational motions near a major earthquake which is yet unavailable. Quantifying the relationship could be a key piece of information to understand the physics behind the relationship. The available data from small to moderate earthquakes seem to fit a linear relationship equally well at both normal and log-log scales. To select the best model to represent the empirical relationship, we compare these two types of relationship in detail using two published data sets from Taiwan and Japan. The results of this study show that the linear relationship on a log-log scale gives a better fit to both data sets. This implies that rotational motion might increase geometrically with increasing ground motions. The relationship also implies that the rotational motions might have large variation at large translational motions. These features are important in understanding the effects of rotational motions on near-field/extreme large strong-ground (translational) motions.

S202S2.01

S202S2 - Rotational seismology

Oral

Rotational ground motion during the 22 February 2011 Mw 6.2 Christchurch earthquake and relevance on buildings

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Research on “Rotational Seismology” has received in recent years a growing interest, based on the evidence that a proper characterization of weak and strong ground motions induced by earthquakes, explosions and ambient vibrations should simultaneously include both the translational and rotational components. Collecting translational and rotational information together, indeed, can yield a complete description of the wave-field, with a substantial improvement in studies of manifold research areas, such as, e.g., the velocity heterogeneity, the source complexity, and the media nonlinearity in strong ground motions. However, from a civil engineering perspective, studies on this topic are limited and, consequently, the knowledge of the effects on structures of the rotational wave-field is still insufficient. The goal of this work is to contribute to the evaluation of the impact of rotational motion on civil engineering structures, with special emphasis to the near-field region of an earthquake, and making reference to the study case of the Mw 6.2 Christchurch, New Zealand, earthquake of 22 February 2011. The exceptionally high values of acceleration recorded, especially for the vertical component, suggest that rotational motions could have played a significant role in the damaged area. At first, rotational ground motions are evaluated semi-empirically, starting from measured translational records in closely-spaced arrays of stations, and numerically, considering the prediction of the variability of strong ground motion in near-field conditions obtained through 3D models of the Canterbury Plains and of the Christchurch earthquake. The relevance of the rotational strong ground motions is then evaluated for types of civil engineering structures as high rise buildings and pounding-prone compounds of buildings, typical of the Central Business District of Christchurch, highly damaged by the earthquake.

S202S2.02

S202S2 - Rotational seismology

Oral

Shear and rotations as inferred from strong motion downhole vertical array observations

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Despite scientific and engineering needs to measure rotational component of earthquake ground motion only limited number of reliable rotational strong motion measurements is obtained so far. Few of them are point measurements, and others are inferred from surface array observations. More than twenty high resolution strong motion downhole vertical arrays are operational in California with primary goal to study site response of different geologic structures to strong earthquake motion. Data recorded at those arrays during a number of recent earthquakes provide an opportunity to calculate shear and rotational component (tilting) of the ground motion, and apparently were not previously used for this purpose. In this paper simple shear, rotations and rotation rates were inferred from downhole array records of the MW 6.0 Parkfield 2004, the MW 7.2 Sierra El Mayor (Mexico) 2010 and the two smaller earthquakes in California. Highest amplitudes of short duration rotations and rotation rates of 1.9E-04 rad and 5.5E-03 rad/sec associated with the S-wave motion were observed at a very close epicentral distance of 4.3 km from the ML 4.2 event in Southern California at the La Cienega array. In contrast, large magnitude Sierra El Mayor earthquake produced very long duration rotational motions of up to 1.5E-04 rad and 2.1E-03 rad/sec associated with shear and surface waves at the El Centro array. High dynamic range instrumentation is necessary for reliable calculation of rotations from array data. Data from dense Treasure Island array near San Francisco demonstrate consistent change of shape of rotational motion with depth and material. In the frequency range of 1-15 Hz Fourier amplitude spectrum of vertical ground velocity is similar to the scaled tilt spectrum. Amplitudes of rotations at the site depend upon the size of the base and usually decrease with depth. They are also amplified by soft material.

S202S2.03

S202S2 - Rotational seismology

Oral

Rotational motion from the strong-motion surface waves observed in the sedimentary basins and their engineering implications

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Strong-motion records are composed by body as well as surface waves, however traditionally surface waves are considered of less engineering importance. Yet, surface waves generated within the sedimentary basin as a consequence of the interaction of incoming body waves with the heterogeneous basin structure could be significant both in the near and the far-fields. In this presentation, we used records from an aftershock of 1999 Chi-Chi earthquake recorded in the Western Coastal Plain in Taiwan to demonstrate the significance of surface waves in the strong-motion records. Further, we adopted a band-pass filtering based on dispersion curves to isolate the surface waves form the body waves. As a matter of fact, the surface waves such as Rayleigh and Love waves do possess rotational motion such as rocking and torsional motions respectively; hence, ignoring the rotational motion would strongly undermine the theoretical foundation. Owing to the non availability of the real measurements, we estimated rotational motions from the isolated surface waves which were recorded from single station records. Finally, we selected two representative structures such as a chimney and a medieval tower which are expected to respond sensitively to the long-period rocking motion and a detailed nonlinear dynamic analysis of these structures were carried out using translational as well as rocking motion as seismic input. The outcomes of the present study are the following; (i) the surface wave contribution to the total motion could be more than 50% in the basin sites, (ii) the maximum resulting rotational motions could be around 1 ×10^(-4) radians, (iii) the tall flexible structures largely respond to the long-period surface waves, hence, the resulting rocking motions have considerable contribution to the structural response which could be as high as 20% of the maximum structural response.

S202S2.04

S202S2 - Rotational seismology

Oral

Evaluation of torsional ground motion in small-basin of Sendai

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Here an effort was made to analyze variation of torsional ground motion in Sendai city, Japan. In this city, Nagamachi-Rifu fault passed through the middle of the town and caused a small basin with large lateral variation. The data from Miyagiken-Nanbu earthquake (September 15, 1998) with M_JMA=5 is employed to analyze torsional ground motion. The earthquake data were gathered from three strong motion arrays of SMALL-TITAN, K-NET, and BRI in Sendai city. The selected stations covered whole Sendai city and are close enough to provide accurate torsional motion estimation within 90 percent accuracy in the frequency range of 0.1 – 1 Hz. In order to estimate torsional motion from accelerogram arrays, a method introduced by Spudich et al. (1995) was used. The estimated torsional motion show large variation, especially near to Nagamachi-Rifu fault trace. This variation was discussed and explained on lateral variation of subsurface geology.

S203S1.01

S203S1 - Advances in global hazard and risk analysis

Oral

ISC-GEM Global Instrumental Earthquake Catalogue (1900-2009) – An improved view of the seismicity of the Earth

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The ISC-GEM global earthquake catalogue represents the final product of a two-year project sponsored by the Global Earthquake Model Foundation (GEM). The catalogue consists of some 19 thousand instrumentally recorded, moderate to large, earthquakes that occurred during the 110-year period between 1900 and 2009. Because of limitations in resources, time and data availability, we introduced time-varying magnitude cut-offs for the earthquakes to be included in the ISC-GEM catalogue. These are 1900-1917: Ms $\geq$ 7.5 worldwide, as well as a selection of shallow events (Ms $\geq$ 6.5) in stable continental areas; 1918-1959: Ms $\geq$ 6.25; and 1960-2009: Ms $\geq$ 5.5.

Hypocenters for all events in the catalogue were redetermined using uniform and rigorous location and depth determination procedures. Body and surface wave magnitudes were recalculated using original amplitude-period measurements. The unprecedented amount of body and surface wave event magnitudes allowed us to derive new, nonlinear regression relations between Ms-Mw and mb-Mw. Thus, each earthquake in the ISC-GEM catalogue is characterized by either a direct measurement of Mw, or an Mw proxy estimate based on our non-linear regressions.

Owing to the ISC-GEM location procedures and to the substantial increase in the volume of observational data used in the relocations and magnitude calculations, the ISC-GEM catalogue offers an improved view of 110 years of global seismicity of the Earth. We show that the relocation effort yields substantially improved locations, especially in the first half of the 20th century. We demonstrate that the ISC-GEM locations are better clustered and considerably reduce scatter in location estimates. Finally, the significantly improved depth estimates for events in the ISC-GEM catalogue provide a better resolution of earthquakes associated with subducting slabs.

S203S1.02

S203S1 - Advances in global hazard and risk analysis

Oral

Challenges for national seismic hazard mapping with rare large continental earthquakes

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Those modelling seismic hazard in intraplate continental regions (Australia, eastern North America, southern India etc) are challenged because the probability of large earthquakes is low yet their potential contribution to seismic hazard can be large. Some modellers substantially assume that the past will repeat itself, but this is a hypothesis that has been found wanting in eastern Canada. While moderate earthquakes seem more likely in Canadian regions that have had prior activity, large earthquakes have happened elsewhere in similar seismotectonic environments with very low seismicity. We agree that rift structures or passive margins now embedded within continents provide long-lasting weak zones that concentrate the release of seismic strain and deserve recognition as seismotectonic sources. While larger earthquakes in historical times cluster at places along the St Lawrence «rift» paleo passive margin, low magnitude (M~<2) earthquakes usefully outline the structures between the clusters. Furthermore the occurrence of deep (z > 10 or 15 km) earthquakes also seems to highlight the weak zones. These may be global phenomena that can be applied to map weak structures within continents, even when the history of past large earthquakes is lacking. A model that (i) considers the probability of M<6.75 earthquakes to be tied to the historical activity (effectively they are belated aftershocks of initiating «random» events) and (ii) adds the rare contributions of «random» M>6.75 earthquakes within the same seismotectonic environment has been implemented in eastern Canada for the 2015 Canadian national hazard maps.

S203S1.03

S203S1 - Advances in global hazard and risk analysis

Oral

Modeling seismic hazard in the Lower Rhine Graben using a fault-based source model

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The Lower Rhine Graben (LRG) is an active tectonic structure in intraplate NW Europe. It is characterized by NW-SE oriented normal faults, and moderate but rather continuous seismic activity. Probabilistic seismic hazard assessments (PHSA) of this region have hitherto been based on area source models, in which the LRG is modeled as a single or a small number of seismotectonic zones with uniform seismicity at a fixed depth. The past few years, efforts have increasingly been directed to using fault sources in PSHA, in order to obtain more realistic patterns of ground motion. This requires an inventory of all fault sources, and definition of their physical properties (at least length, width, strike, dip, rake, slip rate, and maximum magnitude). The LRG is one of the few regions in intraplate NW Europe where seismic activity can be linked to active faults. In the frame of the EC project SHARE («Seismic Hazard Harmonization in Europe», http://www.share-eu.org/), we have compiled the first parameterized fault model for the LRG that can be used in PSHA studies. We construct the magnitude-frequency distribution (MFD) of each fault based on a combination of the catalog MFD (weighted by moment rate) and the frequency of the maximum magnitude predicted by fault dimensions and slip rate. Seismic hazard is computed with OpenQuake (http://openquake.org/), an open-source hazard and risk engine that is developed in the frame of the Global Earthquake Model (GEM). Compared to other commonly-used, non-commercial hazard engines, OpenQuake offers better support for fault sources with simple or complex geometries. We compute hazard maps for return periods of 475, 2375, and 10,000 yr, and compare the results with hazard maps based on area sources. In addition, we conduct sensitivity tests to determine the impact of various parameter choices, e.g. maximum magnitude, inclusion of a background zone to account for lower magnitudes, and GMPE distance metric.

S203S1.05

S203S1 - Advances in global hazard and risk analysis

Oral

Probability of strong earthquake recurrence and time-dependent seismic hazard analysis for Greater Tehran

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Earthquake hazard in the Tehran providence, Iran, a very important big urban area, high population density, incompatible design and construction and inappropriate planning, have increased its vulnerability to natural disasters, especially earthquakes. This city is located near the foothills of the southern Central Alborz Mountains, which is surrounded by several active faults. Many historical and recent earthquakes have affected this region. This is important to predict next great earthquake and its probability of recurrences by using statistical method and time-dependent probabilistic seismic hazard for this region. The estimation of long-term probabilities of occurrence of earthquakes of specific size in a given time interval is a primary goal in the seismic hazard assessment. The probability of the occurrence of the next large earthquake during a specified interval of time can be calculated by Brownian passage time (BPT) distribution. Conditional probability specifies the likelihood that a given earthquake will happen within a specified time. This likelihood is based on the information about past earthquake occurrences in the given region and the basic assumption that future seismic activity will follow the pattern of past activity By maximizing the conditional probability for the model, we estimated approximately the recurrence time of the next strong earthquake in this region. Time dependent models in which some probability distribution, called a renewal process, describes the time between large earthquakes. In the renewal processes, the conditional probability of the next large earthquake, given that it has not happened yet, varies with time and is small shortly after the last one and then increases with time. by using time dependent method for this region, it shows that by increasing time elapsed since last earthquake the probability of Earthquake hazard in the Tehran providence increases.

S203S2.01

S203S2 - Advances in global hazard and risk analysis

Oral

Harmonizing Probabilistic Seismic Hazard Assessment for the Euro-Mediterranean region: An Overview

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Probabilistic seismic hazard assessment (PSHA) is one of the most useful products seismology offers to society. PSHA characterizes the best available knowledge on the seismic hazard of a study area, ideally taking into account all sources of uncertainty. Results form the baseline for informed decision-making, such as defining building codes or insurance rates, and provide essential input to risk assessment.

The EC-FP7 project SHARE (www.share-eu.org) released a community-based probabilistic time-independent hazard model for the Euro-Mediterranean region. The results contribute to the Global Earthquake Model (GEM, www.globalquakemodel.org), a public/private partnership initiated and approved by the Global Science Forum of the OECD- GSF.

SHARE inherited knowledge from national, regional and site-specific PSHAs, assessed new data and built comprehensive hazard relevant databases, rigorously selected ground motion prediction equations and implemented the model in the GEM-OpenQuake framework. For the first time, kernel-smoothed approaches as well as fault-based hazard estimates are included in the Euro-Mediterranean region. The PSHA comprises results for various return periods of engineering interest and various ground motion intensity. Details for single sites, such uniform hazard spectra and disaggregation, are available.

We present insights into the model, results of the PSHA, elaborate on their implications and describe future challenges. The results outline a foundation for future PSHAs that should include time-dependency and sophisticated model evaluation efforts. The outcome can serve as base for a European Probabilistic Risk Assessment.

We envision the results to deliver long-lasting structural impact in areas of societal and economic relevance, to serve as reference for the revision of Eurocode 8 (EC8) provisions and to provide a homogeneous baseline input for the correct seismic safety assessment for critical infrastructures.

S203S2.02

S203S2 - Advances in global hazard and risk analysis

Oral

Modeling earthquake ruptures for PSHA in the GEM hazard engine

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The need of honoring the complexity of Ground Motion Prediction Equations (GMPEs) in the context of PSHA requires an accurate modeling of earthquake ruptures. As a matter of fact, current state-of-the-art GMPEs are more and more relying on different parameters describing rupture properties like hypocenter location, top of rupture depth, dip and rake angle as well as distance parameters which are computed once spatial extension and orientation of ruptures are known. While the 'point rupture' approximation is widely used in PSHA calculations, it still not very well understood which are the consequences of using extended ruptures, especially in view of the fact that parameters describing ruptures geometry, orientation and location can be highly uncertain. Little is present in the literature about modeling ruptures in geometrically complex fault structures (for instance in subduction environments) in a PSHA context. This study presents cases of PSHA calculations based on the GEM hazard calculation engine that follows different modeling conditions (distributed seismicity as well as fault based models) and shows sensitivity studies aiming at explaining how factors affecting ruptures shape, orientation and location (e.g. strike, dip, aspect ratio, hypocenter location) play a role in the calculation of hazard curves. A new algorithm for modeling earthquake ruptures on complex irregular surfaces is presented and applications for realistic cases are discussed.

S203S2.03

S203S2 - Advances in global hazard and risk analysis

Oral

Analysis of seismic hazard on a global scale: Modeling issues and integration of the Global Earthquake Model (GEM) data products

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The Global Earthquake Model (GEM) encompasses many aspects of modelling seismic hazard, risk and social vulnerability. In constructing a global seismic hazard model, GEM is engaging, via its regional programs, scientists and engineers from around the world, to build models that make optimum use of local expertise. In addition, GEM has engaged consortia of expert scientists to construct global sets of earthquake data, including catalogues of historical and instrumentally recorded earthquakes, databases of active faults, sets of ground motion prediction equations and a new global geodetic strain rate model.

The construction of these datasets provides an opportunity to construct (as a matter of scientific enquiry), spatially homogeneous global models of seismic hazard. Whilst such models are not intended as a substitute for high quality local models, and cannot resolve sources to the same level of detail, they offer an excellent opportunity to explore spatial comparisons of hazard and risk for globally distributed portfolios. They can also be subject to a wider testing and evaluation procedure, similar to that proposed by the Collaboratory for the Study for Earthquake Predictability (CSEP).

Preliminary examples of global models of earthquake activity rate and seismogenic sources have been constructed using smoothed seismicity and geodetic strain. Within the model development process, many elements are subject to scrutiny. The characterisation of the tectonic regions, incorporation of subduction sources and the distribution of seismogenic depths and controlling focal mechanisms, are all factors that play a crucial role in the translation of global activity rates to global seismic hazard models. Methods to constrain this information require scalability and objectivity across many different seismotectonic environments. New approaches for achieving these objectives have been considered and highlight many issues fundamental to probabilistic seismic hazard assessment.

S203S2.04

S203S2 - Advances in global hazard and risk analysis

Oral

Extreme seismic hazard and its assessment

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Recent disasters due to great earthquakes revealed a weakness in seismic hazard assessments: ground shaking due to the earthquakes was significantly underestimated. Large-magnitude, rare and hence extreme seismic events are not accounted in the analysis of ground shaking in the most cases due to the lack of information and unknown re-occurrence time of extremes. Our present knowledge about earthquakes is based on observed (recorded) and historical (e.g., from paleo-seismological and archaeological studies) data. We present a new approach to assess regional seismic hazard, which incorporates observed seismicity and modeled extreme events into the ground motion analysis, and apply this approach to probabilistic seismic hazard assessment in the Tibet-Himalayan region. Initially earthquakes are simulated for several thousand years; the synthetic earthquakes occur on the modeled faults due to realistic movement of modeled lithospheric blocks, stress localization and release. The large-magnitude events from the modeled catalogs together with the observed earthquakes are used to generate a set of composite stochastic catalogs. These composite catalogs are employed for Monte-Carlo probabilistic seismic hazard assessment. The results provide information about strong shaking, which could be anticipated in the region, in terms of peak ground acceleration. The resulted seismic hazard map is compared with those modeled earlier and with observed strong-motion data. Our approach to seismic hazard assessment provides a better understanding of ground shaking due to possible large-magnitude events and could be useful for seismic risk assessment, earthquake engineering purposes, and emergency planning.

S203S2.05

S203S2 - Advances in global hazard and risk analysis

Oral

Housing in earthquake prone Delhi using locally available waste building materials

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National capital region, Delhi being in the zone IV is highly susceptible to earthquakes. Certain areas of Delhi not lying on a continuous plate are more likely to hit with higher damage percentage than those areas lying on a continuous plate which are endangered with less percentage of damage. These dangers continuously pose a problem for the government to think of ideas and policies to tackle such kind of problems. While Delhi steals a march over all other metropolitan cities across India, in generating waste, it lags far behind in waste disposal and recycling. National capital region Delhi together is the fastest growing regions of India in infrastructure. This can be explained by rapid population growth, mass migration of population to urban areas, increase in economic activities in the city and the change in lifestyle of the people. A large part of this daily solid waste generated in Delhi comes from construction sites. As the art of exploiting the resources by humans is improving day by day, the demand for modern structure is reaching the heights but this demand is not being met by available resources. The availability of concrete aggregates of required strength is gradually declining. This decline calls for the search of finding alternate solutions besides the conventional ones like, the use of waste building materials for making aggregates. Recycle of these building waste can be a useful building materials for housing construction in the earthquake prone area like Delhi, solving the problem of disposal on the one hand and providing better construction material at low cost on the other hand. In this paper an attempt has been made to highlight various waste materials, including building waste, generated in earthquake prone Delhi region which can be used for the housing construction. This database has been developed through literature review, questionnaire survey and open-ended interviews conducted to generate data from various construction sites.

S301PS.01

S301PS - Earthquake sources – modeling and forecasting

Poster

Spatio-temporal variations of seismic parameters prior to the 2009 L'Aquila earthquake

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The 2009 l'Aquila earthquake (Mw=6.3) was preceded by several foreshocks of which the Ml = 4.0, March 30 earthquake was the largest. After the occurrence of the mainshock, several studies investigated the foreshocks to find changes in seismic parameters. The studies involved changes in temporal and spatial distribution of events, in seismicity rate, b-value, ratio of compressional-to-shear velocity. In all these studies the 30 March 2009 largest foreshock indicates the beginning of temporal changes in different seismic parameters that have been usually correlated to the beginning of the preparation process of the mainshock. However even if concentrated in a little area the foreshocks before and after the magnitude 4.0 largest foreshock have different locations and only a small group of earthquakes of the two periods have similar locations. The primary aim of this study is to analyze a synchronization effect in geophysical signals of different nature and to discriminate between spatial and temporal variations occurred before and after the mainshock occurrence.

S301PS.02

S301PS - Earthquake sources – modeling and forecasting

Poster

The phenomenon of synchronism in the technosphere–magnetosphere–lithosphere dynamical system

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Synchronism in geophysical events became the focus of the research in the second half of the last century when the study of this subject was almost simultaneously launched in the former Soviet Union and the United States. Interest in this issue has recently risen after a 20-year hiatus. The impetus was provided by the successful application of the synchronous detection technique to analyzing vast volumes of digital data on the electromagnetic waves in the magnetosphere and on the earthquakes. These studies revealed signs of the strictly periodic synchronous influence of the technosphere on the regime of electromagnetic oscillations in cosmic plasma and on seismic activity. The phenomenon of synchronism manifests itself in the form of the so-called hour-mark effect and the weekend effect. The hour-mark effect shows itself in the 24th, 48th, and 96th harmonics, and the weekend effect, in the 7th subharmonic of the circadian rhythm. The both effects indicate that the technosphere has a nontrivial impact on the magnetosphere and lithosphere. The present review aims to introduce the morphology of the phenomenon and to focus the attention of researchers on the physical interpretation of the effects of synchronism, which is a challenging problem. A special attention is paid to human impact on the electromagnetic and seismic regime in the North Caucasus. Both the fundamental and practical value of the problem is analyzed. In particular, it is hypothesized that the study of the anthropogenic modulation of the natural wave processes will promote the development of energy saving technologies. The work was supported by Program 4 Project 6.2 of the Presidium of the Russian Academy of Sciences.

S301PS.03

S301PS - Earthquake sources – modeling and forecasting

Poster

On the dynamics of aftershocks after Great Sumatra-Andaman earthquake

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An earthquake can be attributed to the area of critical phenomena. So it is natural to use a number of concepts and ideas from the theory of non-equilibrium dynamical systems and general catastrophes theory when we are analysing the seismic data. In this work, we were guided by two well-known ideas concerning the universal properties of critical phenomena. The first one is that the amplitude of fluctuations increases with approaching the bifurcation point, so that at some moment a fairly strong internal pulse provides the critical transition (catastrophe). This transition will be called spontaneous. The second property is that sufficiently close to bifurcation the susceptibility of dynamical system dramatically increases. This means that even a weak external perturbation can cause the catastrophe. Critical phenomenon of this kind is naturally called the induced transition. We use this knowledge in the analysis of aftershocks after the Sumatra-Andaman earthquake on 26.12.2004, M = 9.3. We point to the two interesting manifestations of induced seismicity. First is the large aftershock (M = 7.1) with a time delay of about 3 h 20 min respect to the main shock. The idea is that the surface waves propagating outwards from the main shock return back to the vicinity of the epicenter after having made a complete revolution around the Earth and, in principle, may induce there an aftershock. The second manifestation is the modulation of the aftershock sequence by the fundamental oscillation of the Earth 0S2 excited by the main shock. In addition, we present a preliminary analysis of the aftershock sequences after other strong earthquakes in the light of the theory of critical phenomena.

S301PS.04

S301PS - Earthquake sources – modeling and forecasting

Poster

Analysis of common laws of solids fracture as a way of earthquake prediction

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Development of many scientific fields proves the usefulness of an interdisciplinary approach to the investigation of phenomena based on the physical analogy of described processes and their general laws. Because the crust is solid, patterns of fracture processes in the Earth's crust manifested in the seismic activity should be similar to the laws of fracture in other solids (rocks, metal or polymer samples) manifested in the acoustic emission. Using laboratory samples facilitates analysis of the factors determining conditions of occurrence of critical events and relations describing these conditions. This is confirmed by investigations of the fracture of metal specimens under different types of loading fulfilled with the registration of acoustic emission. Some results of these studies are presented in the report. The basic regularities in the kinetics of damage accumulation before fracture of metallic specimens [1] are found to be similar to those in the dynamics of seismicity before earthquakes [2]. Physical interpretation of parameters used for earthquake prediction is suggested. Scale invariance of the main regularities in the evolution of damage is demonstrated. It testifies to the possibility to use metallic specimens for investigation of the kinetic features of natural processes during of earthquakes preparation. Work is supported by the grant 12-05-00779 of the Russian Foundation for Basic Researches.

[1]. Botvina L.R. Fracture: Kinetics, Mechanisms, Common Regularities. Moscow: Nauka, 2008.

[2]. Zavyalov A.D. The medium-term earthquake prediction: Fundamentals, Methods, Implementation. Moscow: Nauka, 2006.

S301PS.06

S301PS - Earthquake sources – modeling and forecasting

Poster

The evolution of radiated energy in Italian seismic sequences

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In this work, we propose the application to Italian seismicity of an equation (Gentili, 2012) describing the evolution of seismic sequences in terms of radiated energy. The equation has been previously tested on Californian seismicity only. The radiated energy during time is described as function of the p and c parameters of the Modified Omori Law and of the energy radiated in a selected time period after the mainshock. The equation is obtained analytically under the assumptions that the sequences can be approximated by the Reasenberg and Jones (1989, 1994) equation, and that the logarithm of the energy depends linearly on the earthquakes magnitude.

The approach proposed in this work allows to make an alternative evaluation of p and c parameters, less sensitive to catalog incompleteness. In particular, the value of c estimated by frequency based approaches has been widely debated (Kagan and Houston, 2005, Lolli and Gasperini, 2006, Utsu et al., 1995, Shcherbakov et al., 2004, Kagan, 2004 and Lippiello et al., 2007), because it is sensitive to the rate of seismicity at times close to the mainshock, i.e. when, due to the waveform superposition, many small earthquakes are lost. By using the energy rather than the number of events in describing seismic sequences, we circumvent the problem, because, close to the mainshock, the contribute of small aftershocks to the total radiated energy is negligible.

The parameters of the Italian seismic sequences have been evaluated by a maximum-likelihood estimate. The likelihood function adopted is the one proposed by Zaliapin et al (2005) for cumulative moment fitting.

S301PS.07

S301PS - Earthquake sources – modeling and forecasting

Poster

Earthquake nucleation on faults with a revised rate- and state-dependent friction law

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Quasi-static nucleation is expected to occur on faults embedded in elastic continuum before it ruptures dynamically. So far, consequences on the nucleation from two popular versions of rate- and state-dependent friction (RSF) law, both of which have their own shortcomings in reproducing laboratory results, have been studied, and important differences have been noticed. With the 'aging' version of RSF, nucleation behaves as expanding crack and can grow quasi-statically to a fairly large size. In contrast, with the 'slip'-version of RSF, the later stage of nucleation proceeds as a narrow migrating slip pulse, and the expected moment release is much less. Recently, using a new rigorous approach in experimental data analysis, Nagata et al. [2012] has proposed a new revised version of RSF, where the previously known shortcomings have been eliminated: Nagata law can reproduce experimental results under different types of imposed loading conditions (i.e., velocity-step and slide-hold-slide tests) with the same set of parameter values, this is a far better description of laboratory friction. The present paper presents numerical experiments of earthquake nucleation using Nagata law and discusses the implications at a phenomenological level. Our preliminary simulation results show that nucleation has characteristics of both slip pulse and expanding crack and we have confirmed that the crack-like expansion, which can grow to a fairly large limiting size for faults obeying the aging law, is not sustainable for faults obeying Nagata law. This agrees with the theory attributing such a large quasi-static growth to the aging law's characteristic of slip-weakening distance increases linearly with the magnitude of strength drop because the Nagata law predicts more or less fixed slip-weakening distance.

S301PS.08

S301PS - Earthquake sources – modeling and forecasting

Poster

Source process of the 2005 Zarand earthquake, in Kerman province, south-east Iran

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In this study, the source process of the 2005 Zarand earthquake was investigated and the observed teleseismic bodywaves of mainshock were modeled in order to obtain the image of temporal and spatial variation of slip on the fault plane. Information from field investigations and the results of aftershock activity were considered as supplementary data. The moment tensor functions were obtained and the corresponding best double couple showed two nodal planes striking N255°E (dipping 70°SE) and N 100° E (dipping 22° SW). The post-seismic field investigation, the aftershocks distribution and the orientation of the Zarand Fault, all suggested that the nodal plane of striking N255°E (dipping 70° SE) having rake 81°, was the causative fault of Zarand earthquake. Thus, Zarand earthquake accompanied by a nearly EW striking vertical fault plane, with northern block moving upwards relatively to the southern block. The scalar seismic moment was calculated to be M0 =2.0 ×1019 Nm and the moment magnitude was calculated to be Mw=6.8. The static distribution of slip on the fault plane, obtained through inversion procedure, indicated that the rupture with slip amplitude greater than 0.4 m was as long as 40 km and the area with slip amplitude 0.8 m was about 30 km. The slip-concentrated area with amplitude greater than 2 m was localized in central area with a total length about 5 km. The maximum amplitude of the slip was about 2.2 m. The average slip amplitude over the whole rupture area is about 1.2 m.

S301PS.09

S301PS - Earthquake sources – modeling and forecasting

Poster

Slip-inversion and Coulomb stress transfer of the August 11, 2012 Varzaghan twin earthquakes in NW Iran

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On 11th of August 2012, two earthquakes with magnitudes 6.4 and 6.2 (Mw) occurred within 11 minutes, rupturing through the city of Varzeghan in the northwest of Iran. These two earthquakes were followed by numerous aftershocks with magnitude up to 5.3. It was known that there had been large events in this area previously, but the area was fairly quiescent prior to these two events, so it was not known exactly which fault was responsible. The Ahar fault is now suspected.

The Global CMT solution reported a pure strike slip fault for the first earthquake and an oblique thrust fault for the second one. We used broadband data (between 20 to 80 degrees) obtained from IRIS to invert for the slip distribution of these events using the teleseismic body waveform inversion method of Kikuchi and Kanamori. The estimated mechanism is very similar to the Global CMT solution. Other workers have produced solutions which all agree on the mechanism of the first event but they report different results for the second one. This ambiguity comes from the limited amounts of waveform data that exist for the second event due to interference between the wavetrains of the first and second events.

Using the slip-inversion results, we have calculated the Coulomb stress transfer to study the possible triggering effect of the first earthquake on the second one. Furthermore, comparing different Coulomb stress results from various probable fault models based on data such as surface rupture trace and aftershock distribution enabled us to constrain the true fault and slip.

S301PS.10

S301PS - Earthquake sources – modeling and forecasting

Poster

Estimation of stress state around an M2 fault in a South African deep gold mine based on borehole breakout and core discing

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Strength of a fault in a geological structure is one of key questions to understand the generation process of earthquakes. Stress state around a fault on which an earthquake occurred should provide an important clue to solve the question. We, therefore, drilled a hole penetrating a fault of Mw2.1 earthquake in a deep gold mine in South Africa to obtain information of stress state from borehole breakouts and core discings.

The fault-penetrating hole of 90 m in length was drilled 1.5years after the Mw2.1 earthquake. We observed the borehole wall by inserting a small video camera. We found that sub-horizontal borehole breakouts were severe in the hanging wall of the fault, while they were insignificant in the footwall. The sub-horizontal breakout is consistent with the focal mechanism solution of normal faulting of the Mw2.1 earthquake. Distribution of core discings was generally consistent with that of borehole breakouts. That is, core discing was severe in the hanging wall. Especially, for 10m in the hanging wall from the fault, drilling cores were not recovered probably due to too severe discings. The distributions of borehole breakout and core discing imply a significant difference in the stress states between two sides of the fault. When this information is combined with the uniaxial compression strength and the uniaxial tensile strength measured in laboratory, we can constrain the in-situ stress state around the fault. Six months before the earthquake, we installed strainmeters in the dyke and in the host rock. They recorded the preseismic and the coseismic stress changes in the source region. Therefore, the preseismic in-situ stress state around the fault can be recovered by integrating them with the post-seismic stress state constrained by drilling through the stress modeling around the rupture surface by a boundary element method in which mining sequence is replicated.

S301PS.12

S301PS - Earthquake sources – modeling and forecasting

Poster

Reflection of strong Caucasian earthquake in seismical, geophysical and seismogeochemical fields (Azerbaijan-Zaqatali city, 07.05.2012)

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On May, 07-th, 2012 in the north-west of Azerbaijan, in the Zagatalian seismoactive zone there was a strong earthquake (ml=5.6; Mpv=6.1; h=8.2 km). It had a big aftershock activity: only on 07.05.2012 have been registered 136 pushes (ml=0.6-5.7) and five of them (ml>=4.0) were felt with intensity 4-7 points. Everything, from 07.05-31.05.2012 it has been registered 520 aftershocks (ml=0.5-5.0), which migrated on depths h=10-15 km. Emission of total seismic energy corresponded $E=23.85*10^{11}$ dj. The basic seismic centre was localized in the Vandam block of a southern slope of the Big Caucasus, within the crystal base. Spatial distribution of hypocenter notable aftershocks (ml>=4.0) corresponded to direction the north-west to south-east, and migration of weaker went in direction from the north-east to the south-west. The given fact specifies in activization in this zone as longitudinal, and the general Caucasian deep breaks. As a whole, the centre zone of Zagatalian earthquake is in an operative range Balaken-Djunut longitudinal and Salavat cross-section deep breaks. By results of the analysis and interpretation of the data seismological, geophysical and seismic geodinamical fluid monitorings have been in details studied as the mechanism of processes in the the hypocenter of Zagatalian earthquake, and synchronous, intensive changes of the geomagnetic fields and seismic geodinamical fluid (level and expense underground waters in chinks, change of ionic-salt structure sea and underground waters, intensity of an alpha field on a surface of the Earth) fields are revealed. It has been established that all abnormal effects have arisen at the final stage of preparation of this seismoevent. It is necessary to notice that else in 2007 on the maps of the intermediate term and long-term forecast earthquakes, we have allocated the Zagatalian seismic zone as a potential seismic centre with magnitude Mpv>=5.0.

S301PS.13

S301PS - Earthquake sources – modeling and forecasting

Poster

Cases of violation in the empirical scheme's general laws of strong earthquake short term forecast

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By space-geophysical concepts of seismo-tectonic genesis [1] earthquakes with magnitude M> 6 tend to occur after geoeffective phenomena on the Sun (such as flares or coronal mass ejections) in [(2 or 3) weeks plus-minus 2 days] (1) However, some empirical experiments on the earthquake short term forecast in accordance with the scheme SC OME (Scintific Centre of Operative Monitoring of the Earth, Moscow, Russia), which lies at the heart of the new seismo-tectonic genesis concept, rare instances of deviations from the laws (1) were identified, when an earthquake occurs in one week plus or minus 2 days. The first such cases were the earthquake near Sumatra: 2007.12.22 with M=7.4 and 2010.05.09 with M=7.2; off the coast of Kamchatka 2011.07.18 with M=5.2 (Sea of Okhotsk) and with M=5.6 and M=5.2 (near the Rat Islands). Later seven-day seismic efficiency of geomagnetic disturbances according to the scheme SC OME sometimes was observed by the example of earthquakes in Taiwan and Japan, as well as of accidents and gas explosions in Kuzbass coal mines (Russia). It was found that some of the schemes SC OME general laws failures occurred in the case of the powerful typhoons passage near the future earthquakes epicenter. This is usually affected at an earlier period of earthquakes or the actual magnitude decrease compared with predicted values. Spectacular examples of a predicted seismic activity on volcanic replacement in Kamchatka, Italy, Chile and Japan are shown. The possible physical causes and mechanisms of such deviations from SC OME general geophysical patterns are discussed. The reported study was partially supported by RFBR, Research project No. 11-08-00795 Reference [1] Earthquakes forecasts following space – and ground – based monitoring, Acta Astronautica 69 (2011) 18-23.

S301PS.14

S301PS - Earthquake sources – modeling and forecasting

Poster

S-Mg-Si-rich water circulation in fault zones promoting sepiolite lenses in the Galera fault (Betic Cordillera, SE Spain): influence on the local seismic behaviour

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We studied the influence of water circulation processes on the clay mineral crystallization in the Galera fault (Betic Cordillera, SE Spain). The Galera fault is an active fault located in the NE of the Guadix-Baza Basin (central Betic Cordillera) with 23 km of long and N50°E strike of average. It has a 1.5 width fault zone with several parallel splays dipping between 40° and 60° to the NW, which cut Pliocene and Pelistocene rocks (fundamentally lacustrine limestones and evaporites). This fault has current low-moderate seismicity. Groundwater circulating through the fault is characterized by specially high contents in S, Mg and Si and a low temperature in the discharge. Nevertheless, hot and even higher mineralized waters discharged in some thermal springs associated to the fault. Fault rocks develop lenses dominated by sepiolite which chemical composition shows large gains in Mg, Si Li and As as regard their protoliths. Given that sepiolite is restricted to these lenses, we conclude that the heat and water flows were confined to the fault zone. Sepiolite can increase plasticity, compressibility, and swelling potential of the fault rocks, helping to explain the presence of localized mechanical weakness zones that could affect the seismic behaviour of the fault.

S301PS.15

S301PS - Earthquake sources – modeling and forecasting

Poster

FEM simulation of interseismic and coseismic deformation associated with the 2008 Wenchuan earthquake

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We make use of two-step modeling to simulate inter- and coseismic deformation within one seismic cycle by means of visco-elastic finite element method (FEM). The first step is to perform inversion to find the optimum modeling parameters by fitting the observed interseismic deformation. Then the model continues to produce a major seismic event to simulate the Wenchuan earthquake. The model results show that, in order to fit the observed interseismic deformation, it needs a soft lower crust and upper mantle beneath the Eastern Tibet, and a very strong lithosphere of the Sichuan basin. The computed interseismic strain accumulation in the lower crust beneath the eastern Tibet is much faster than that in the other regions. Especially, the elastic strain energy density rate (ESED) accumulates very rapid in and around the Longmen Shan fault in the depth above 30 km that may explain why the great Wenchuan earthquake occurs in the region of such a slow surface deformation rate. Simulations of coseismic processes reveal relationships among slip acceleration, normal stress and shear stress changes on surface of the seismogenic fault. Coseismic slip appears to initiate in the gently-dipping section of the fault, but primary slips (coseismic rupture) on both gently-dipping and steeply-dipping sections take place simultaneously. Minor fault slip accelerations decrease normal stress on fault surface to reduce frictional strength of fault, and in general increase shear stress on fault surface to enhance tectonic stress on the fault to drive the fault further slips. Both processes facilitate major slip or rupture on the listric reverse fault. Coseismic slip distribution also suggest that an important role of high-angle listric reverse faulting is to transfer overwhelming horizontal deformation of the Eastern Tibet into significant vertical displacement in the Longmen Shan during the 2008 Wenchuan earthquake.

S301S1.01

S301S1 - Earthquake sources – modeling and forecasting

Oral

Modeling of transient seismic process - laboratory and field scales

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Results of the physical modeling of seismic process on laboratory and field scales are considered. Laboratory and field modeling is powerful tools for investigation of the nature of seismicity. Laboratory experiments allow studying the regularities of the failure in dependence on the stress-state and properties of the samples. Man-made initiation of seismicity allows analyzing origination and evolution of seismicity under natural conditions, that makes possible to fill the gap between laboratory experiments and investigation of tectonic driven seismicity.

The seismic process involves different-type feedbacks that determine and control the evolution of seismicity. It is difficult to reveal and study these feedbacks in stationary conditions, since the variations in the background seismicity are insignificant, and their nature is usually known poorly. It is more preference from the methodical point of view to investigate the transient mode of the seismic process – the response of the geophysical medium to the different impacts that disturb its stationary state. Identification of the regularities in the transient mode offers the possibility to gain an insight into the character and specific features of the key properties of the medium and its physical mechanisms, which govern the dynamics of the seismicity.

Results of carried out analysis of acoustic activity under various modes of stress initiation and by water infusion as well are discussed. On field scale results of analysis of seismicity induced and triggered by different impacts (water injection, reservoir filling, power electric sounding) are considered. In both scales regularities of changes of self-similarity exponents for seismicity and «acousticity» in relation to the stress state and the fracturing were revealed.

S301S1.02

S301S1 - Earthquake sources – modeling and forecasting

Oral

Statistical features of earthquake sequences and their physical meaning

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Forecasting the temporal and spatial distribution of earthquakes on different time scales has been a major research target during the last few decades. Statistics-based models have been developed and the results from their applications to earthquake sequences are intended to describe or predict the spatiotemporal distribution of seismicity and also reproduce many properties of real seismicity. Confirmed models of the statistical properties of an earthquake sequence can be hoped to lead to better understanding of the physical system, and can potentially lead to better hazard assessment. These models are based on the application of probability theory to seismic sequences and can be conditioned by the occurrence times and also by other parameters, such us the earthquake magnitudes. We analyze data from seismic catalogues for geographical areas selected based on their tectonic structures and past seismicity to seek temporal and spatial changes in the pattern of behavior. Current focus is on the evaluation of assumptions included in the statistical approaches applied, upon which the reliability of derived results are strongly dependent. Specifically, we wish to assess if significant changes in patterns of seismicity can be confirmed, especially prior to large events.

S301S1.03

S301S1 - Earthquake sources – modeling and forecasting

Oral

Specific features of energy distribution of acoustic emission signals at the initial stage of fracture of rocks

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The energy distributions of acoustic emission (AE) signals have been analyzed on two scaling levels corresponding to deformation of dry and water-saturated granite samples and processes on the mining plants of the Russian Far East. It has been found that the initial stage of fracture (~0.5-0.6 of the sample lifetime) defects are formed uniformly in the sample. The energy distribution of signals from the entire sample is not approximated satisfactorily either by a power-law or an exponential function. Spatial "scanning" allowed us to find the regions in the samples with markedly differing functional forms of energy distribution. When localization of defect formation occurs, the energy distribution has a power-law behavior. We analyzed experiments in which formation of defects was disperse up to macrofracture. This fracture pattern was observed during deformation of water-saturated granite samples. The distribution remains exponential and does not change to a power-law function. The analysis of a functional form of energy distribution of AE signals obtained in the mining plants has shown that at the initial stages of fracture the distribution can be approximated by the exponential function. In the process of accumulation of defects the functional form of distribution becomes the power function. Not always the energy distribution is approximated by a power-law function. If fracture is disperse, the energy distribution is exponential. In the region of fracture localization the distribution becomes a power-law one. If the distribution is a superposition of the power-law and exponential functions, it is possible to find (by spatial "scanning") spatial regions in which the distribution is approximated by only one of the functions. The functional form of distribution at the early stages of loading allows one to reveal the spatial region of the sample in which localization of defect formation leading to eventual macrofracture will occur.

S301S1.04

S301S1 - Earthquake sources – modeling and forecasting

Oral

Uncertainty analysis of static coulomb stress change induced by earthquake: Case study from the 2008 Mw 7.9 Wenchuan, China, earthquake

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The Coulomb Failure Function (CFF) model for stress transfer and triggering is used a kind of physics-based forecasting model in the earthquake prediction experiments. Rapid calculation of the static Coulomb stress changes (ΔCFF) induced by the mainshock is an important tool to analyze the potential hazard followed the mainshock. However, some inputting parameters for the ΔCFF calculation are unable to be well constrained from laboratory experiments and field observations. Given different parameters may directly affect the ΔCFF pattern, such as the location and geometry of both source and receiver faults as well as the slip distribution on the source plane. Several researchers have calculated the ΔCFF induced by the May 12, 2008 Mw 7.9 Wenchuan earthquake and evaluated seismic hazards on the surrounding faults with different calculation models and parameters. However, their results demonstrate big differences in surrounding faults of the Wenchuan earthquake. The difference is not only in the size but also in the sign which can lead fatal errors on seismic hazard estimations. We take the 2008 Wenchuan earthquake as an example to systematically investigate the impact factors of the ΔCFF changes. We build the receiver matrix of our study area using the improved receiver faults method given by Toda et al. (2008, GRL) as a basic compared model. With changes of given parameters in the basic model, we discussed the impacts of different crustal models, earthquake slip models, projected depths, friction coefficients and the geometry of receiver faults to the ΔCFF calculations. We find that gravity, position and strike of receiver faults have little impacts on the ΔCFF calculation, but other parameters can change the value and sign of the results in various degrees especially around the earthquake rupture plane. Therefore the uncertainty analysis of the ΔCFF induced by earthquake should be taken into consideration of the CFF model for earthquake hazard analysis.

S301S1.05

S301S1 - Earthquake sources – modeling and forecasting

Oral

Radiation efficiency of earthquakes in the continental crust

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One of important questions in seismology is whether large and small earthquakes are governed by the same physics. Studies of earthquake scaling relations involve comparison of seismic moment M0 and radiated energy Es. Radiation efficiency of the earthquake is the ratio of radiated energy to the sum of radiated and fractured energies. This parameter is proportional to the normalized seismic energy. The question of whether radiation efficiency of earthquakes scales with moment or it is constant and doesn't depend on event size as for self-similar events is widely debated and is still essentially unresolved. We used Brune model to calculate normalized seismic energies values at various distances from events of wide ranges of magnitudes. The results of calculations show a brakedown of self-similar scaling for seismic events of small scale due to heavy attenuation of high frequencies. Thus the strong scale dependence of Es/M0 , (see for example Mayeda et al. 2005), may be an artifact and is not related to the physics of the source. However there is some scale effect due to the earthquake fault properties. Analyzing of the rupture energy budget we conclude that radiation efficiency can be expressed through of media properties and event scale. In particular, this parameter is determined by the product of the shear stiffness of the earthquake fault by its length. In linear case stiffness is inversely proportional to the fault length and radiation efficiency does not depend on the scale. We use the results of our measurements of fault stiffness's in a wide scale range to get empirical relations between earthquake radiation efficiencies and the fault lengths. We show that the efficiency of earthquakes do not depend on scale for little events. However we see a gradual increase of the efficiency for earthquake with intermediate magnitudes 7>M>3. These conclusions are supported by the results of seismological observations in several regions of the former Soviet Union.

S301S1.06

S301S1 - Earthquake sources – modeling and forecasting

Oral

Evaluation of coulomb stress changes from earthquake productivity variations after the 2010 earthquake sequence in Corinth Gulf

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The spatial variation of the static Coulomb stress field (ΔCFF) caused by the coseismic slip associated with the 2 moderate magnitude events in January 2010 in Corinth Gulf, Greece is investigated. The analysis is carried out by considering the changes of earthquake production rates. The data comes from a relocated catalogue with an adequate level of completeness before and after the main shocks occurrence. The spatial distribution of aftershock productivity is compared with the static stress changes due to the coseismic slip at different depths inside the seismogenic layer, defined from the vertical distribution of the aftershocks. Seismicity rates of the smaller magnitude events with $M \geq Mc$ for different time increments before and after the main shock are then derived from the application of a Probability Density Function (PDF). The differences between the earthquake occurrence rates before and after the main shock are compared and used as input data in a stress inversion algorithm based upon the Rate/State dependent friction concept in order to provide an independent estimation of stress changes. This model incorporates the physical properties of the fault zones (fault constitutive parameters, effective coefficient of friction, characteristic relaxation time,) with a probabilistic estimation of the spatial distribution of seismicity rates, derived from the application of the PDF. The stress patterns derived from the previously mentioned approaches are compared with each other and its correlation is quantified along with its confidence intervals. Different assumptions and combinations of the physical and statistical parameters are tested for the model performance and robustness to be evaluated. Simulations will provide a measure of how robust is the use of seismicity rate changes as a stress meter for both positive and negative stress steps in a complex and actively tectonic region.
This work was supported by the THALES Program of the Ministry of Education of Greece and the European Union in the framework of the project entitled «Integrated understanding of Seismicity, using innovative Methodologies of Fracture mechanics along with Earthquake and non extensive statistical physics – Application to the geodynamic system of the Hellenic Arc. SEISMO FEAR HELLARC

S301S1.07

S301S1 - Earthquake sources – modeling and forecasting

Oral

Variation of seismic activity before rockbursts

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The method of «seismic calm» is widely used for forecasting of strong natural earthquakes. The «seismic calm» means that during some time period before the main earthquake, the smaller events (with energies of 3-5 order smaller than that of the main earthquake) do not occur. In the presented paper the applicability of the method based on the idea of seismic calm for forecasting rockburst is considered. Three mine seismicity cases are analyzed: Tashtagol iron-ore mine, Vorkuta and Barentsburg coalmines. The catalogues of seismic events were processed and strong events were chosen for study. It was found that the number of seismic events with magnitudes M=0.5-1 decreased in a month before the main strong event (M=2.3) at Vorkuta coalmines. This event was not directly related with coal mining, its epicenter was located aside of coal mining area. In Barentsburg mine the rockburst was not so strong as in Vorkuta. The number of events with energies M=0.5 decreased slightly before the rockburst, but not so obviously as in Vorkuta case. The seismic events with high energies occur often at Tashtagol iron deposit. Mining methods used there differ from the coal deposit mining: the iron deposit is developed by blasting. Not all rockbursts occur immediately after the blasting, so, the problem of the rockburst prediction is important for mining safety. To find rockburst precursors it was necessary to separate the events occurred due to the block blasting from the seismic events due to relocation of stresses in the rocks. Only the events of the second type should be used if one is looking for the rockburst precursors. As the result of the analysis, the decrease of number of events with energies M=0.5 was noticed in 65% of considered cases. Meanwhile, some diminishing of the seismic activity was detected in all mines, so the «seismic calm» precursor of the strong rockbursts (which are not immediately follow the blasting) should be considered more thoroughly.

S301S2.02

S301S2 - Earthquake sources – modeling and forecasting

Oral

Retrospective test of an operational earthquake forecasting model for Canterbury

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Following the damaging Canterbury earthquake sequence commencing with the M7.3 Darfield earthquake of September 2010, a hybrid operational earthquake forecasting model is being used for decision-making on building standards and urban planning for the rebuilding of Christchurch city. The model estimates occurrence probabilities of magnitude $M \geq 5.0$ for the Canterbury region for each of the next fifty years. It combines short-term, medium-term and long-term forecasting models. Short term models include the STEP (Short-Term Earthquake Probability) and ETAS (Epidemic-Type AfterShock) models. Medium-term models include two versions of the EEPAS (Every Earthquake a Precursor According to Scale) model with different weighting strategies. The long-term models include several different smoothed seismicity models, which have regard to different periods of the instrumental and historical earthquake catalogues at different magnitude thresholds. Due to the very low seismicity rate in the region prior to the Darfield earthquake, there is a particulary wide variation among the long-term models. The weights accorded to each individual model in the operational hybrid were determined by an expert panel. The component models have been installed in the CSEP New Zealand earthquake forecast testing centre, in order to test the individual and hybrid models insofar as is possible from the existing earthquake catalogue. To that end, retrospective annual forecasts from 1987 on were made with time-horizons ranging from zero up to 25 years. We report on the performance of the individual and hybrid models at each time-horizon, where the performance is measured by the information gain i.e., the increase in the log likelihood, per earthquake compared to a model of least information. Two general conclusions are that the information gain decreases as the time-horizon increases, and that hybrid models tend to outperform individual models.

S301S2.03

S301S2 - Earthquake sources – modeling and forecasting

Oral

Global large-earthquake forecast based on five tectonic categories

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We constructed a testable global forecast by combining two published results: a high resolution, long term forecast of moderate and larger earthquakes by Kagan and Jackson [2011]; and a set of magnitude distribution functions for five tectonic categories covering the entire earth, by Kagan et al. [2010]. The moderate earthquake forecast predicts the rate of earthquakes at magnitude 5.0 and larger on a 0.1 by 0.1 degree grid covering the whole earth. The set of magnitude distributions assumed a three-parameter “tapered Gutenberg-Richter” distribution for each of 5 tectonic categories. The three parameters were chosen to fit the rate of observed magnitude distribution and the tectonic deformation rate for each category. By combining the two results we constructed a magnitude-specific forecast of the earthquake rate at each of the 0.1 by 0.1 degree pixels. We’ve tested the forecast retrospectively at magnitude thresholds 7.0, 7.5, 8.0, 8.5, and 9.0 using a likelihood test on catalogs of 5 years and longer duration. The likelihood distributions for observed events were consistent with those predicted by the forecast in every case. Because our forecast was based on the spatial distribution of magnitude 5.0 and larger events, the retrospective success of our forecast suggests that the locations of frequent, moderate earthquakes provide reliable information on the locations of larger ones. Confirmation of this conclusion will of course require a prospective test, which is now possible through the auspices of the Collaboratory for Study of Earthquake Predictability.

S301S2.04

S301S2 - Earthquake sources – modeling and forecasting

Oral

New Zealand map of expected earthquakes for 2011-2015: Results of 2011-2013 monitoring

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The first results of the MEE algorithm for medium-term earthquake prediction in New Zealand were represented at the General Assembly of IUGG in Melbourne in July 2011. We analyzed a series of maps of expected earthquakes (MEE) for different 5 year time intervals (time interval for prediction). In this work the New Zealand regional catalog of earthquakes for 1980-2010 compiled by GeoNet Project (http://www.geonet.org.nz) was used. The results showed that 34 out of 40 (85%) of large earthquakes with M5.5+ and their groups occurred in areas where the level of conditional probability was 70%. In this case it was found that waiting area was about 48% of the total square of seismically active zone. The most recent map of expected earthquakes in this series has the forecast period 2011-2015. Exactly it is a subject for discussion in the report. Over the past two-plus years there have been 14 earthquakes with M5.5+ in the region under consideration. Among them 10 events were occurred during 2011 in an epicentral zone of Christchurch EQ 3/09/2010, M=7.1. They can be considered as its aftershocks and excluded from further consideration. Two pairs of the remaining events occurred in areas with the level of the conditional probability of more than 90% (in the south) and more than 70% in the north. The results of investigation once again confirm opportunities of MEE algorithm for the medium-term forecast of strong earthquakes. Work is partly supported by the grant of the Russian Foundation for Basic Researches # 12-05-00779 and by the grant NSh-5583.2012.5 “Physics and Prediction of Earthquakes” under the Program of state support for scientific schools.

S301S2.05

S301S2 - Earthquake sources – modeling and forecasting

Oral

Extension of scaling relations of seismic moment, source and asperity areas, and average slip to M9-class earthquakes

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We compiled seismic moment (M_0), rupture area (S), average slip (D) and asperity area (Sa) of seven M~9 earthquakes (the 2011 Tohoku, 2010 Chile, 2004 Sumatra-Andaman, 1964 Alaska, 1960 Chile, 1957 Aleutian and 1952 Kamchatka earthquakes) and compared them with the previously-proposed scaling relations for plate-boundary earthquakes with M~6 to 8 (Murotani et al., 2008, Earth Planets Space). The scaling relations $S = 1.48 \times 10^{-10} M_0^{2/3}$, $D = 1.48 \times 10^{-7} M_0^{1/3}$, $S\mathrm{a} = 2.89 \times 10^{-11} M_0^{2/3}$ and $S\mathrm{a}/S = 0.2$ are applicable to the M~9 megathrust earthquakes, and can be used for prediction of future tsunami heights. However, for the strong-motion prediction, Strong Motion Generation Area may need to be considered (e.g., Miyake et al., 2003, BSSA).

The slip models for the M~9 earthquakes used in this study were estimated by the common method using tsunami data with geodetic data if available. We defined the rupture area as the areas of subfaults with slips more than 0 m, computed the average slip, and defined the asperity as subfaults with slips more than 1.5 times of the average slip. When the slips on subfaults of each earthquake were arranged in descending order, they showed an exponential distribution. This may indicate that every earthquake has a self-similar structure. The largest slip was 38 m of the 2011 Tohoku earthquake, followed by the 1960 Chile earthquake (30 m) and the 2004 Sumatra-Andaman earthquake (25 m). The maximum slip was two to four times of the average slip. The total area of subfaults with average or larger slip was 25-52 % of the rupture area, while the asperity area was 16-32 %.

S301S2.06

S301S2 - Earthquake sources – modeling and forecasting

Oral

Modeling the 2013 North Aegean (Greece) seismic sequence

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The 8 January 2013 Mw5.8 North Aegean earthquake sequence took place on one of the ENE–WSW trending parallel dextral strike slip fault branches in this area, in the continuation of 1968 large (M=7.2) rupture. The source mechanism of the main event indicates predominantly strike slip faulting in agreement with what is expected from regional seismotectonics. It was the largest event to have occurred in the area since the establishment of the Hellenic Unified Seismological Network (HUSN), with an adequate number of stations in close distances and full azimuthal coverage, thus providing the chance of an exhaustive analysis of its aftershock sequence. The mainshock was followed by a handful of aftershocks with M>4.0 and tens with M>3.0. Relocation was performed by using the recordings from HUSN and a proper crustal model for the area. Investigation of the spatial and temporal behavior of seismicity revealed possible triggering of adjacent fault segments. Theoretical static stress changes from the mainshock give a preliminary explanation for the aftershock distribution aside from the main rupture, as well as triggering of seismicity in the adjacent fault segments, providing evidence for future seismic hazard. In an attempt to forecast occurrence probabilities of the strong events (Mw≥4.0), estimations were performed following the Restricted Epidemic Type Aftershock Sequence (RETAS) model, applied to data samples before each one of these strong events. Stochastic modeling was also used to identify ‘quiescence’ periods before the examined aftershocks. Real aftershock rate decrease before the next strong shock, compared to the modeled one, was not found for all examined cases, a result revealing that rate decrease is not a clear precursor of strong shocks in the sequence.

S301S2.07

S301S2 - Earthquake sources – modeling and forecasting

Oral

Estimation of errors of small events magnitudes calculations

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We use a dislocation model of Brune to evaluate some potential errors sources of magnitude and source parameters of small seismic events. We show that the main errors are caused by the distortion of the spectrum of recorded seismic waves in comparison with source spectrum because of the absorption of high frequencies. One can expect an essential underestimation of the values of magnitudes of small events at distances of several kilometers, and the value of this underestimation increases with the distance.

More undervalued magnitude is M_E calculated for small events on the base of seismic energy by the use of integrating of the waveforms. Some of the best results can be expected by using the spectral approach of estimation the value of seismic energy.

A limited frequency band of the apparatus accounts for the additional errors in determining the source parameters. Calculations performed for the seismic type SM-3, widely used in Russia, have shown that the use of these sensors at regional distances can lead to a significant underestimation of the peak ground velocities. We propose the way of the numerical correction of seismograms on the basis of the method of multiplying the frequency response. This procedure almost completely recovers the true values of the ground motion.

Comparison of the results of the calculations with the data obtained in several regions of Russia shows a good agreement.

S301S2.08

S301S2 - Earthquake sources – modeling and forecasting

Oral

Application of stochastic tools for the investigation of recent seismicity properties in Corinth Gulf (Central Greece)

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Accurately located earthquakes regard a fundamental criterion, for the application of stochastic methodologies on complete seismicity data sets for identifying possible correlation between the occurrence of events and their tend to form clusters. The asymmetric graben of Corinth Gulf, which is located in Central Greece and exhibits high seismicity through time is investigated. Corinth Gulf is considered to be one of the most active seismogenic zones with evidenced clustering and numerous earthquakes occurring close in time and space. In this study there is an attempt to quantify clustering using stochastic tools and investigate spatial, temporal or magnitude relation between earthquakes. The statistical properties for events, which occurred since 2000 and were relocated, are employed in the current analysis. The statistical properties of seismicity are determined through the application of stochastic tests such as the Modality and the Bump – Hunt smoothed bootstrap tests, aiming to identify the complexity of the magnitude distribution. The distribution of inter-event time and inter-event distance of concurrent events which belong to both clustered and de-clustered catalogues are examined. For this reason complete earthquake catalogues of recent seismicity were compiled. The fractal dimensions for these parameters were calculated and the results were used in order to reveal seismicity clustering and any prevalence of certain fault zones in the region. A combination of the outcoming results is attempted in order to provide implications regarding the seismicity properties of the entire region and fault attributes bounding the graben of Corinth Gulf. This work is co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program «Education and Lifelong Learning» of the National Strategic Reference Framework (NSRF)-Research Funding Program: HeracleitusII.

S301S3.01

S301S3 - Earthquake sources – modeling and forecasting

Oral

Short-term precursory foreshock activity: observations and spring-block modeling

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A global overview of foreshock sequences indicates that: (1) in well monitored areas foreshocks are detected in about 50% of strong, shallow mainshocks; (2) foreshocks occur up to a few weeks before the mainshock but mainly in about the last ten days; (3) the event rate tends to increase with the inverse of time towards the mainshock; (4) the b-value usually drops with respect to b in aftershocks or in the background seismicity. These features imply that precursory quantitative changes related to foreshocks may indicate the place and approximate time of mainshock. However, no quantitative relations were found so far between mainshock magnitude, M, and foreshock area, A. This is investigated in Greece, Italy, Japan and S. California. Systematic search for the spatial extend of event rate and b-value changes before the mainshock showed that A increases systematically with the increase of M. This opens prospects for the prediction of mainshock magnitude. A critical change in foreshock sequences is that of b-value. To investigate further this issue we examined the role on seismicity of fault characteristics, such as the strength of coupling and fault geometry. The asperity model stipulates that instead of smooth planar fault surfaces most of coupling is concentrated to the contact between irregularities of the fault surfaces. As a result the tectonic stress is accumulated in the real contact area, than in the total fault area. We introduce a modification of the OFC spring-block model for the dynamic evolution of faults due to the real contact areas of asperities. Through simulation experiments, it is shown that for a wide range of model parameters there is a clear monotonic relationship between the real contact area of asperities and the corresponding power-law exponent b. As a result, based to the proposed model, the different macroscopic b-values can be mapped by different asperity distributions within the fault.

S301S3.02

S301S3 - Earthquake sources – modeling and forecasting

Oral

The extremely-shallow 2012 earthquake swarm in McAdam, New Brunswick, Canada

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In March of 2012 hundreds of inhabitants of McAdam, New Brunswick, reported feeling and/or hearing many earthquakes just within a 1-2 km area of the village. The larger of these (Mw<~01.aug; Mw's are estimated from local magnitudes) were recorded by regional seismographs, the closest being GGN at 65 km. Because of the numbers of felt events, their localization, and public concern despite their small size, the GSC deployed weak and strong motion instruments, initially at 3 sites about 1.5 km apart. The University of New Brunswick later deployed a broadband seismograph at a 4th site. Activity died off into April-June, but events are still being felt in January 2013. The GSC instruments were removed in August and the UNB instrument in January 2013. The smallest felt event was Mw -1, and it is likely the ~50+ events reported felt include many earthquakes Mw <zero. 29 earthquakes, all reported felt and all Mw <1.8, were located, some with 3+ stations allowing precise depth determination. All the earthquakes were extremely shallow (depth range 0.0-1.2 km; median depth 0.4 km). Epicentres lie in a WNW-ESE trending ellipse. A well-constrained composite focal mechanism indicated thrust faulting in response to the regional NE-SW compression. A strong motion recorder captured PGA=9%g from a Mw~1.0 earthquake with S-P=0.10 s (about 0.8 km hypocentral distance; depth=0.27 km), validating the felt reports as being sharp bangs and explosion-like. There was no human activity that could have induced or triggered the swarm. McAdam sits on Silurian metasediments intruded by the granitic Pokiok Batholith exposed just to the NW. No faults are mapped close to McAdam, but the major NE-striking Fredericton fault lies ~5 km to the SE, and could have a NW- SE splay. Further analysis to refine the depths, identify the rupture plane, and categorize events into families is underway. Swarms like this are probably common in eastern Canada, but are seldom this well reported or recorded.

S301S3.03

S301S3 - Earthquake sources – modeling and forecasting

Oral

Anomalous seismicity and estimates of future earthquake in Western Nepal Himalaya and vicinity

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Three medium size earthquakes of 1980 (mb 6.1), 1984 (mb 5.6) and 1999 (mb 6.6) occurred in the Western Nepal and its adjoining Indian region were preceded by well defined patterns of anomalous seismicity/ precursory swarm. The first of these was the Bajhang earthquake of which most of its preparatory processes during 1967-1980 were confined approximately in the central part of the area between the MCT and the MBT. Subsequently the seismic activity shifted towards east in the northeast-southwest direction which produced another mainshock of 1984 (mb 5.6). Seismic activity started concentrating in and around Chamoli area (India) since 27 November 1995 which was preceded by a quiet low seismicity in the region. After Chamoli earthquake in 1999, a low seismic activity was observed in the region which continued for the next two years till 14 April 2001. We investigate seismicity data from 1999 to 2006, and observed two additional cases of characteristic seismicity patterns in 1999-2006, and 2003-2006. In these two cases, though the anomalous seismicity exists, no mainshock has occurred so far. After critical analysis of the data, it is observed that the seismicity from 1999 onwards fluctuates in the order as low-high-low phases. The occurrence of the earthquake swarm sequence followed by quiescence with a significant low seismicity, which is still continuing, is an indication of the existence of the anomalous seismicity gap in the region. The study suggests that the parts of the Western Nepal and the adjoining region are potential for the future medium size earthquakes

S301S3.04

S301S3 - Earthquake sources – modeling and forecasting

Oral

The earthquake temporal distributions and the variation of the Earth rotation angular velocity

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The analysis of the connection between a cyclic increasing and decreasing of the seismic activity (SA) and variation of the Earth rotation angular velocity was carried out. The periods of the SA was compared for different latitudinal belts of the Earth. The variations of the seismicity for the events with M>=7.0 from 1900 up to date were under study. The catalog NEIC (USGS) was used. The entire range of observations was subdivided into 5-year intervals. The temporal earthquake (EQ) distributions were calculated separately for eight latitudinal belts (wide 15°). Separately were analyzed: the EQ with M>=8 and with 7 <=M <8. The temporal analysis of the seismicity for 1700-1900 was also fulfilled on qualitative level. The data base IERS and data from the work [Morrison, 1973, Nature] was used to compare the variation of the Earth rotation angular velocity from 1676 to 2012 years. The clear expressed peaks and decays of the SA (with M>=8) were marked in temporal EQ distributions for all studied latitudinal belts. Two peaks of activity (1900-1925 and 1935-1955) observed for latitudinal belts 60°-45°N (45°-30°N). The average number of the EQ in these time intervals are equal to 6 (5.8) and 3 (3.5) events per 5-year interval respectively. After that the decay of the seismic activity (1970-2010) with average number of the EQ equal to 0.2 (0.7) per 5-year follows. It was shown, that the sharp peaks of the SA correlate in time with the periods of the increasing of the absolute value of the gradient of the Earth rotation velocity (for example in period 1905-1920). The peaks and decays of the seismicity do not coincide in time for different latitudinal belts and especially for the belts located in Northern (NH) and Southern hemispheres (SH). The existence of nonrandom component in temporal distributions of the EQ between NH and SH was marked before [Sasorova et al, 2006]. The mathematical-statistical model was proposed, which is in a close accord with observation data.

S301S3.05

S301S3 - Earthquake sources – modeling and forecasting

Oral

Afterchock's process temporal and power parameters of the Kuriles-Kamchatka earthquakes

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Aftershock sequences of 32 strong and moderate Kuriles-Kamchatka earthquakes in magnitude interval 5.3 < MW < 8.3 were considered. The duration in time Taft (in days) and total scalar seismic moment M0cum aft, liberated during aftershock process development have been estimated. The information base for Kamchatka earthquakes was the Regional catalogue of Kamchatka earthquakes, and for Kuriles - the Operative seismological catalogue of Geophysical survey of Russian Academy of Science and the Earthquakes Catalogue of geological service of USA (NEIC). Also Catalogue CMT and the Unified catalogue of earthquakes of Northern Eurasia (Ulomov, Kondorskaia) have been used. Transition from magnitudes of the weak and moderate earthquakes to the scalar seismic moment (M0) was carried out on the available or specially received correlation dependences. For strong (MW > 5.5) earthquakes the scalar moment was taken directly from catalogues CMT or Geological survey of USA. The criterion of the aftershock process termination was its output on a background that has been defined, as a rule, on a time series of the scalar seismic moment liberation. Correlation dependences between log (M0cum aft) and log Taft (in days) from magnitude of the main event MW have been received in the form of: Log10(M0cum aft) = 1.554MW + 7.10 RC = 0.931 Log10 Taft = 0.645 MW - 2.394 RC = 0.879 As to aftershock process relative intensity, defined as ratio M0cum aft/M0ME (M0ME - the scalar seismic moment of the main event) any significant dependence of this parameter from MW has not been revealed. It is possible to note only, that it changes in rather wide limits 0.0038 < M0cum aft/M0ME < 0.234. In summary we shall note, that the similar estimations received for other regions of the Earth, will show, possibly, correlation communication close on RC value between log (M0cum aft) and log Taft on MW, but the parameters of similar dependences can essentially differ from resulted above.

S301S3.06

S301S3 - Earthquake sources – modeling and forecasting

Oral

Seismicity variations as a result of critical latitude effect and the Earth rotation instability

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The spatial-temporal analysis of the earthquake (EQ) number with M>=7 since 1900 to 2012 was fulfilled for eight latitudinal belts of the Earth. Worldwide catalog NEIC (USGS) was used. Two magnitude diapasons: 7<=M<8; 8<=M; and the following belts: 60°-45°N, 45°-30°N, 30°-15°N, 15°-0°N, 0°-15°S, 15°-30°S, 30°-45°S, 45°-60°S were considered. Above 40% of all events with M>8 had occurred in the middle latitudes of the Northern hemisphere (60°-30°N) and about 30% in the Southern hemisphere (15°-45°S). About 10% of the EQ located in each subequatorial belt in both hemispheres (0°-15°N, 0°-15°S). The EQ with M>=7 did not observe in high latitudes. The analysis of the shape of ellipsoid of revolution and similar figures (using works of Maclauren, Newton and Kelvin-Leibenzon) and the study carried out by authors had shown, that the geoid is possessed the critical latitudes in the both hemispheres (near ±35°). The changes of the angular velocity had to lead to pulsations of the spheroid with fixed location of the critical latitudes. Just in these latitudes take place: the maximums of inertia moment gradients, the qualitative changes of total curvature of the spheroid shape and the abrupt conversion from compression zone in the polar caps to extended zone in subequatorial area. The observed latitudinal amplification of the seismic activity in the belt 45°-30° can be explained in frame of the pulsating geoid model. The clear expressed peaks and decays of the seismic activity were marked in temporal EQ distributions for all studied latitudinal belts. The EQ average number per 5-year interval was determined. This value is equal to 26.4 EQ for period 1905-1925 and it becomes equal to 5.6 in period 1955-2010.The observed periods of the seismicity amplification were in coincidence with fixed period of increasing of the absolute value of the Earth rotation velocity gradient. The database IERS was used for calculation of the Earth rotation velocity gradient.

S301S4.01

S301S4 - Earthquake sources – modeling and forecasting

Oral

Early aftershocks statistics as a tool to study stress changes

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Models of aftershock occurrence predict a delay of the power-law decay (Omori law) depending on stress heterogeneity caused by the main shock positively depending in its term on the stress accumulated prior to the main shock. For example, the Limited Power Law (LPL) model explains the Omori law as a superposition of many exponential decays with various characteristic times. The larger is the distribution of the stresses in the area of aftershocks, the larger is the duration of the power-law behavior. However, this power-law behavior is limited both at short and long times. For short times, in case the stress heterogeneity is not large (the pre-seismic stress was not high) a deficit of long characteristic times causes a delay of the power-law behavior. This delay may be measured by constant c in the Omori-Utsu law. The larger is c-value, the smaller are the pre-seismic stresses. A set of observations confirmed this hypothesis. In this talk we focus on most recent findings.

First, we study the dependence of the c-value on the focus depth together with subdividing main shocks in different faulting styles. Dependence of the c-value on the focal mechanisms was demonstrated in earlier studies. This dependence remains similar at different depth: c-value is lower for thrusts, higher for normal faults and intermediate for strike slips. C-value for all faulting styles decreases from the surface to the depth of about 5 km. At deeper layers the changes become less contrast, and the amplitude of the changes due to different focal mechanisms differences of the c-value decreases.

Next, we demonstrate that the 4-years independent test of the EAST earthquake forecast model, based on the discussed phenomenon, shows good results. The most of earthquakes of magnitude 4 or higher in California have occurred in sites of low c-value. During four years of the test in CSEP testing center the model demonstrated significantly better performance relative to a standard reference RI model.

S301S4.02

S301S4 - Earthquake sources – modeling and forecasting

Oral

Dynamic rupture models incorporating realistic complexity in fault geometry, stress state, and surrounding material setting

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Modeling studies of earthquakes often isolate the effects of a single parameter or type of input complexity on the overall rupture behavior. However, earthquakes in the real world involve many types and scales of complexity, such as large- and small-scale nonplanar fault geometry, regional- and fault-scale stress state, and hetereogeneous material setting around the fault. Using the 3D finite element method, we build a dynamic rupture model that incorporates many of these different types of complexities, in order to determine their individual and cumulative effect on rupture behavior and the resulting ground motion. We use a stepover on the San Jacinto Fault, southern California, as our model system because it has geometrical complexity on many scales, and because the surrounding materials are very heterogeneous. We draw our fault geometries from the USGS Quaternary Fault Database, our material properties from the SCEC Community Velocity Model, our regional stresses from seismicity literature, and our small-scale stress complexities from a self-similar random distribution. We find that, as we incorporate more types of complexity, the specific effects of any individual type of complexity become less apparent within the overall rupture behavior. That said, we still find that fault stress complexity, which is strongly modulated by complexity of fault geometry, has the strongest control over where rupture terminates. The effects of a heterogeneous material setting are far more apparent in the ground motion. Overall, the combined effect of all of the modeled heterogeneities not only prevents rupture from jumping the larger stepover, but even from propagating through the entirety of either of the two main fault strands. Directivity effects are apparent in the ground motions, but the strongest shaking occurs in the modeled sedimentary basins, to the point where basin sites further from the fault may shake stronger than sites that are directly on the fault in harder rock.

S301S4.03

S301S4 - Earthquake sources – modeling and forecasting

Oral

The dynamic system parameters that form the observed variations of geophysical fields at different time scales

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In this paper, the behavior of the three main parameters of invariant dynamic system - the correlation dimension D2 , the dimension of the state vector of the system N and the correlation entropy K2 of volumetric strain during the long-term observations in Parkfield, California is considered. These parameters were estimated in series of individual components at different time scales with the sampling period from 10 minutes to 1 day. In addition to volumetric strain, the continuous series representation of the seismic parameter as the component of the cumulative series of earthquake energy was analyzed.

With the growth time scale of series, the volumetric strain indicate a decrease D2 , but in the case of seismic parameter, this parameter increase. The opposite changing may be due to the seismic data shortage at small time scales. Another future is that on the large scales (dt > 19h), the correlation dimension of seismic process is higher than the dimension of the volumetric strain. A similar pattern is observed in the analysis of the system equations dimension that forms the observed processes N .

Available seismic data's of the region allow to estimate K2 . The obtained values can be represented by the power law.A similar calculation is performed according to the variations of the volumetric strain at the station PK DLT. The dependence indicates different exponents in short and long time scales. Exponents for the systems, which form the variation of deformation and seismicity in large scale have similar values. Higher values K2 on the short scale confirm the previously allocated feature of D2 and N for this scale range. We can assume that on the short scales (dt< 5 h), there are influence of additional factors, which take part in forming the observed variation of volumetric strain.

The analysis of the dynamic systems of geophysical fields shows the propriety of the joint changes of D2,N,K2 in different time scales.

S301S4.04

S301S4 - Earthquake sources – modeling and forecasting

Oral

The law of seismic entropy production and monitoring of strong earthquake: by example of seismic system Sakhalin

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The development of strong earthquakes in the geological medium is studied by introducing the large-scale specific volume of the lithosphere (the seismic system) with the segments of active faults that can potentially generate the strong earthquakes. The system is considered to be well definite if it satisfies the law of seismic entropy production. This critical regularity controls a non-equilibrium dynamics which allows determine the ensemble of strong earthquakes with minimal threshold magnitude. The monitoring of strong earthquakes preparation used the concept of cumulative energy and seismic entropy calculated by statistics of seismicity. Such approach allowed transferring the description of real seismic processes in a mathematical plane, which is expressed in the construction of trajectory and energy diagrams. Preparation of the earthquake is depicted by step trajectory, which ultimately falls into the attractor and ends by strong earthquake. Trajectory diagram makes it possible to forecast the different manifestations of seismicity before the strong earthquake. Monitoring of the attractor is made also on the basis of the dynamics growth of probability of energy and entropy in seismic cycles. The results are illustrated by the example of the SS Sakhalin. We also present here the attractors for the hierarchy of seismic systems in Sakhalin forming ensembles of strong earthquakes with the threshold magnitudes M_{th} equal to 5.6 and 6.2. It is shown, that in the preparation of the ensemble of strong earthquakes in Sakhalin play a crucial role indicator earthquakes in the magnitude window $M_h \leq M < M_{th}$, ($M_h = 4.3$), were cumulative number of indicator earthquakes are not correlated with the Gutenberg-Richter empirical law and occur randomly. The phase portrait (spiral diagram) for the preparation of separate strong earthquake from ensemble is also examined.

S301S4.05

S301S4 - Earthquake sources – modeling and forecasting

Oral

Determination of dynamic parameters of earthquakes in relevance to development of stress reconstruction method, by the data on North Tien Shan territory

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KNET seismological network which consists of 10 digital broadband stations installed at the territory of Northern Tien Shan provides registration of local seismicity and determination of kinematic and focal parameters of the earthquakes. Moreover this network allows determination of earthquakes dynamic parameters as well as the main data for catalog (time of event occurrence, parameters of the hypocenter, event magnitude and/or energy), and focal mechanism data. Partially motivated by that the evaluation of dynamical parameters (especially the stress drop) can contribute to problem of Crust stress reconstruction by method of cataclastic analysis of discontinuation displacement (CADD, Yu.L. Rebetsky) we developed new programs to determine dynamic parameters by KNET seismograms. Both: site- effect and change in the spectrum while propagation of waves have been taken into account. New approach has allowed the computation of the radius of the shock source («Brune radius»), seismic moment (M0), and stress drop ($\Delta\sigma$) for the earthquakes of moderate magnitudes (the energy class is from 11-to 13).

The results presented in given work involve the evaluations of dynamic parameters for of 14 earthquakes occurred at the territory of Northern Tien Shan in 1998-2009. Also we determined focal mechanisms, and used their parameters to specify kind of stress-strained state of the Crusted.

The results obtained have revealed a scattering of values of the source radius and stress drop even for earthquakes of close energy class. The range of $\Delta\sigma$ is from several tens of MPa to some units of MPa. It is worth to remark that no strong earthquake (with class exceeding 14) took place during studied period on a territory inside polygon of KNET stations.

The research has partially been supported by: grants of RFBR, the project 12-05-00234-à and Basic Research Program of the Presidium of the RAS ¹14, Project ¹ 4.4.

S301S5.01

S301S5 - Earthquake sources – modeling and forecasting

Oral

The mechanism analysis of the Guza station borehole strain's wave phenomenon before the 2008 MS8 wenchuan earthquake, China

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Guza station is located in the cross zone of *Longmen Mountain* fault and the *Xianshuihe* fault. The distance between *Guza* station and the MS8 Wenchuan earthquake in 2008 is 200km. *Shimian* station is located in the southern of *Guza* station, the distance is 90km, which is in the *Xianshuihe* fault. *Guza* station and *Shimian* station are near to the *Dadu* River. Before the 2008 Wenchuan earthquake, the borehole strain of *Guza* station and water level observation of *Shimian* station appeared wave phenomenon, the period of these wave are about 3-5 days. This paper is base on the *Guza* borehole strain data and atmospheric pressure, temperature, rainfall and the *Shimian* water lever observation data, using the method of regression analysis and plane strain model to explain the wave phenomenon of the *Guza* borehole strain before the Wenchuan earthquake. The results showed that: 1st,the four component borehole strain self-checking results of *Guzha* station is good, showed that the observed wave before the earthquake is the reflection of the crustal strain change; 2nd, the regression correlation between the *Guza* station borehole strain and the rainfall is larger, the atmospheric pressure's correlation coefficient is small, indicated that the years periodic variation we observed maybe more affected by rainfall influence, less affected by pressure; 3rd,using the borehole strain of *Guza* station and the water level of *Shimian* station, we built a planar load strain model. the inversion calculation result showed that, the wave phenomenon of *Guza* station borehole strain before the earthquake is mainly caused by *Dadu* River water level changes. The relationship between the 2008 MS8 Wenchuan earthquake and the wave phenomenon is not significant.
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S301S5.02

S301S5 - Earthquake sources – modeling and forecasting

Oral

Multifractal variability in Very Low Frequency (VLF) signal during some recent earthquake

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The subionospheric VLF signal transmitted from Bafa (TBB) transmitter, Turkey (geographic coordinates:37°24'N, 27°19'E) was continuously received at Sudden Ionospheric Disturbance (SID) Monitoring station located in South of France (AAVSO observer code -A118). The data was analyzed during two year period for the earthquake (M>5) occurred inside the Fresnel zone of VLF path during 2011-2012. To clarify the possible effect, we used a wavelet-based multifractal method of data analysis, which was very useful for long term time series analysis. We found specific dynamics of their fractal characteristics before the earthquake, appearance of sudden fluctuation and increase of the fractal dimensions, which began a few days before the main shock and probably continued a few days after it. It is possibly due to increase of the regular electric field due to intensification of planetary waves by seismically influenced atmospheric turbulence during the earthquake.

S301S5.03

S301S5 - Earthquake sources – modeling and forecasting

Oral

An earthquake (M ≥5) on its way (as on Dec. 2012) at Koyna, India: hydrochemical precursors suggest

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Even after decades of earthquake research worldwide, earthquake forecast is still an enigma, primarily because of complex processes involved (both short and long term) in the earth's crust at deep as well as shallow depths. Present study is an effort in understanding the relation between hydrochemical precursors and seismicity, if any, in an area believed to be influenced by the Reservoir in the stable continental part of India. Periodic hydrochemical and isotopic measurements are being carried out since last 8 years in 15 bore wells (100 to 250 m) specially drilled for seismic related studies. Two M 5.1 earthquakes (March 2005 and December 2009) occurred during the study period indicated precursory hydrochemical anomalies in some of the observation wells. The recorded anomalies had a quiescence time of about 1.5 years after the earthquake and dropped down to background level (~4 times reduction of peak values) with in a very short time. The hydrochemical anomalies in the form of progressive temporal increase from the background level made it possible to project, during March 2009, the possible future earthquake of M ≥ 5 which was realized on 12-12-2009. A mixing model is hypothesized to explain the observed precursory anomalies and validated with the field data. The piezometric head of the confined aquifer and regional tectonic stress are the main factors controlling the mixing of different waters, and verified with EC depth profiling in the wells several times. The cyclic pattern of the recorded precursory anomalies over the study period suggests another earthquake of M ≥ 5 is on its way since Sep. 2011.

S302PS.01

S302PS - Earthquake prediction research

Poster

Evaluation of two years of prospective short-term M≥4 earthquake probability forecasts for California and Western Nevada

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This study evaluates three different 5-day earthquake probability forecasts of M≥4.0 mainshocks for California and western Nevada that were issued prospectively in 2007 and 2008. The first forecast model was based on observations of excess short-term clustering of mainshocks in the region relative to a Poisson process for the M≥4.0 mainshock seismicity of the area from 1932 to 2006. The second forecast model was based on a Hidden Markov Model (HMM) of the seismicity, where the HMM was used to compute the probabilities of different spatial and temporal states of the seismicity based on the past seismicity. The third forecast model was based on a purely Poissonian distribution of the temporal behavior of the seismicity. The study area was split into eastern and western regions, divided by a line from the central San Joaquin Valley to the Imperial Valley. Separate forecast probabilities were issued for each region. Cumulative log-likelihood ratios indicate that the first two forecasting methods both outperformed the Poisson model forecasts, although the improvement over the Poisson model was small. Some details of the first forecast model were not verified by the forecasts. The average rate of M≥4 mainshocks during the forecast periods was much greater than expected. Also, contrary to the forecast model, more mainshocks took place during the winter and spring compared to the summer and fall, and the rate of mainshock seismicity in the western region exceeded that of the eastern region. The spatial patterns of the forecast earthquakes were not well replicated by the observations. The results of the analyses indicate that short-term temporal clustering of M≥4 mainshocks in California and Nevada is greater than that expected from a Poisson model but that there are significant variations in the average rate and spatial pattern of this seismicity with time.

S302PS.02

S302PS - Earthquake prediction research

Poster

Physical aspects of earthquake preparation, deformation and stress forecasting for Vrancea (Romania) seismic source

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Vrancea seismically active region of Romania is known for large and destructive intermediate-depth earthquakes. Attempts at earthquake predictions in the past, based on statistical considerations only, failed. On the other hand, valuable observations that fault- plane solutions of small and moderate events offer information on the window of time for the next large earthquake have been forgotten. Our data suggest geophysical measurements of any kind performed at the Earth's surface based on investigation of large volume of rocks are not able to indicate small conductivity variations in the focal region at 100-150 km depth. However, before the intermediate-depth earthquakes the stress is transmitted to the Earth's crust and amplified around faults. Shear-wave splitting (SWS) around a fault has been discussed in the literature as method to indicate stress variations before earthquakes at a large distance from the focal region. The same idea can be used for magnetotelluric (MT) phase splitting (MTPS). MTPS is the electromagnetic equivalent of MWS. MTPS is a consequence of spatial differences or gradients in conductivity, not the intrinsic bulk properties of the conductivity tensor itself, and in this respect is fundamentally different from SWS. Our bio-location variations recorded around a fault in crust as a precursor of intermediate-depth earthquakes in Vrancea and some anomalies of the horizontal component of geomagnetic field can be explained by MTPS. Our data at present are able to perform a stress forecasting but are not sufficient to solve the problem of earthquake prediction in Vrancea. Future programs based on a multitude of physical parameters might clarify the preparatory process of large and destructive earthquakes with the hope of a successful earthquake prediction.

S302S1.01

S302S1 - Earthquake prediction research

Oral

Predicting predictable about earthquakes

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The quality of a fit of a trivial or, conversely, delicately-designed model to the observed natural phenomena is the fundamental pillar stone of any forecasting, including seismic hazard assessment, earthquake forecasting, and prediction. Using precise mathematical and logical systems outside their range of applicability can mislead to scientifically groundless conclusions, which unwise application can be extremely dangerous in assessing expected risk and losses. Are the relationships that are commonly used to assess seismic hazard enough valid to qualify for being useful laws describing earthquake sequences? Seismic evidences accumulated to-date demonstrate clearly that most of the empirical statistical relations commonly accepted in the early history of instrumental seismology can be proved erroneous when testing statistical significance is applied. The time-span of physically reliable Seismic History is yet a small portion of a rupture recurrence cycle at an earthquake-prone site. Seismic events, including mega-earthquakes, are clustered displaying behaviors that are far from independent. Their distribution in space is possibly fractal, definitely, far from uniform even in a single fault zone. Evidently, such a situation complicates design of reliable methodologies for earthquake hazard assessment, as well as search and definition of precursory behaviors to be used for forecast/prediction purposes.

The situation is not hopeless due to available geological evidences and deterministic pattern recognition approaches, specifically, when intending to predict predictable, but not the exact size, site, date, and probability of a target event. Understanding the complexity of non-linear dynamics of hierarchically organized systems of blocks-and-faults has led already to methodologies of neo-deterministic seismic hazard analysis and intermediate-term middle- to narrow-range earthquake prediction algorithms tested in real-time applications over the last two decades.

S302S1.02

S302S1 - Earthquake prediction research

Oral

Monitoring crustle processes by use of absolute stress tensor field observations

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A method for estimating the complete stress tensor at the hypocenters of obsereved microearthquakes has been designed and tested on data from the Icelandic IMO seismic network. It is based on two central assumptions: - the crust is assumed to be highly fractured at all scales, and, - the stress field is allowed to be quite inhomogeneous (all earthquakes strocngly affects the stress fields in their cloce vicinity). The method will be described and motivated. Examples of use of the stress field for earthquake warnings in Iceland will be shown, the dramatic stress increases before the vulcanic eruptions in Iceland 2010 will be shown, an example of the stress field before a M=3.2 event in the Geyser geothermal area in California will be shown, and interesting tests with earthquake warning before induced M=1.5-2 events in a deep mine will be presented.The access to in situ complete stress tensor fields is of great value for all monitoring of crustal deformations. As the microearthquakes often are produced by slip down to 0.01 mm it means that the microearthquake method is very sensitive. It has long been known that very small stress changes can cause microearthquakes. The main problem with this method is of cause that no stress information is achieved from volumes with no observed microearthquakes. However the occurrence of foreshocks has been widely known as a good precursor, the method then allows an improved understanding of all microearthquakes and their relation to the global processes which make it easier to recognize the foreshocks.

S302S1.03

S302S1 - Earthquake prediction research

Oral

Role of a high rigidity asperity before a M6.6 earthquake in Iceland

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A model is proposed to explain the spatial distribution of foreshocks of the June 17th 2000, Ms 6.6 earthquake in the South Iceland Seismic Zone (SISZ) and the high stress drop of the mainshock. From the distribution of aftershocks, from geodetic data and from strong-motion inversions, the presence of an asperity is inferred in the hypocentral region. The evolution of the stress field around a high rigidity asperity embedded within a left-lateral transform domain (as pertinent to the SISZ) is studied theoretically. The asperity is modelled as elastic, embedded within a medium with low long-term effective rigidity. The asperity may be an intrinsic feature of the heterogeneous medium in the SISZ or may be generated by rock-fluid interaction: fluids of magmatic origin, ascending at near-lithostatic pressure through a low permeability layer perturb the regional stress field, inhibiting fluid flow laterally, where a high strength asperity is left. Regional stresses due to E-W left lateral tectonic motions prevailing in the SISZ are perturbed by the presence of the high rigidity asperity, enhancing the production of hydro-fractures and foreshocks in the NW and SE quadrants, as actually observed during several years before the mainshock, and increasing considerably the shear stress within the asperity, eventually leading to the big mainshock.

S302S1.04

S302S1 - Earthquake prediction research

Oral

New Geophysics: The future of earthquake prediction

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Nearly universal observations of shear-wave splitting (SWS) indicate that the Earth is pervaded by fluid-saturated stress-aligned microcracks that are so closely-spaced they verge on fracture-criticality and fracturing. SWS monitors changing stress. If there are appropriate source-to-receiver paths, stress changes in *in situ* rock can be measured, the approach to fracture-criticality monitored, and impending earthquakes stress-forecast. ‘Stress-forecast’ is used rather than ‘prediction’ to emphasise the different formalism.

Self-organised criticality of Gutenberg-Richter indicates that earthquakes are critical phenomena that cannot be predicted deterministically. This is not surprising. Earthquakes are extraordinarily complicated and depend on a huge range of geological/geophysical/tectonic details at depth which cannot be assessed. However, one characteristic common to all earthquakes is they release stress. Observations of SWS time-delays have retrospectively monitored stress-accumulation and, when fracture-criticality is reached, have stress-forecast times, and magnitudes, and estimated fault-breaks of 16 earthquakes worldwide. On one occasion, when SWS was routinely monitored, time, magnitude, and fault-break of a M5 earthquake in SW Iceland was successfully stress-forecast three days before it occurred.

New Geophysics, where compliant critically-microcracked rocks are critical-systems, cannot be understood from experience based on conventional sub-critical geophysics. A paradigm shift in understanding is required. Critical-systems verging on criticality in this way are extremely common and range from the very small (quantum mechanics) to the very large (stellar radiation) and very complex (climate), and impose fundamentally-new properties on conventional sub-critical geophysics making New Geophysics the most significant scientific advance in solid-Earth geoscience for many decades and important 'Knowledge For The Future' of Earthquake Prediction.

S302S1.05

S302S1 - Earthquake prediction research

Oral

Triggering of earthquakes - A comparison of stress models for the South Iceland Seismic Zone and the North Anatolian Fault

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Coulomb stress increases are usually assumed to be an indicator for future seismicity. We compare two active strike-slip zones with respect to the triggering of large events ($M \geq 6$). For the South Iceland Seismic Zone (SISZ) all large earthquakes since 1706 were taken into account (13 events), for the North Anatolian Fault Zone (NAFZ) all since 1939 were considered (10 events). We assumed co- and visco-elastic post-seismic stress changes as well as the contribution from plate tectonics, including a stress level before the first event. No dynamic triggering was investigated as the events were separated by at least 5 minutes (at a distance of 24 km in this case) and usually by years. For an event to be accepted as triggered, we demanded that at least 50 % of the future rupture plane showed a stress change of at least 0.01 MPa, the empirical trigger threshold. - For the SISZ only those events in a cluster (separated by 5 minutes to 19 months from the preceeding ones) meet these triggering criteria very well, while the first events of the clusters (being separated for 16 to 112 years) do not. For the NAFZ at least two thirds of the events are likely triggered by the preceeding one. - In addition to presenting these results, the differences between the two fault zones leading to this dissimilar behaviour are discussed, as there are age, morphology, crustal structure, etc.

S302S1.06

S302S1 - Earthquake prediction research

Oral

Warnings on the long- and on the short-term, ahead of large earthquakes can be realized in Iceland by operating long term continuous watching and modeling, related to each fault plane

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The goal of earthquake prediction research is to mitigate risks by providing warnings ahead of them. Even if the science is still far from being able to predict all aspects of large impending earthquakes, progress in observations and understanding of the preparatory processes is increasing fast. Such an understanding is already now a basis for risk mitigating warnings about significant aspects of earthquakes before they occur.
Multinational and multidisciplinary studies of the physics of pre-earthquake patterns in Iceland, especially in the South Iceland Seismic Zone indicate that it is possible to observe and physically to model fault conditions and crustal process, leading to a large earthquake, during decades before it strikes. The basic data for this conclusion are various information carried continuously by micro-earthquakes from seismogenic depths. The preparation process of no two earthquakes can be assumed to be the same. This moves our efforts from relying on universal precursors towards studying the ongoing pre-earthquake process at individual faults: To create a constitutive relationship for the pre-earthquake process, to extrapolate these conditions in space and time to predict activity, and to constrain such predictions by forthcoming monitoring of micro-earthquake activity, and thus gradually to refine the constitutive relationship.
It is stated that by such an approach useful warnings / information about significant aspects of any large earthquake in Iceland may be issued during it´s preparation period, provided that relevant multidisciplinary geo-watching procedure is applied. Such a watching procedure, consisting of automatic and manual operations, should be capable of real time modeling which explains the continuous observations. Gradually more accurate warnings/information can be provided, to help science and society to take action to mitigate future risks, ultimately by short term warning for the earthquake and it´s expected effects.

S302S2.01

S302S2 - Earthquake prediction research

Oral

Stress state analysis on the southwestern Longmen Shan fault zone, SW China

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Since the 2008 Wenchuan Ms8.0 earthquake occurred on the central-northern Longmen Shan fault zone, related researches indicated that the southwestern segment of Longmen Shan fault zone is becoming one of portions with significant Coulomb stress increase. What the present seismic hazard on the segment will be has become the research hot topic for seismologists and geologists.

Using the seismic data of $M_L \geq 2.0$ earthquakes recorded by the Sichuan Seismic Network, we calculated b values in the frequency-magnitude relationship, $\log_{10}N=a-bM$, and its variation Δb between two different periods, i.e., from 1977.1.1 to 2008.5.11 and to 2012.12.31, respectively, to analyze the current stress state and assess earthquake risk on the segment.

The result shows the mean b value for the southwestern segment is about 1.02, slightly lower than that before the Wenchuan earthquake. On the Δb map, only on some potions, especially near Luding, b values significantly decrease; while on nearly half of the southwestern segment, b values are stable or slightly increase, implying stress increase after the Wenchuan earthquake is not for the entire southwestern segment. The b-value map indicates the relatively low b values are distributed near Tianquan, Baoxing and its east, which means relatively high stress level there. However, even with significantly b-value decrease, Luding is still included within the high b-value area, showing present stress level and strong earthquake risk relatively low there. Comparing with the character of b-values before the Wenchuan earthquake, the probability of large earthquake on the segment is relatively low in the near future, however, moderate to strong earthquakes maybe occur near Tianquan, Baoxing and its east.

S302S2.02

S302S2 - Earthquake prediction research

Oral

Heterogeneities of S wave attenuation field in the region of Baikal rift zone and their relation to seismicity

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We have been mapping short-period shear wave attenuation field in the lithosphere of Baikal rift zone (BRZ). We were analyzing earthquake recordings, obtained by station ULN at epicentral distances of ~400-1300 km. We considered ratios of maximum amplitudes of Sn and Pn waves (Sn/Pn parameter). As a whole, Sn/Pn values in BRZ region are considerably higher, than in the other regions of Central Asia. It was shown, that areas of relatively lower S wave attenuation correspond to rupture zones of large earthquakes, occurred in XIX-XX centuries (till 1959). Areas of higher attenuation were picked out in Baikal region, where large earthquakes (M~>7.0) did not occur at least during 200 years. Ring-shaped seismicity structures are connected with two such areas (at southwestern and northeastern terminations of the lake). We suppose, that processes of preparation for large earthquakes are observed in these areas. Using dependences of seismicity ring characteristics on magnitude for earthquakes with normal faulting mechanism we estimated Mw values for preparing large events (~7.2 and 6.7 for southwestern and northeastern areas correspondingly). We discuss possible reasons for correlation between the attenuation field and seismicity characteristics.

S302S2.03

S302S2 - Earthquake prediction research

Oral

A case study: Similarities between eruptions and earthquakes

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New Geophysics: a case study. Retrospective observations of shear-wave splitting (SWS) show similar behaviour before the 2010 eruption of Eyjafjallajökull Volcano, Iceland, and before a nearby M5 earthquake (1998), whose time, magnitude, and fault-break was successfully stress-forecast three days before it occurred.

The Eyjafjallajökull ash-cloud eruption in SW Iceland disrupted air traffic in NW Europe for six days in 2010 and generated much international interest. A nine-station seismic monitoring network was set up around the volcano to record the swarm of seismicity which migrated towards the (25km-distant) much larger and more dangerous Katla Volcano. Seismic records from the network were telemetered to Edinburgh. Only one station, GOD, was within the restrictive shear-wave window for monitoring SWS, but this displayed spectacular variations. Retrospective monitoring of SWS time-delays at GOD showed a nearly-linear stress-accumulation increase 230-to-40 days before the eruption and a crack-coalescence decrease starting 40 days before the eruption. These are similar to variations seen retrospectively before ~16 earthquakes worldwide. The variations before Eyjafjallajökull are compared with a similar increase and decrease before the successfully stress-forecast 1998 M5 earthquake recorded at Station BJA (~40km distant from GOD). The SWS time-delays before Eyjafjallajökull would have allowed the onset of the eruption to have been stress-forecast to within a few days. Following the eruption, the SWS time-delays at GOD showed a very shallow increase which may be associated with the M5.3 and M5.6 earthquakes (October 2012) in the Tjörnes Fracture Zone in North Iceland. Similarities in SWS time-delay variations before eruptions and earthquakes are strong confirmation of the universality and predictability of the New Geophysics, which makes New Geophysics important for understanding and exploiting the dynamics of deformation in the critical solid Earth.

S302S2.04

S302S2 - Earthquake prediction research

Oral

Relationship between seismic and other geophysical precursors

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The previous earthquake prediction programs based on complex of geophysical fields imply their simultaneous anomalous manifestation prior to an earthquake. The earlier reliability requirements suggested by geophysical community consisting of the fact that identification of a geophysical precursor must be confirmed by other precursors for reliability.

Our results led to a fundamental revision of such approach: we showed that a complex of geophysical fields cannot develop simultaneously. The studies shown that different frequency ranges of medium's oscillations cause various physical changes in it and the gradual decline of main frequency of microseisms prior to the earthquakes leads to different precursory manifestations.

The ranges of megahertz are sufficient for the excitation of electromagnetic emission. Whereas the changes in the electric field correspond to the range of tens and hundreds of kilohertz, and the emergence of hydro-geological anomalies - to hundreds of hertz. So, their appearances depend on the main frequency range of seismic waves in each time. That is, different wave lengths of microseisms correspond to the physical manifestations of a different nature in the medium, and each precursor has time range for its emergence.

The greater the magnitude of a future earthquake, the sooner the manifest of one or other geophysical precursor, and the greater the difference in times of their occurrence. Detection of one of them means that another one's have already emerged, but were not registered, and others have yet to «emerge». And more accurate monitoring of other fields is required, because the difference between times of their occurrence allows evaluating the intensity and time of the future earthquake occurrence.

The above mentioned may be important in the development of real methods of earthquake prediction by atmospheric and ionospheric anomalies in order to determine the sequence, rate and informativity of their precursory manifestations.

S302S2.05

S302S2 - Earthquake prediction research

Oral

Combining probabilistic and non-probabilistic forecast models using differential probability gains

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We propose a method to combine probabilistic and non-probabilistic earthquake forecast models into probabilistic ones. Probabilistic models estimate the expected rates of earthquake of a given magnitude on a geographic grid. Non-probabilistic models include different alarm-based models, precursors, color maps. The general procedure is to create new generations of a rate-based model by injecting into the current generation the additional knowledge carried by precursory patterns or any kind maps. Precursor patterns are presented by a control parameter called also alarm function. Any color code of a map also may serve as an alarm function.

For a single iteration (one precursory pattern or a map), we use the differential probability gain calculated in the Molchan diagram that evaluates the performance of the pattern or the map with respect to the current generation of the rate-based model. We find an empiric function between the control parameter and the differential probability gain. For the forecasts the control parameter is determined in each point of space. Using the empiric function we find the corresponding value of the differential probability gain, thus assigning its local values. Then, at each point in space and time, the new rate is the product of the current expected rate times the local differential probability gain. The main advantage of our combining method is to produce high expected event rates using maximum of available predictive information. The only restriction is that each precursory pattern or a map has to bring additional amount of information with respect to the current generation of the alarm-based model.

We demonstrate the method on several examples. One example is combining an alarm-based non-probabilistic forecast model EAST and a rate-based model EEPAS. Both models are being tested in the California testing center of the Collaboratory for the Study of Earthquake Predictability (CSEP).

S302S2.06

S302S2 - Earthquake prediction research

Oral

Exploring the way to numerical earthquake prediction

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Numerical weather forecast took half a century to become practical. Can earthquake numerical prediction be explored? There are five key issues for numerical earthquake prediction: basic equations (physics of earthquake), computation capacity to solve the equations, the lithosphere structure and rock property for a specific region, 3D boundary conditions and initial conditions for the problem. The numerical prediction cannot be made at present, because the initial conditions are almost unknown and the boundary conditions are poorly known, however, physical understanding and numerical technique make it possible to start the exploration.

For the process of stress accumulation and earthquake generation, a visco-elastic model characterized by ductile lower crust of western Sichuan is established. Stress rate is found highest at the bottom of upper crust beneath the Longmenshan fault zone corresponding to the Wenchuan earthquake fault, and stresses are in favor of thrust fault in the SW segment and lateral strike slip in the NE segment.

For co-seismic stress changes, a layered finite element earth model of 4 million elements is constructed to investigate the far field stresses in North China due to the Mw9.0 Tohoku earthquake. Calculated displacements are in good agreement with GPS observation. Calculated co-seismic stress is characterized by a nearly E-W tensile stress of magnitude ~ kPa. Since North China is under NEE compression from earthquake mechanism and in-situ stress measurements, with annual increment of ~ 0.25kPa, the co-seismic changes due to Tohoku earthquake will reduce seismic risk in North China for a period of at least a decade.   Another example is Coulomb stresses due to reservoir impoundment at Zipingpu reservoir, Xinfengjiang reservoir and Aswan reservoir by poro-elastic finite element computation, which give a quantitative way to investigate triggering of reservoir earthquakes.

S303PS.02

S303PS - Synchronisation and triggering: From fracture to earthquake process

Poster

The spatio-temporal features of the earthquake stress perturbation based on the simplified two-layer viscouselastic medium model

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Based on the simplified two-layer viscouselastic medium model and its temporal characteristics in deformation process, considering the joint action of the instantaneous elastic stress perturbation in the upper layer (more elastic) and the delayed and long-term load on upper layer due to the viscous relaxation deformation in lower layer (more viscous), the spatio-temporal variation of the earthquake stress perturbation has been studied. The results show that the stress perturbation increases quickly during a short time since the earthquake and then decays slowly for a long time. When model parameters approach to real data more and more, the increasing and decay process of the stress perturbation is more slowly, and the duration is more longer. Therefore, the long-term influence of stress perturbation could not be ignored in the study of Coulomb stress triggering. The stress perturbation has a limited acting range in space, which decreases obviously with the distance from the earthquake, the decay rate is large near by the epicenter and is small far away from the epicenter. For the model parameters used in our paper, which approach to the real status for some extent, the effective acting range of the stress perturbation is about 2.5 times of the linear fracture size of the earthquake. The stress perturbation increases gradually with the mainshock magnitude, it can not be ignored when magnitude is larger than M6. The relative error of stress perturbation, resulting from the measurement errors of the fracture size, is relational to the fracture size and epicenter distance. It increases with the epicenter distance, but the total influence are not very large, it tends to constant when distance is large enough. For earthquake with M6, M7 and M8, the maximum relative errors of stress perturbation are smaller than 22%, 30% and 38%.

S303PS.03

S303PS - Synchronisation and triggering: From fracture to earthquake process

Poster

Changes in seismic activity following the 2011 Tohoku-oki earthquake: Effects of pore fluid pressure

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We examined the effects of pore fluid pressure on seismicity changes following the 2011 off the Pacific coast of Tohoku (Tohoku-oki) earthquake through the analysis of aftershocks based on the Coulomb failure criterion. Background tectonic stress fields in Northeast Japan are generally characterized by E-W compression. After the Tohoku-oki earthquake, as expected from decrease in the Coulomb failure function (= shear stress – 0.4Xnormal compressive stress), seismicity in the upper crust of Northeast Japan decreased except some restricted regions, where we observed many aftershocks with unfavourable focal mechanisms to the background stress fields. By mapping the focal mechanisms of aftershocks on the 3-D Mohr diagram region by region, we confirmed that the aftershocks occurred on optimally oriented faults in some regions but on misoriented faults in other regions. The aftershocks on optimally oriented faults indicate the increase in regional ambient fluid pressure caused by the flow of over-pressurized fluid from a deep reservoir. On the other hand, the aftershocks on misoriented faults, which cannot be attributed to coseismic stress rotation, indicate the increase in fault-confined fluid pressure relative to the ambient fluid pressure.

S303S1.01

S303S1 - Synchronisation and triggering: From fracture to earthquake process

Oral

Triggering and synchronization of stick-slip and earthquakes

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Triggering and synchronization are encountered in various fields, from mechanics to biological and social processes. Thus, it is only natural that synchronization phenomena are observed in many geophysical fields, as the Earth is embedded in the oscillating field of different origin, with extremely wide range of frequencies, from seconds to months and years.

New tools for quantification of the strength of triggering/synchronization between the phases of synchronized process and synchronizing impact developed last years make the corresponding assessments much more reliable in case the time series is long enough. We present the results of laboratory experiments on the electromagnetic (EM) and mechanical triggering and synchronization of mechanical instability (slip) in the spring-slider system. Slip events were recorded as acoustic emission bursts. The striking effect of high order synchronization of stick-slip events by weak electromagnetic or mechanical periodic forcing was discovered.

Besides, field data on the forcing of local seismicity by strong electromagnetic pulses, large water reservoir exploitation and remote earthquakes are analyzed. The nonlinear dynamic tools were used to analyze field data, namely the triggering effect of series of strong MHD pulses on regional seismicity regime during experiments performed in Central Asia at the Bishkek test area in 1975-1999 and seismic activity around Enguri high dam reservoir located in the Western Georgia. In both cases a tendency to ordering/phase synchronization of the local seismicity is found.

The results obtained point to possibility of revealing new fine details in the stick-slip process which can be very useful for refining the physical mechanism of frictional motion in general and seismic process in particular.

S303S1.02

S303S1 - Synchronisation and triggering: From fracture to earthquake process

Oral

The triggering effects of power typhoons and remote earthquakes on local seismicity

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The first part of this study is concerned with the effects of powerful Pacific typhoons on the seismicity of Kamchatka, Japan, and the Philippines. We used complete seismological catalogs for these regions that span a few tens of years. It was found that the typhoons that originate from the western Pacific generally do not exert a significant triggering effect on the seismicity of these three regions, at least in the short term, during a few weeks. The ground motion generated by typhoons, which might be treated as a trigger, does not have amplitudes above those in the motion due to numerous local earthquakes of moderate magnitudes (~4–5) and larger teleseismic earthquakes. We studied also the influence of remote earthquakes with magnitudes > 7.5 on the seismicity of Kamchatka. The increase of seismic flow was found during 1 month after the date of corresponding strong event if the dynamic strain threshold exceeded 10^{-6}. Especially significant effects were revealed after Simushirskoe (15.11.2006, M = 8.3), Sumatra (26.12.2004, M = 9.1), and Tohoku (11.03.2011, M = 9.0) earthquakes. The tenso-sensitivity of local seismicity to the triggering event varied with time.

S303S1.03

S303S1 - Synchronisation and triggering: From fracture to earthquake process

Oral

Molecular transport as the mechanical counterpart of preseismic interaction processes

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We follow the Asymmetric Continuum Theory with the introduced molecular transport processes, which may form the possible nuclei of the fracture phenomena. Here, we try to explain the two kinds of the earthquake precursors processes. First, we consider the migration of the paramagnetic ions, the radicals, towards an Earth surface. The related charge diffusion spreads almost without any mechanical processes, however, it could be based on the molecular transport flow. Second, we try to explain some effective earthquake precursory signals based on the observation of the micro-seismics: the synchronization effects of microseismic background oscillations as described in a number of papers by Sobolev G. and Lyubushin A. An explanation of such synchronization effects may be also related to an influence of the molecular transport processes in regions of the expected earthquakes.

S303S1.04

S303S1 - Synchronisation and triggering: From fracture to earthquake process

Oral

The loss of multifractality and entropy increasing of seismic noise as indicators of Earth's crust consolidation

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Development of broad-band seismic networks and high speed internet access to continuous records of seismic noise provide the possibility to estimate and visualize evolution of low-frequency seismic noise properties in the form of their spatial maps within moving time windows of different lengths. Two statistics of noise waveforms are considered: multi-fractal singularity spectrum support width D and minimum normalized entropy En of squared orthogonal wavelet coefficients. The experience of using these maps for the data from Japan network F-net (1997-2012) and for regional broad-band networks in California (2008-2012) shows that seismically danger regions correspond to relatively low values of D and high values of En. These observations turn to be true for the region of Tohoku mega-earthquake 11 March 2011. The analysis of seismic noise after March 2011 extracts the region of Nankai Trough by low values of D and high En, which could be an indicator of the next mega-earthquake near Japan Islands. Visual comparing of noise waveforms shows that high values of D and low values of En are connected with existence of irregular high-amplitudes spikes. Such peculiarities of waveforms probably are connected with mutual movements of Earth's crust small blocks. Thus, decreasing of D (the loss of multifractality) and increasing of En detect the process of consolidation of Earth's crust in the region of high seismic danger. Besides that, the data analysis shows that seismically danger regions are the regions with relatively low noise kurtosis.
Key words: seismic noise, consolidation, singularity spectrum, wavelet-based entropy, kurtosis.

S304PS.01

S304PS - Earthquake Source Dynamics: Observations and Modeling

Poster

Seismic effect of fault thickness and seismic asymmetric moment tensor

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If an earthquake takes place on a fault with finite thickness, there is an additional single-couple term in body force equivalence due to the stress drop in the strength-weakening zone. Using the far-field approximation of Green's function, we derive the asymmetric seismic moment tensor representation of this kind of earthquake source. In the far-field, the displacement term corresponds to a symmetric moment tensor; the traction term corresponds to an asymmetric moment tensor, and the symmetry constraint is not necessary. During an earthquake, the asymmetric tensor indicates angular momentum exchange between seismic source region and the rest of Earth, and the whole Earth's angular momentum is conserved. For a representative point on the fault, the duration of the displacement term and the traction term are different. But for an earthquake, considering the rupture of the whole fault plane, their duration is dominated by the rupture time. So, we can assume that all the terms in asymmetric seismic moment tensor have an identical source time history. In the finite thickness fault model, ambiguity in fault plane identification disappears. The traction term is equivalent to a single-couple, the strength of the two single-couples (along the slip direction on two nodal planes) are no longer equal. For the two nodal planes, the one with larger strength is the fault plane; the one with smaller strength is the auxiliary plane. On the fault plane, the directions of the extra single-couple and its torque give constraints on the asymmetric seismic moment tensors. Not all the asymmetric moment tensors are valid to represent such kind of earthquake sources. Only after appropriate constraints, we can separate the displacement component and traction component from asymmetric seismic moment tensor. If the traction term is ignored (as in the model without fault thickness), the scalar seismic moment will be overestimated by as much as half of the moment of extra single-couple.

S304PS.02

S304PS - Earthquake Source Dynamics: Observations and Modeling

Poster

Seismicity triggering and source process of the future earthquake in Garhwal Himalayas

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As studies indicate that whole Himalayan belt are under greatest threat of Earthquakes. The seismicity of the Himalayas is ascribed to the convergence of Indian and Eurasian lithospheric plates, producing several prominent tectonic features in the area. Namely, the Main Boundary Thrust (MBT) and the Main Central Thrust (MCT) had evolved throughout the entire length of the Himalayas. As the Indian Plate is pushing against the Eurasian Plate, the stress is building up and there have been many earthquakes in this region. The Garhwal Himalaya constitutes the north-western part of the Himalayas and has been strongly affected by tectonic movements, resulted to the development of innumerable folds, faults and weak planes in the region. This region has a well-known and recorded history where large magnitude earthquake break very repeatedly. The entire area is under zone IV and V as per the seismic zone map of India with a very high seismic vulnerability. During one and half century this area has already faced 36 major earthquakes of M>5.0 on Richter scale, having 12 events of magnitude 6.0 plus. The return period for an earthquake of magnitude 6.0 in this region is about 8-9 years. This area was hit by a severe (M=6.6) earthquake in October 1991. Its epicentre was near the town of Uttarkashi, located south of the surface trace of the northerly dipping MCT. The two swarms of small earthquakes on 1995/10/22-24 and 1996/09/13-18 occurred in the close proximity to each other and to the epicentre of Uttarkashi earthquake, provide unique opportunity to study the possible effect of the Uttarkashi event on the future seismicity of the region. The source process of these swarm were explained by triggering effect i.e. Coulomb stress change that contributes to the investigation of seismicity triggering by previous strong earthquakes. Seismicity migration to nearby faults affects their proximity to failure, thus changing future earthquake probability.

S304PS.03

S304PS - Earthquake Source Dynamics: Observations and Modeling

Poster

A method for simulating earthquakes: Verifications and application

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We present an earthquake simulation method used to calculate dynamically and statically induced displacements on faults near a large earthquake. Our results are aimed at improved safety assessment of underground waste storage facilities, e.g. a nuclear waste repository. We use the distinct element code 3DEC, which we benchmark against analytical as well as numerical results in separate test models. First, we compare 3DEC results with the closed-form solution given by Stokes for a time dependent point load. We then run other benchmark models containing finite-area sources and compare the responses at a number of surface receivers to the corresponding results obtained from the COMPSYN code. The results from the benchmark models show that the 3DEC results agree both with the analytical and the COMPSYN results. In our application to simulated earthquakes near a storage facility, we use a model with a pre-defined earthquake fault plane surrounded by numerous smaller discontinuities representing faults in which shear movement may be induced by the earthquake. The earthquake fault plane and the smaller discontinuities are embedded in an elastic medium. Initial stresses are applied and the fault rupture mechanism is simulated through a programmed reduction of the fault shear strength, which is initiated at a pre-defined hypocenter. The rupture is allowed to propagate at a typical rupture propagation speed and is arrested when it reaches the fault plane boundaries. The fault residual strength properties are assumed uniform over the fault plane. The method allows for the calculation of secondary fault movements induced by both static stress redistribution and dynamic effects. When we apply the earthquake simulation approach to the Forsmark nuclear waste repository site in Sweden we obtain both fault slip and fault slip velocities that are high compared to those found in real earthquakes. The calculated secondary movements reach some tens of mm in 300 m diameter fractures.

S304PS.04

S304PS - Earthquake Source Dynamics: Observations and Modeling

Poster

Seismotectonics of the Garmsar region based on simulation of small earthquakes

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Garmsar basin is one of a series of basins in the foredeep of the Alborz mountains which created depression in northern part of Great Kavir. Currently there are so many major and active faults in the Garmsar region which most of them are unknown in terms of seismic activity , earthquakes return periods and focal mechanisms. Occurrence of large historical earthquakes in this region and closeness of this area to capital region represents an important necessity for Seismological studies in the region. At present, tectonic activity of Alborz mountain range in northern Iran is summarized to two movements, one convergence of central Iran and Eurasia and the other, clockwise rotation of the South Caspian Basin relative to Eurasia (Djamour et al., 2010). ISOLA software (Sokos and Zahradnik, 2009) have been used to calculate the moment tensor of small earthquakes. Seismotectonics of the region was interpreted by resolving the focal mechanisms and determining the trends of seismicity. Obtained focal mechanisms in the western part of the Garmsar fault and seismicity trend shows that slope of this part is to the North, and also compressional movements in the central and western part of The Garmsar fault can be seen. North Semnan fault shows a very high slope to the Northwest and the focal mechanism on this fault shows compressional mechanism with left-lateral strike-slip component. Obtained focal mechanisms and trend for Firuzkuh fault shows Normal and left-lateral strike-slip movements for this fault. Two obtained focal mechanisms for Mosha fault confirms left-lateral strike-slip movements of this fault. Chashm fault with compressional outcrop is a left-lateral strike-slip fault with almost vertical slope. Also normal movements were observed in Northern foothills of the Garmsar fault, which can be explained as a strain release between the two compressional Garmsar and Sorkhe faults.

S304PS.05

S304PS - Earthquake Source Dynamics: Observations and Modeling

Poster

Characteristics of the 2006 Silakhor (Lorestan), western Iran, earthquake sequence

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The Silakhor earthquake occurred in Zagros suture zone, in between Drood and Brujerd cities in Lorestan province, producing extensive destruction but relatively low rate of human loss. Field investigation and the distribution of aftershocks suggest a NW-SE trend faulting with a right-lateral strike slip mechanism. The recorded aftershock activity was extended to a length of about 40 km and a depth of about 30 km. The majority of aftershocks took place at a depth range 10-20 km and was scattered indicating a complex mode of faulting. The result of waveform inversion indicated that the mainshock followed mainly strike slip mechanism and the source process incuded two major fault slip. The total seismic moment was calculated to be M0= 3.1×1025 dyne cm. The calculated maximum dislocation is about 50 cm and the obtained moment magnitude in this analysis is Mw = 6.2. The average stress drop was estimated to be 25 bar and the average dislocation was 25 cm. The Silakhor earthquake is one of the rare events that has occurred in Zagros suture zone with magnitude greater than 6. Therefore, the ground-motion characteristics during the mainshock should be considered for the high safety design of structures in the damaged area.

S304PS.06

S304PS - Earthquake Source Dynamics: Observations and Modeling

Poster

Development of methods for the solution of wave propagation in an elastic medium under the influence of cylindrical inclusions

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We research assimpthetical conduct of decision, it was worked out and made up programmed ABCDE in Turbo PASCAL's 7.0 language. The formed decision consists of two parts, each of them at explosive front of waves are similar to certain kind of waves with the characteristic velocity, but with the growing in the both parts of decision there are properties of both kinds of waves. If we into consideration the speed importance of spreading longitudinal and diametrical waves in different kinds, there was learned the speed modification of environment parts according to time at different distances from cylindrical inclusion. On this work at the same time was researched dynamics of structure in the case of cylinder with the oscillation.

S304PS.07

S304PS - Earthquake Source Dynamics: Observations and Modeling

Poster

Modeling of seismic waves in layered media and the inversion of source parameters

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This paper is organized as follows. After a discussion of the differential equations for wave propagation in the horizontally stratified medium and of the initial and boundary conditions, we derive the displacements on the free surface of the layered medium for plane waves when a point source is located on the s'th imaginary boundary at the depth (physical parameters of the layers s and (s+1) are put to be identical). Then, the source will be represented as a moment tensor point source. Method for the solution of the direct seismic problem is considered based on the matrix method of Thomson-Haskell. Further, we give the results for the field of displacements on the free surface. The results of this direct problem we use in the inversion of source parameters. The inverse method relies on inverting for components of the moment tensor and a determination of an earthquake source-time function.

S304PS.08

S304PS - Earthquake Source Dynamics: Observations and Modeling

Poster

On an experimental method for investigating the dynamic parameters of multi-storey buildings at vibrating seismic loadings

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Research of dynamic properties of various materials and elements of structures at shock affecting and on the waves so many scientific works of the Azerbaijani scientists are devoted [1-10]. However, experimental definition of dynamic parameters of fluctuations of constructions and buildings while carries estimated character.

The purpose of the present experimental researches is definition of parameters of fluctuations of installation of observations, in this case, a mockup of four floor buildings and sixteen floor skeleton-type buildings built in the Baku with the stiffening diaphragm at natural vibrating seismic affectings.

S304PS.09

S304PS - Earthquake Source Dynamics: Observations and Modeling

Poster

Deformation monitoring around the active fault in the metro Manila

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The Republic of the Philippines lies across the boundary between the Eurasian plate and the Philippine Sea plate, an area ridden with active faults and frequent earthquakes. The Valley fault, running from north to south along the eastern edge of the Manila metropolitan, is a right-lateral active fault with two to four activities recorded over the past 1400 years; the estimated recurrence cycle translates to 200 to 400 years. Creep deformation along the southern part of the fault has produced some cracks running in a north-south or northeast-southwest direction. As a result, roads and ground structures near the fault exhibit vertical displacements. According to recent studies, the last activity of the fault took place on August 19, 1658. In consideration of the estimated recurrence cycle, the region now faces a high risk of a devastating earthquake with a magnitude of 7 or higher. In this study we measured land deformations around the Valley fault, by means of InSAR time series analysis using ENVISAT and PALSAR data. According to our data analysis, several phase anomalies were detected in the Manila. Most of them could be found a strong correlation with the vertical movements of the groundwater levels, the deformation at each location progresses monotonically. The maximum average deformation velocity was measured 91 mm a year. Meanwhile, some of the land deformations are independent of the groundwater levels in the surrounding of the Valley fault. The difference in measurement times may partially explain this discrepancy, but we cannot deny the possibility that it resulted from creep deformation around the Valley fault, as the spatial geometry of the surface deformation runs in parallel with the fault and sites in the eastern part of the Valley fault stopped subsiding and began moving upward in around 2007.

S304PS.10

S304PS - Earthquake Source Dynamics: Observations and Modeling

Poster

Finite-source rupture modeling of 2004 Mw 6.2 Kojur-Baledeh earthquake, Iran

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Earthquake source process is dynamic shear rupture including fracture and frictional slip on fault surface. In order to learn about the process i.e.; spatial and temporal behavior of the rupture front should be resolved. The method to confine a slip model by data is slip inversion. Finite-fault source inversion uncovers the spatial intricacy of earthquake slip distribution on fault plane.

We have analyzed the seismic data of the 2004 Mw 6.2 Kojur-Baledeh earthquake occurred north Iran, to estimate finite-source rupture model that images spatio-temporal evolution of earthquake rupture. May 28, 2004, Mw 6.2 Kojour-Baladeh earthquake was one the large earthquakes that occurred in Iran with magnitude of Mw=6.2 and 21 dead. The spatial slip distribution of the earthquakes was studied and areas of peak slips and their depths, propagation of rupture and its velocity were analyzed.

S304S1.01

S304S1 - Earthquake Source Dynamics: Observations and Modeling

Oral

50 years of earthquake source dynamics: What we have learned and directions for future work

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Till the early 1960's, the study of fracture mechanics was confined initially to tensile cracks and later to anti-plane shear cracks but without friction. Thus, such studies were not directly useful to earthquake studies, and even led to some early misunderstandings.In 1964 and 1966, Kostrov published two seminal papers. Together with Kostrov and Nikitin's 1970 paper, it changed the study of earthquake sources for ever. A review of this history is givenin Broberg's 1999 textbook Cracks and Fracture.

We now know that a very important parameter controlling earthquake damage are changes in the rupture speed. We also know that earthquake faults are heterogeneous in strength, which leads to many changes in the rupture speed.We will discuss the history of development of our understanding of shear fracture, with particular reference to the work of Burridge, Ida, Andrews, Das, Aki, Madariaga and Freund among others, from the 1970's through to recent understanding of very fast rupture speeds, seen both observationally and in the laboratory.

Even today, ideas accepted in the 1970's are being refined, and many important ideas still remain unexplored fully.

For the problem of how earthquake generated waves cause damage, Mach waves from different parts of the fault during super-shear ruptures could interfere constructively in some cases to increase the ground shaking at some places but could interfere destructively in other regions lowering the ground motion. The widely used rate-and state fault properties have not been sufficiently well compared with direct observations, neither for real earthquakes nor for data from laboratory experiments. Laboratory experiments pioneered by Rosakis and Shimamoto provide such data and slowly the quality of strong motion data from earthquakes is improving so that such comparisons will become feasible in the near future.

S304S1.02

S304S1 - Earthquake Source Dynamics: Observations and Modeling

Oral

Dynamic inversion and Brune's model

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We have performed dynamic inversion of a number of earthquakes in different geophysical contexts. In the spirit of the classical Brune model our goal is to find the simplest dynamic model that fits the observed data. We use strong motion records from instruments located near the epicentre of the earthquake. The accelerograms are integrated to ground velocity or ground displacement and filtered and low pass filtered at 1 Hz. The model we look for is a relatively simple dynamic rupture process where we specify the initial stress field and the frictional properties of the interface. Inversion is carried out using either the Neighbourhood Algorithm or the Genetic algorithm for the search of the best model. We also use Monte Carlo to study the neighbourhood of the ideal solution because the inverse problem has many secondary minima. Observed and synthetic seismograms are compared using a normalized L2 norm. The forward model is solved by staggered grid finite differences and propagation to seismic stations is carried out using the frequency wave number method in a layered structure. The best recorded event that we have inverted so far is the 24 July 2008 (Mw=6.8) Northern Iwate, intermediate depth earthquake in Japan using strong motion records from the K NET and Kik-Net networks. We also inverted events in Chile and Mexico. The optimal solutions converge to very similar source models with semi-minor axes of the order of a few km and large stress drops in the 30-45 MPa range. Energy release rate for the best models was in the range 23-36 MJ/m2, a rather large value for events of this size. For each event we found a region of models in parameter space that fit the strong motions data within a certain error. These dynamic models share certain non-dimensional numbers: the dynamic similarity parameter kappa, the stress ratio S and a limited energy momentum ratio. Just as in the Brune's model very few parameters control the overall properties of seismic ruptures.

S304S1.03

S304S1 - Earthquake Source Dynamics: Observations and Modeling

Oral

Insight into the dynamic inversion procedure using strong motion data of the 2004, Mw6.0, Parkfield, California, earthquake

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We present a range of dynamic inversions of the September 2004, Mw6.0, Parkfield, California, earthquake, using an elliptical sub-fault approximation. In this approach, the rupture is restricted to occur within elliptical patches, in which stress and friction are assumed to be uniform. The aim of this study is to explore the transition from the kinematic to the dynamic approach, using the results of Twardzik et al. (GJI, vol. 191, pp. 1245-1254, 2012). In the first step, we only invert for the dynamic parameters (Stress parameters and the friction law), the geometry and spatial location of the rupture area being taken from the kinematic inversions. We start from a simple model of two connected ellipses, elongated in the strike direction and restricted to a narrow band of 5 km around the depth of the hypocenter. Using a trial and error approach, we estimated a set of parameters which reproduce the rupture process determined from the kinematic inversion. From this set, we define different parameter ranges to use during the inversions. A series of inversions is then carried out using a Neighbourhood Algorithm (NA). It shows that the solution can easily get trapped in secondary minima, depending on the parameter range used. Once we find the best model with the NA, we study the neighbourhood of this solution using a Monte Carlo technique. We show that the models which explain the data best are associated with a specific range of values for the parameter kappa (ratio of the available energy to energy release rate) and S (measure of material strength relative to tectonic stress). Then, we study the kinematic models having a more complicated rupture process. In particular, we focus on inversions which led to slip distributions with 2 distinct asperities, requiring a jump of the rupture process from one asperity to another. Finally, we perform a full dynamic inversion of the Parkfield earthquake where we also invert for the geometry and position of the rupture patches.

S304S1.04

S304S1 - Earthquake Source Dynamics: Observations and Modeling

Oral

Uncertainty quantification in earthquake source models: Statistical comparisons in space and time and the SIV project

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Finite-fault source inversions estimate earthquake rupture kinematics using a variety of available data sets and inversion approaches. Rupture models are obtained by solving an inherently ill-posed inverse problem, subject to numerous a priori assumptions and noisy observations. Despite these limitations, near real-time source inversions are becoming increasingly popular, while we still face the dilemma that their uncertainties are essentially unknown. Yet, the accurate estimation of earthquake rupture properties, including proper uncertainty quantification, is critically important for earthquake seismology and seismic hazard analysis, to adequately characterize earthquake complexity across all scales. This presentation covers two aspects related to uncertainty quantification in earthquake rupture modeling: statistical comparisons in space and time and the source inversion validation (SIV) initiative. We propose various statistical measures to quantify the variability between finite-fault rupture models; these are implemented for (1) different models for the same earthquake (as inferred by different research groups), and (2) different models from benchmark exercises for which a true solution exists. The emphasis is on complete models described by space-time solution. Our approach includes multiple metrics to handle the space- and time-dependent variability, interpolation to harmonize the different datasets, and fast computation for rapid application to large data volumes. The SIV-projectis a collaborative multi-institutional effort to understand the intra-event variability in rupture models, and to propose improved source-inversion approaches and corresponding uncertainty metrics. The SIV efforts include a rigorous testing platform to examine the current state-of-the-art in earthquake source inversion We present the SIV-strategy, and discuss latest SIV-test results for a scenario rupture embedded in a 3D heterogeneous Earth model.

S304S1.05

S304S1 - Earthquake Source Dynamics: Observations and Modeling

Oral

Doubly stochastic earthquake source model: random lacy rupture front sweeps a surface with random local stress drop

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Three properties of broadband earthquake waveforms are poorly understood: the “omega-square” behavior of high-frequency spectral asymptote; the often observed two-corner shape of source spectrum, and greatly reduced directivity of wave amplitudes at high frequencies (as compared to distinct low-frequency directivity). A kinematic fault model is proposed that is capable to reproduce each of these features. The model combines: (1) the proposal of Andrews[1980] that local stress drop over an earthquake fault is random self-similar (fractal) 2D field with amplitude spectrum of $1/|\boldsymbol{k}|$kind; (2) the assumption that source slip is concentrated within a running strip or slip pulse, whose width *l* is significantly lower than fault length L [Heaton 1990]; and (3) the hypothesis of Gusev[2012] that the shape of earthquake rupture front is tortuous, multiply connected, with the geometry of a random fractal line (polyline). To integrate these concepts, it is assumed that for any elementary failing patch of a fault, propagation of radiated fault-guided, mostly Rayleigh, waves, is confined by slip pulse, and thus the characteristic distance of propagation of these waves is determined by the value of *l*. Formation of earthquake waves is assumed to follow the theoretical description after Das&Kostrov[1983, 1986] for the failure of fault-asperity; on this basis, numerical experiments have been performed based on kinematic description of rupture. It was found that assumptions 1 and 2 lead to formation of source spectra of “omega-square” kind, with flat acceleration spectrum, and two corners. At low *l/L*ratio, the relative level of acceleration spectrum is the highest, and the second corner is most prominent. Assumptions 1, 2, and especially 3, result in source incoherency at high *k* that directly leads to low directivity of high-frequency radiation. The developed source model may occur useful for more realistic broad-band strong motion description.

S304S1.06

S304S1 - Earthquake Source Dynamics: Observations and Modeling

Oral

Dynamic rupture process of Wenchuan earthquake: The role of fault geometry

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With 3D curved grid finite-difference method (CG-FDM), we simulate the spontaneous dynamic rupture process of Wenchuan Earthquake of China, 2008. The influences of complex geometry of fault on rupture process are investigated through rupture dynamic simulations. In our simulation, uniform background tectonic stress field are assumed, and slip-weakening law with homogeneous friction coefficients are utilized. We found that the typical heterogeneous spatial distribution of final seismic slip on the fault can be generated by the realistic non-planar complex geometry of fault surface. If an appropriate geometry is chosen, the pattern of final slipping derived by spontaneous dynamic simulation can fit very well with the kinematic source models derived from the inversion of seismic waves and geodetic data (e.g., Zhang et al., 2008; Shen et al., 2010; Wang et al., 2012). Rupture front is significant affected by the non-planar fault and free surface. Changing of strike direction will slow down the front, while the free surface will accelerate the rupture speed. Strong ground motion generated by the simulated rupture shows high concentration near fault; coincides with the slip distribution from the results geological field survey.

S304S2.01

S304S2 - Earthquake Source Dynamics: Observations and Modeling

Oral

Analogue Earthquakes: Reproducing the 2002, Mw7.9, Denali supershear earthquake in the laboratory

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We present a series of dynamic mode II rupture investigations which model the 2002, Mw7.9 Denali fault earthquake and the remarkable set of near source ground motion records obtained at pump station 10 (PS10) of the trans-Alaska pipeline This station is located at 3km north of the fault and approximately 85km east of the hypocenter. Motivated by the unique kinematic signatures of these records, we attempt to mimic this strike-slip rupture scenario and to replicate these results using the laboratory earthquake setup introduced by Xia, Rosakis, and Kanamori some years ago [1]. A high-speed photoelastic image sequence provides a spatially resolved full-field view of the event while heterodyne laser interferometers provide continuous fault parallel, fault normal and fault vertical particle velocity records at a point lying close to the fault on the surface of the H-100 test specimen.

Scaling relationships based on the principles of dynamic fracture mechanics are presented, and are used to set the correctly scaled location of the analogue measurement. These relationships also transform near-fault particle velocity records through six orders of magnitude in space and time, to match the scale of the PS10 ground motion records. The scaled laboratory records are then shown to capture the major features displayed within the PS 10 ground motion records and are used to validate the hypothesis that a major segment of the Denali strike-slip fault exhibited a prolonged supershear burst. The remarkable agreement between the PS10 records and the scaled experimental records provide direct justification for using highly instrumented analogue laboratory earthquake experiments in directly studying near-fault ground shaking signatures in the lab in a safe, repeatable and fully scalable setting.

[1] Xia, K., Rosakis A. J., and Kanamori, H., “Laboratory Earthquakes: The Sub-Rayleigh-to-Supershear Rupture Transition”, Science, 303, 1859–1861, (2004)

S304S2.02

S304S2 - Earthquake Source Dynamics: Observations and Modeling

Oral

From sub-Rayleigh to supershear ruptures during stick-slip experiments on westerly granite

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Evidence for supershear earthquake ruptures, i.e. ruptures propagating faster than the shear wave velocity, have so far been provided by theoretical studies, natural earthquakes and laboratory experiments on analogous brittle materials but never on crustal rocks. Here, for the first time, we demonstrate that during stick-slip experiments in saw-cutWesterly granite supershear ruptures are systematically observed. These ruptures occur when the normal stress exceeds 40 MPa with stress drops in the range of 6 - 40 MPa, comparable to earthquake stress drops. We further demonstrate that in our stress conditions, the sub-Rayleigh to supershear transition length is only a few millimeters, suggesting that the rupture velocity inferred at large scale for earthquakes might be a global average and rupture of small asperities along a fault may propagate, locally, at supershear velocities.

S304S2.03

S304S2 - Earthquake Source Dynamics: Observations and Modeling

Oral

A constitutive model accounting for dynamic fracture damage during earthquakes

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The micromechanical damage mechanics formulated by Ashby and Sammis, 1990, and generalized by Deshpande and Evans 2008 has been extended to allow for a more generalized stress state and to incorporate an experimentally motivated new crack growth (damage evolution) law that is valid over a wide range of loading rates. This law is sensitive to both the crack tip stress field and its time derivative. Incorporating this feature produces additional strain-rate sensitivity in the constitutive response. The model is also experimentally verified by predicting the failure strength of Dionysus-Pentelicon marble over strain rates ranging from quasi-static to dynamic levels. Model parameters determined from quasi-static experiments were used to predict the failure strength at higher loading rates. Agreement with experimental results was excellent.

S304S2.04

S304S2 - Earthquake Source Dynamics: Observations and Modeling

Oral

Nucleation process of dynamic ruptures and associated radiated wavefield during laboratory earthquakes

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Earthquakes are produced by a sudden slip event localized on a fault, which releases the tectonic loading. These slip events can be physicallydescribed as the development of slip instabilities, the dynamic of which is controlled both by the elasticity of the surrounding rocks and by the contact law between the fault walls.

Here we focus on the initiation stage of ruptures, during which the slipping zone grows slowly in a quasi-static way. We use a laboratory toy-model, where in plane shear (mode II) ruptures are produced on a pre-cut fault in a plate of polycarbonate. The fault is cut at the critical angle that allows a stick-slip behavior under uniaxal loading. The ruptures are thus naturally nucleated. The material is birefringent under stress, so that the rupture propagation can be followed by ultra-rapid elastophotometry. A network of 12 acoustic sensors and 4 accelerometers is disposed on the plate to measure the radiated wavefield and record laboratory near-field accelograms. The far field stress level is also measured using strain gages.

We show that in the early stages of the rupture history, the rupture velocity grows as a power law function of time. This evolution can be related to a power law dependency of the velocity with respect to the rupture length, as was proposed by Ohnaka and Shen [1999][1]. We also show that the rupture front acceleration depends on the initial stress level. These dependencies can be relatively well explained theoretically using an equivalent of Charles's law for mode II ruptures and specific relationships between the slip weakening distance D_c or the specific fracture energy G) and the initial stress.

[1] Ohnaka and Shen (1999), *Journal of Geophysical Research*, **104**, B1, p.817-844.

S304S2.05

S304S2 - Earthquake Source Dynamics: Observations and Modeling

Oral

Is the initial thermal state of a fault crucial for its dynamic evolution?

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Earthquakes prediction undoubtedly remains one of the most pursued goals of the modern seismology. The initial state of the fault system and the choice of the governing model describing its rheological behavior play a fundamental role in the description of the earthquake recurrence. Within the framework of a deterministic description of earthquake faulting, by assuming a rate– state– and temperature–dependent (RST) rheology, we investigate whether the initial thermal state of the fault (namely the initial temperature) can have a significant role in earthquake dynamics. Within the RST models, it is well known that the initial state of a fault, expressed in terms of the sliding velocity and shear distribution, plays a fundamental role in predicting the behavior of a fault (e.g., the time occurrence of an instability). Thus, the main aim of the present work is to explore whether the initial thermal state of the fault also plays an important role in the determination of repeated slip failures on the same seismogenic structure and in the overall dynamics of the fault.

Our numerical results clearly demonstrate that the initial temperature greatly influences the cosesimic slip (and thus the earthquake magnitude), the released stress (and thus the radiated energy) and finally the interevent time (i.e., the earthquake recurrence). Despite the remaining issues on the concept of earthquake cyclicity, our results can contribute to the lively debate on the deterministic hazard assessment, illuminating that also the temperature field plays a fundamental and not simple role in earthquake dynamics, not only because it controls possible phase changes and the chemical environment of the fault zone, but also because it affects the response of a brittle fault and earthquake cycles.

S304S3.01

S304S3 - Earthquake Source Dynamics: Observations and Modeling

Oral

Modeling scale-independent heterogeneities of earthquake dynamic rupture

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Various macroscopic scaling relations for earthquake sources suggest the self-similarity of seismic sources, at least as a first degree approximation. In addition to these relations, several studies suggested that the heterogeneity of seismic sources is also scale invariant: namely a small earthquake is simply a self-similar miniature of a large event. The properties of statistically self-similar complex rupture was studies by Ide and Aochi (2005), using numerous circular patches whose size-frequency statistics obeys a power law. Each patch has its own slip-weakening law and the slip-weakening distance and fracture energy of each patch is proportional to the patch radius. This circular patch model can simulate various features observed in real earthquakes, such as multiple subevents, overall subshear rupture propagation with occasional supershear propagation, irregular rupture onsets like initial phases, and spontaneous termination. It can be also applied to real earthquakes: the complex rupture process of the 2011 Tohoku-Oki earthquake (Mw 9.0) is reasonably explained with patch distribution estimated based on the historical seismicity.

S304S3.02

S304S3 - Earthquake Source Dynamics: Observations and Modeling

Oral

Heterogeneous initial stress fields for dynamic earthquake rupture on geometrically complex faults

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Heterogeneous initial stresses can have large effects on rupture behavior along geometrically complex faults. In this study, we examine two geometrically complex fault systems, the Aksay restraining double-bend stepover of the Altyn Tagh fault, and the branching fault system of the 2008 M 7.9 Wenchuan earthquake. For the former, we use a 2D multi-cycle dynamic model to study dynamic rupture behavior across the Aksay bend. We use a viscoelastic model with analytical solutions to solve for stress evolution on the fault between two adjacent earthquake ruptures, effectively including effects of tectonic loading and stress relaxation through off-fault deformation processes. Coseismic dynamic rupture processes are simulated by a finite element method, with initial stresses that are a result of previous earthquake cycles. Although a dynamic rupture can hardly jump across this double-bend stepover in a uniform regional stress field, heterogeneous stresses developed over multiple earthquake cycles can facilitate dynamic triggering across the stepover, resulting in large events that rupture through the stepover. For the branching fault system of the Wenchuan earthquake, we perform 3D dynamic rupture modeling using a 3D finite element method. We find that a uniform regional stress field on the fault system cannot produce dynamic branching and incomplete slip partitioning features observed in the event. If the most compressive horizontal stress (sigma1) rotates between the two branched faults, the observed features in rupture propagation and slip partitioning can be reproduced. Furthermore, if sigma1 further rotates along strike of the Beichuan fault, the triggered rupture on the fault ~~40 km northeast of the epicenter reported by a recent kinematic inversion can be reproduced. These dynamic rupture models with constraints from observations suggest that the stress orientation on the fault system is non-uniform.

S304S3.03

S304S3 - Earthquake Source Dynamics: Observations and Modeling

Oral

Possible earthquake rupture speeds

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Though mode II shear fractures (primarily strike-slip earthquakes) can not only exceed the shear wave speed of the medium, but can even reach the compressional wave speed, steady–state calculations showed that speeds between the Rayleigh and shear wave speeds were not possible, thus defining a forbidden zone. For more than 30 years it was believed that this result, in which the rupture jumps over the forbidden zone, also holds for 3-D ruptures, in which mode II and mode III (mainly dip–slip faulting) are mixed.

Using unprecedentedly fine spatial and temporal grids, we show that even in the simple configuration of homogeneous fault properties and linear slip-weakening friction law, a realistic 3-D rupture which starts from rest and accelerates to some higher velocity, actually does pass smoothly through this forbidden zone, but very fast. The energy flux from the rupture tip is always positive, even within the so-called forbidden zone, contrary to the 2-D case. Finally, our results show that the width of the cohesive zone initially decreases, then increases as the rupture exceeds the shear wave speed and finally again decreases as the rupture accelerates to a speed of ~90% of the compressional wave speed. Several movies illustrating the development of the ruptures will be shown.

S304S3.04

S304S3 - Earthquake Source Dynamics: Observations and Modeling

Oral

Stochastic-dynamic earthquake models and tsunami generation

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Dynamic models are now understood to provide a physically plausible faulting scenario for ground motion prediction, but their use in tsunami hazard is in its infancy. Typical tsunami generation methods rely on kinematic or dislocation models of the earthquake source, in which the seismic moment, rupture path, and slip distribution are assumed a priori, typically based on models of prior earthquakes, aftershock distributions, and/or some sort of stochastic slip model. However, such models are not guaranteed to be consistent with any physically plausible faulting scenario and may span a range of parameter space far outside what is physically realistic. In contrast, in dynamic models the earthquake rupture and slip process (including the final size of the earthquake, the spatiotemporal evolution of slip, and the rupture path on complex fault geometry) are calculated results of the models. Utilizing the finite element method, a self-affine stochastic stress field, and a shallow-water hydrodynamic code, we calculate a suite of dynamic slip models and near-source tsunamis from a megathrust/splay fault system motivated by the geometry in the Nankai region of Japan. Different stress realizations produce different spatial patterns of slip, including different partitioning between the megathrust and splay segments. Because the partitioning of slip between fault segments has a first-order effect on the surface deformation and tsunami generation, the modeled near-source tsunamis are also highly variable. We will discuss how the variability of dynamically generated tsunamis compares to that of tsunamis generated by standard dislocation techniques, and address whether such variability can be incorporated into tsunami hazard calculations.

S304S3.05

S304S3 - Earthquake Source Dynamics: Observations and Modeling

Oral

Splay fault rupture as a mechanism to enhance ocean floor motion during the Great Tohoku-Oki earthquake : insights from BIEM dynamic rupture simulations

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We investigated the effects of interaction between the subduction interface and possible subsidiary faults branched off the main interface at shallow depth to understand the coseismic rupture propagation of the 2011 Tohoku-Oki earthquake. The fault network geometry combine realistic non-planar slab interface with several planar branched faults with various dip angles in the shallow wedge above the subduction interface, representative of possible structures identified in the wedge by seismic reflection surveys in this area. Realistic ocean bottom topography is used.

To compute interactions between the faults and free surface, we used a Boundary Integral Equation Method developed for modeling dynamic ruptures of faults close to the free surface. We assumed a realistic initial stress state on the faults. We considered 3 independent stresses: 1) a horizontal tectonic stress 2) a lithostatic stress and 3) a slip-deficit stress that is derived from a back slip modeling assuming a fully locked slab interface with an assumption of 8cm/yr background secular slip rate for 1000yrs accumulation time. We tried several typical distributions for frictional constitutive parameters. Given the initial state of stress and frictional constitutive parameters, the spontaneous rupture can be computed. The rupture is initiated at the deeper part of the slab interface and propagates updipward, as in Tohoku earthquake. When the rupture reaches the junction, a branch fault rupture can be triggered. Depending on the splay fault considered, double rupture or shadow effects are observed. Sea floor displacements are enhanced by splay fault rupture.

During the Tohoku-Oki earthquake, a large shallow slip was observed which might be an origin of the huge tsunami disaster. Dynamic interactions could have triggered rupture on multiple structures in the shallow wedge, which in turn might have enhanced the large displacement observed close to the trench.

S304S4.01

S304S4 - Earthquake Source Dynamics: Observations and Modeling

Oral

The long nucleation of most interplate earthquakes

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It has long been known that many earthquakes are preceded by foreshocks. However, the mechanisms which generate foreshocks and the reason why they occur before some shocks and not others remain unknown. We show, by analyzing seismic catalogs in some of the world best documented areas, that there is a remarkable contrast between the earthquakes which take place along the interfaces of the tectonic plates and the ones which result from the internal deformation of the plates. Most of the large ($M \geq 6.5$) shallow plate-interface earthquakes which have occurred in the well-instrumented areas of the North Pacific over the past 12 years have been preceded by an acceleration of seismic activity, indicating the presence of foreshocks. The location of these shocks and the contrast observed with intraplate earthquakes, for which foreshocks are much less frequent, suggest that the plate interface begins to slip slowly long before it ruptures. If these results are confirmed, the relatively long duration of this preparation phase may help mitigate earthquake risk in the future.

S304S4.02

S304S4 - Earthquake Source Dynamics: Observations and Modeling

Oral

The MW6.9 Yushu, Qinghai, earthquake of 14 April 2010: Inversion of source rupture process and applications to fast emergency response to the earthquake disaster relief

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The MW6.9 (MS7.1) Yushu, Qinghai, earthquake of 14 April 2010 occurred on the Garze-Yushu Fault, a southeast-striking, left-lateral strike-slipping fault, which lies on the southern boundary of Bayan Har Block. For fast emergency response to the earthquake disaster relief, we obtained the source rupture process by inverting the seismic recordings and had it released on the website and reported to the authorities about 2.5 hours after its occurrence. The released inversion results show that the Yushu earthquake consists of two distinct sub-events. The first (minor) sub-event occurred in the first 5s releasing less seismic moment, and the second (major) sub-event occurred in the later 11s releasing more seismic moment. Spatially, the minor sub-event or slip-concentrated patch was closer to the hypocenter, and the major one, about 30 km away from the hypocenter, was much closer to the Yushu city and breached the ground surface. The inverted peak-slip and peak slip-rate are about 2.1m and 1.1m/s, respectively, indicating that the Yushu earthquake is an event with large slip-velocity on the fault plane. Overall the Yushu earthquake is a southeastward propagating unilateral rupture event with rupture velocity varying from 1.6 km/s up to 4.0 km/s or a super-shear rupture velocity. It was inferred that the Yushu city, located 44 km to the southeast of the epicenter, would be heavily destroyed due to the facts that the inverted major slip-concentrated patch to the southeast of the epicenter breached the ground surface, and that the strong focusing of the seismic energy to the southeast of the epicenter caused by the seismic Doppler effect. These results have been confirmed later by the tremendous damage in the Yushu city discovered by the field survey and proved to be very informative in the Yushu earthquake disaster relief.

S304S4.03

S304S4 - Earthquake Source Dynamics: Observations and Modeling

Oral

Modeling the strong ground motion of January 27, 2011, Rigan earthquake, using Empirical Green's Function method

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The purpose of this study is modeling the strong ground motion for January 27th, 2011, Mohammad Abad Rigan earthquake, using Empirical Green's Function method. The studied area is enclosed between 57° to 61.5° East longitudes and 27° to 30° North latitudes which is located in south-eastern of Iran.

We analyze the strong motion accelograms of the mainshock (Mw=6.2) and one of its prominently recorded, large (Mw=5.2) aftershocks. First, we estimate the parameters fc (corner frequency), $\Omega 0$ (long period spectral level), seismic moment, moment magnitude, source size and average stress drop of these two events. In the next step, we use this approximate values and Empirical Green's Function approach in an iterative manner, to model the strong ground motion and rupture characteristics of the causative fault. The best reliable estimates of fault parameters show that length and width of the rupture plane is 9.5 ×9 kilometers, hypocentral depth is about 15 kilometers and strike, dip and rake of the fault plane are 126°, 77.5° and -5° respectively and also, the estimated focal mechanism is strike slip. The simulated results are compared with observed records in both frequency and time domain. Comparison of fourier and response spectra for observed and simulated records are in good conformity with each other and our results are also in good agreement with other seismological centers reports.

S304S4.04

S304S4 - Earthquake Source Dynamics: Observations and Modeling

Oral

Slip distributions of three slow slip events beneath the Bungo Channel, southwest Japan, inferred from inversion analyses of GPS data

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We estimated spatiotemporal distributions of three long-term slow slip events, which occurred on a plate interface beneath the Bungo Channel which is located convergent plate boundary between the oceanic Philippine Sea plate and the continental Amurian plate, southwest Japan during periods from 1997 to 1998, 2002 to 2004, and 2009 to 2011. For this purpose, we have developed an inversion method using ABIC which includes three prior constraints: an indirect prior constraint that the slip distribution is smooth to some extent, a direct prior constraint that slip directions are mostly oriented in the direction of plate convergence, and a constraint that temporal change of slip is smooth to some extent. As a result, the three long-term slow slip events had a common feature that slipped region expanded southwestward with acceleration of slip rates. We also found that major slipped regions moved southwestward with approximately 40 km/yr. On the other hand, southwestward or northeastward motion of slipped regions were able to be identified before or after the periods when slip rates were fast, whose direction was different from event by event. Comparing the obtained spatiotemporal slip distributions of the three slow slip events with slip-deficit rate distributions obtained in our previous study, we also investigated process of strain accumulation and release caused by the latter and the former, respectively. In the western plate interface beneath the Bungo Channel, since slip-deficit rate was small and the amounts of slips associated with the three slow slip events were large, most of the accumulated slip-deficit was estimated to be released. On the other hand, in the eastern plate interface, slip-deficit rate was large and the amounts of slips associated with the three slow slip events were small, slip-deficit was estimated to be accumulated effectively.

S401PS.01

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Modeling stress field around the fault of the 1995 Kobe earthquake (M7.2) using focal mechanisms

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Recent numerous studies about stress field estimated from focal mechanism of microearthquakes succeeded to estimate stress field in seismogenic zone. They showed heterogeneous feature around the fault. Matsumoto et al. (2012) have developed a method that models stress field composed by regional stress field and inelastic deformation in the medium. Stress variation resulting from inelastic deformation in a medium can be expressed as equivalent body forces in the medium. Thus we applied the method to the focal mechanism data of the earthquake in the aftershock area of the 1995 Kobe earthquake. The tension and compression axes inferred from the focal mechanisms of the microearthquakes generally have the same direction that could coincide with principal direction of tectonic stress in this region. However, the axes of the focal mechanisms at some parts of the earthquake fault change their direction. We performed the method to the data with assumptions that are 1) slip of the microearthquake occurred on the pre-existing small fault in the direction of maximum share stress on the fault, 2) stress field consists of the regional stress and the moment tensors at the spatially distributed grid points along the fault. The maximum direction of the obtained regional principal stress is in ESE-WNW as expected from the general tendency of focal mechanisms. The estimated moment tensors became larger at the edges of the earthquake fault. In addition, that was also relative large at around the initiation point of the earthquake. The results of the moment tensors revealed interesting information about the stress field in the target region. The inelastic deformations at the both edges of the earthquake fault and at the middle of the fault, which might relate to the initiation and termination of the earthquake rapture.

S401PS.02

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Seismic unrest at Katla Volcano- southern Iceland, is the sleeping giant waking up?

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Natural phenomena in the earth depict the dynamic nature of our planet, but human vulnerability and lack of appropriate emergency management leads to physical, environmental and financial impact. Volcanic eruptions are among these natural phenomena that leave a physical and chemical signature throughout the crust. Almost all active volcanoes exhibit changes in seismicity arising from magma movement in the crust before eruption. Meanwhile, the study of seismicity and the propagation of elastic waves through the earth have the potential to give us much information about internal structure and processes of volcanoes. Katla is one of the most active subglacial volcanoes in Iceland with at least 20 eruptions since 930 A.D., the last one in 1918. The long repose at Katla since 1918, the general unrest since 1955, and the 2010 eruption of the neighbouring Eyjafjallajökull volcano has prompted concerns among geoscientists about an imminent eruption. The permanent seismic monitoring network of the Icelandic Met Office in the area was increased to ten seismographs in 2011. Subsequently, seismicity and geothermal activity increased substantially.

A collaborative project between Uppsala University and Icelandic institutions was started in 2011 with installation of seismographs at the Katla caldera and around the Mýrdalsjökull glacier as a part of the Volcano Anatomy project and the Centre of Natural Disaster Science. Data from temporary and permanent stations will be analysed with 3-D local-earthquake and ambient-noise tomography to model the velocity structure of the subsurface and image a possible magma chamber and its plumbing system in order to increase our understanding of the volcanic reservoirs, active seismicity and the present state of the volcano

S401PS.03

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Along-strike topographic variation of the Longmen Shan and its significance for landscape evolution along the eastern Tibetan Plateau

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Regional topographic and geomorphic analyses reveal first-order topographic variations from high elevation and low-relief interior plateau to the relatively low elevation, high-relief marginal plateau in eastern Tibet. Field investigation and slip distribution modeling after 2008 Ms 8.0 Wenchuan earthquake indicate significant along-strike variability during the rupture that appears to correspond to different segments of a single fault system. This observation motivates a more careful examination of topographic features along the Longmen Shan to explore the connection between the seismic cycle and mountain building. Analyses of topographic relief, hillslope gradient, and channel gradient indices reveal significant differences in the character of topography along the Longmen Shan mountain front. The central portion of the range exhibits the highest slope, relief and steepness of river longitudinal profiles. Whereas the southern Longmen Shan exhibits only subtle differences associated with slightly lower hillslope and channel gradients, the northern Longmen Shan is characterized by topography of significantly lower relief, lessened hillslope gradients, and low-gradient channels. We consider two explanations for these topographic differences; first, that the differences in topographic development along the Longmen Shan reflect different stages of an evolutionary history. Alternatively, these may reflect differences in the rate of differential rock uplift relative to the stable Sichuan Basin.

S401PS.04

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Update on CRUST1.0 - A 1-degree global model of Earth's crust

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Our new 1-degree global crustal model, CRUST1.0, serves as starting model in a comprehensive effort to compile a global model of Earth's crust and lithosphere, LITHO1.0. The Moho depth in CRUST1.0 is based on 1-degree averages of a recently updated database of crustal thickness data from active source seismic studies as well as from receiver function studies. In areas where such constraints are still missing, for example in Antarctica, crustal thicknesses are estimated using gravity constraints.

The compilation of the new crustal model initially followed the philosophy of the widely used crustal model CRUST2.0 to assign elastic properties in the crystalline crust according to basement age or tectonic setting (loosely following an updated map by Artemieva and Mooney, 2001). For cells with no local seismic or gravity constraints, statistical averages of crustal properties, including crustal thickness, were extrapolated. However, in places with constraints the depth to basement and mantle are given explicitly and no longer assigned by crustal type. This allows for much smaller errors in both.

In each 1-degree cell, boundary depth, compressional and shear velocity as well as density is given for 8 layers: water, ice, 3 sediment layers and upper, middle and lower crystalline crust. Topography, bathymetry and ice cover are taken from ETOPO1. The sediment cover is based on our sediment model (Laske and Masters, 1997), with some near-coastal updates. In an initial step toward LITHO1.0, the model is then validated against new global surface wave dispersion maps and adjusted in areas of extreme misfit. This poster presents the next validation step: compare the new Moho depths with in-situ active source and receiver function results. We also present comparisons with CRUST2.0. CRUST1.0 is available for download at http://igppweb.ucsd.edu/~gabi/crust1.html.

S401PS.05

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Resolving details of the Icelandic upper crust using local earthquake and ambient seismic noise tomography

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The mutual interest in understanding both the structure and dynamic processes in the Icelandic upper crust, with particular focus on geothermal and volcanic areas, has led to a coordinated data acquisition effort in the Hengill/Reykjanes region in Southwest Iceland. Participating research institutes include Uppsala University, MIT and LBL in the US, along with several Icelandic research institutes. The Hengill/Reykjanes volcanic area, being a highly active volcanic region located within the mid-Atlantic ridge, constitutes an interesting natural laboratory for investigating geothermal systems, volcanic processes and related seismic activity. The main objective lies in better understanding volcanic activity and geothermal processes and investigating detailed structural features of the upper crust of the Hengill/Reykjanes volcanic area. A combination of local earthquake travel time tomography and ambient seismic noise tomography will be conducted and possibly linked to observed seismicity results. The pursued objective includes the extraction of shear wave splitting information and determination of receiver functions from the data and, thus, works towards a potential implementation of anisotropy, which is of high interest for accurate modelling and posterior interpretation in terms of physical properties, such as fracture porosity in geothermal systems. Jointly inverting for 3D resistivity structure along with the seismic velocities is also an aim of the project partners. The installed seismic network includes short period (1 and 5 s period) as well as broadband stations up to 120 s period. Data has been recorded over the past 4 years (2009-2013) with 50 stations being active during the years 2010-2012 allowing for long-term variations of physical properties within the system to be captured. This enables time-lapse studies of model constraining parameters that will allow us to better understand the ongoing processes and include a time dependency into our models.

S401PS.06

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Automated determination of P-wave polarization at GRSN

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Body wave traveltimes are often analyzed for the investigation of crustal and upper mantle structure. In addition, Pwave polarization may yield valuable information on lateral heterogeneity and anisotropy close to the recording station. However, a large number of recordings has to be studied to identify contaminations by noise and to study the dependence of the polarization attributes as a function of backazimuth and epicentral distance. We automatize the determination of Pwave polarization attributes by developing tools for the determination of the incidence angle, azimuthal deviation and linearity in different frequency ranges. We analyzed 20 years of recordings at the German Regional Seismic Networks (GRSN). These tests showed (1) that the tools yield robust estimates of the polarization parameters including quality measures if high quality data for more than about 5 years are available. (2) Misorientations of the sensors may be detected. (3) Incidence angles as well as azimuthal deviations of P-waves vary with frequency. (4) The azimuthal deviations are mainly a function of the backazimuth. (5) Fast propagation directions of P-waves may be determined by harmonic analysis of the azimuthal deviations as a function of backazimuth. Applying harmonic analysis to the azimuthal deviations measured at each station of the GRSN at different frequency bands, we extracted their dependence on the events backazimuth. It has been possible to retrieve the amplitude of the 180° periodicity term representing the anisotropy of the local structure, assuming an horizontal hexagonal symmetry axis for the anisotropy.

S401PS.07

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Pervasive Hercynian deformation vs. fossil olivine fabrics in rigid mantle-lithosphere domains of the Bohemian Massif

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Inferences from seismic anisotropy study based on teleseismic data of dense networks of seismic stations image the Bohemian Massif as a mosaic of microplates that preserve a consistent fossil olivine fabrics in the mantle lithosphere. Mantle-lithosphere domains (Babuska and Plomerova, Gondw. Res. 2012) correspond to the Saxothuringian (ST), Tepl á–Barrandian (TB), Moldanubian (MD) and Brunovistulian (BV) units. Hercynian microplate collisions led to thrustings of the MD mantle lithosphere under the TB domain and of the BV mantle lithosphere under the MD domain. On the other hand, the steep ST/TB suture shows no underthrust mantle fragment.

Boundaries of the mantle domains indicate that shapes of the MD and BV blocks changed during their underthrusting. However, seismic anisotropy in their underthrust part is consistent with that of the whole domain and indicates a preserved orientation of the fossil olivine fabric. How to explain such discrepancy? Laboratory deformations of aligned olivine aggregates show a viscous anisotropy and a grain-boundary sliding as an important (if not dominant) deformation mechanism in the upper mantle (Hansen et al., Nature 2012). Intragranular deformation of olivine is accommodated by slip on the (010)[100] system, that coincides with the high P velocity direction [100], or with the (010)[100] high-velocity foliation plane. Shapes of the underthrust MD and BV mantle domains may have changed due to pervasive deformation along the slip system of olivine grains preferably oriented obliquely to the major north-westward oriented stress during amalgamation of the microplates. On the other hand, the (010)[100] slip system of the ST mantle lithosphere dips to the north and the block might be thus strong enough to resist a potential southward thrusting under the TB unit. We suggest that a change of outer shape of colliding blocks of the mantle lithosphere does not necessarily mean a change in orientation of their internal olivine fabric.

S401PS.08

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Structure of the lithosphere across the Trans-European Suture Zone obtained by teleseismic P-wave tomography

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* The presented study is a part of the PASSEQ project done by the PASSEQ Working Group. The project aims to study the lithosphere and the asthenosphere around the Trans-European Suture Zone (TESZ) - the transition between the old Proterozoic lithosphere in the Northern and Eastern Europe and the younger Phanerozoic lithophese in the Central and Western Europe. Nearly 200 short-period and broadband temporary seismic stations were installed along 1200 km long and 400 km wide area from Germany throughout Czech Republic and Poland to Lithuania, and provided continuous recordings from May 2006 to June 2008. From the PASSEQ data set we picked 8308 arrivals of teleseismic P-waves and non-linear teleseismic tomography was used to obtain the model of the seismic P-wave velocity variations in the upper mantle beneath the TESZ. In the area under study the crustal thickness varies from 30 km in the Phanerozoic crust to more than 50 km in the Proterozoic crust. In addition, the thickness of the sedimentary cover varies significantly, which could have a pronounced effect on results of teleseismic tomography. We corrected the observed travel times for crustal effects using the continent-scale EUCrust07 crustal model that was upgraded using regional crustal velocity models for Poland and Lithuania. Modelling with synthetic tests has shown that using of precise crustal corrections could improve significantly the results of teeseismic tomography for the upper mantle. The final model showed a number of high- and low velocity anomalies in the region under study, with the most complicated structure beneath the TESZ.

S401PS.09

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

On the geodynamics of western Greece deduced from massive seismological observations

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Catalogue and recent waveform earthquake data are used to study the geodynamic regime in western Greece. The study area includes Epirus, Aitoloakarnania, western Corinth Gulf, Patras Gulf, western Peloponnesus and Ionian Islands (Zakynthos, Cephalonia, Ithaki, Lefkas, Corfu). This region was activated during the last decade with the occurrence of several moderate to strong events, providing a large amount of new information of enhanced quality obtained by the recently developed Hellenic Unified Seismological Network (HUSN). A new catalogue of seismic phase data was compiled, including seismic activity with $M_L \geq 2.0$, recorded by the HUSN. Additionally, available phase data recorded by local networks in the frame of aftershock sequences monitoring and temporary microearthquake campaigns were employed. To achieve improved hypocentral locations the concept of double differences was applied and more than 15000 events were relocated. A catalogue of all available focal mechanisms was constructed and evaluated. The catalogue was de-clustered and a damped iterative technique was used to invert the focal mechanisms, in order to obtain the spatiotemporal regional stress field parameters. The combination of the above procedures allowed the detection and investigation of several seismogenic and aseismic zones across the study area, enlightening up to a degree the complex style of its crustal deformation with the elaboration of a geodynamic model. In the context of a future detailed survey, a strategy for collecting complementary data at specific sites in the area is proposed.

S401PS.10

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Illuminating upper mantle structures beneath Taiwan region by joint inversion of local- and tele-seismic data

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The Taiwan region in Southeast Asia situated at a junction among a passive continental margin and two subduction systems (Rykyu trench to the east and Manila trench to the south) exhibits a complicated tectonic framework. The architecture (particularly under the central to northern Taiwan) of the continental lithosphere and subducting slabs remains intensely debated. Models as lithospheric collision, continental subduction, tandem suturing, slab tearing, and subduction flipping were proposed sequentially but lack clear images in the upper mantle. A most recent tomographic model produced by TAIGER (TAiwan Integrated GEodynamics Research) project with deeper resolution up to 200 km revealed an east-dipping high velocity zone that seems continuously beneath Taiwan Island, but the imaging gradually diminished northward. The slab interaction in the northern Taiwan is therefore still enigmatic. To improve the general resolution, we integrated the EHB data (Engdahl et al., 1998), a groomed version of ISC (International Seismological Center) bulletin, with Taiwan broadband seismic network (deployed by BATS and CWB) to expand the regional station span and our data amount. In addition, a high-resolution local tomographic model (Huang et al., 2013) was also embedded in a broader regional one as the initial model (i.e. crustal heterogeneity eliminated). We then conducted a joint inversion of local- and tele-seismic data in a nonlinear iterative manner to count the ray path effect in a highly heterogeneous region like Taiwan. Results showed that both the subducting slab can be well imaged. A gap of high velocity zone between slabs appears in the deeper part under northern Taiwan, implying two slabs are separated by the continental lithosphere in between. However, the interaction geometry is complicated. Together with relocated seismicity, detail structures were then delineated and discussed in this study.

S401PS.11

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Gravity gradient for Greenland and its tectonic interpretation

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Gravity gradient is the indicator of the stress conditions in the lithosphere. Range of the changing for gradients of gravity in free air anomalies from –96.1 to 135.8E. and for gradients of gravity Bouguer's anomalies – from –122.6 to 141.9 E.

Range of the changing for gradients of gravity Glennie's and isostatic anomalies are substantially smaller, for gradients of gravity Glennie's anomalies – from –27.6 to 25.5 E, and for gradients of gravity isostatic anomalies – from –19.2 to 21.2 E. Analysis of gravity gradient shown the following:

1. In the western part of the researching region are distinguished three linear structures (two maxima and one minimum), which marked rift zone of the Baffin Bay and Davis Strait. This disappeared rift characterized by depressed zone, lengthened from Nares strait along the west sea coast of Greenland. In the south part of this zone localized deep fault, which northward become lesser expressed. To the north and north-east from the Nares strait lengthened to the North Pole zone of compression, blocked up existing previously rift, by which the rotation of the Greenland part of Canadian shield from its cardinal part happened.
2. The fading of the west rift began after disclosure of the rift zone of northern part of the Mid-Atlantic ridge. Meanwhile arising east rift zone lead to the changing of the Greenland moving direction, that, probably, offer to origin compression zones in all coastal zone of Greenland, lead to orogeny. At At the same time the central part of the Greenland plate was not compressed and remained weakly strained.
3. The Mid-Atlantic ridge is exhibited in the gravity gradients much weaker than the west rift zone. The linear structure (axis of the gravity gradient minimum) was not observed, but then the changing and characterized by the negative gravity gradient, while region to the east of the rift, gravity gradient are positive.

S401PS.12

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Gravity gradient for Antarctica and its tectonic interpretation

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Gravity gradient indicate deep faults, weaken zones and zones of the raised tension of lithosphere.

Range of the changing for gradients of gravity in free air anomalies - from –56.3 to 57.3 E, and for gradients of gravity Bouguer's anomalies – from -75.6 to 56.4 E. Analysis of Bouguer's anomalies gradient (it is evidently more significant) shows the following:

1. East Antarctica has most simple tectonic structure. Here compression stress concentrates in region of the Transantarctic mountains, In central zone either weak extension has place, or stresses are in the average absent, in coastal zone, apparently, compression takes place, which seaward changed by extension. So, East Antarctica is platform region (stresses are weak), borded orogens and deep faults (region of compression changed by extension);
2. West Antarctica has more complex structure, this, seemingly, due to the fact, that it is a conglomerate of the terrains of different origin. The depression, corresponding with the front mountain flexure of the Transantarctic mountains, subjects to extension, this regionchanged in central zone (Marie Byrd Land and adjusted eastward zone, till Weddell sea) by compression, Antarctic peninsula and Ellsworth mountains subjects to compression, but directed by the other angle. This coimpression zone, seemingly, continued in western parf of Weddell sea;
3. Scotia sea, appear comparatively small region, has very complex structure. Compression zones changed here by extensive zones, in which stresses changes its direction, and dominating its direction close to latitudinal. This situation becomes more complicated through the inclusion of the continental crust blocks, yet, that, generally, Scotia sea crust is oceanic.

S401PS.13

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Lithosphere: some negative effects of the increasing stress state of the medium

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Over the past 50 years, the number of atmospheric disasters (hurricanes, tornadoes, floods, etc.) has grown immeasurably, reflecting environmental changes resulting from uncontrolled human activity. We assumed that large-scale disturbances in one Earth sphere should be reflected in another one - in lithosphere, followed by powerful and stable increasing of the stress state of the medium, cause negative effects that infringe on the interests of many countries, as they may be the cause of rapid watercut and destruction of the oil fields. Note that our work has shown that external impacts with incorrectly selected tactics of fields' development cause more significant destruction of them. According to analysis of the official world statistics, 2003-2007, the scale of negative changes appeared to be more serious: fix a trend we have identified - a fact of steadily drop in oil production from year to year in all regions with more or less intensity, depending on external impact. Thus, the significant drop observed in a number of fields in Baltics, Central Asia, Siberia, and Tatarstan, making up to 10% in some years, at a normal rate of 1-2%. The maximum decrease in daily production in North America was noted in Mexico (this region has repeatedly been subjected to UNE, and inexplicable sharp drop in oil production in the Gulf of Mexico was noted a year before the disaster) - 12.3% (!), in the U.S. - 6.4%, in South America - in Chile (the most powerful earthquake of the twentieth century was noted in this country) - 17.5%, in Bolivia - 8.8%, and in Venezuela - 6%. Further, in other countries: in England - 13%, in Austria - 7.8%, in Bulgaria - 33.3% (!), in Croatia - 9.1%, in Egypt - 6.4%, in Syria (14%), in New Zealand (14.8%) - (areas that are also close to UNE). Thus, the loss from oil production and destruction of fields during the past decade (and consequently in oil reserves), the real unveiled economic loss caused by adverse environmental effects, grows many times.

S401PS.14

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Lithospheric block model as test bench for plate reconstructions and plate-mantle coupling

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Existing global plate reconstructions are based purely on surface observations, i.e. primarily seafloor magnetization. For plates where only little or contradicting information is preserved, assumptions must be made by extrapolating the existing evidence.

In general, plate motion is a consequence of viscous coupling between the plates and the underlying mantle and friction between the plates themselves. Thus, an unambiguous reconstruction of plate motion requires the knowledge of this whole force balance. However, this is inherently problematic because the mantle velocity field is generally unknown; it can only be inferred from surface motion, and usually the reconstructed plate motion is used directly as a velocity boundary condition for mantle models.

As a consequence, the motion of some oceanic plates that have largely been subducted is only poorly known. However, it is possible to improve our knowledge of plate motion by including physical constraints. We use a numerical lithospheric block model to determine the plate boundary forces; by testing different rheological assumptions, we can infer implications on the plate motion and also on the mantle velocity field, due to its smooth nature.

S401S1.01

S401S402S1 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

Recent and historic stress and strain around the Gothenburg-earthquake of 1759

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The largest earthquake of the SW edge of the Baltic shield area occurred in 1759 near Gothenburg. It is an intraplate region where the dominant horizontal stresses are compressive NW-SE caused by lithospheric plate motion. The recent instrumentally recorded earthquakes show a gradual geographical scatter across the bedrock area of western Sweden into the Kattegat Sea with stepwise thicker sediments up to the order of ten kilometers, i.e. no concentrated activity in any of the large scale geological boundaries across Denmark. Geodetic and geological strain measurements show a dominating smooth uplift bulge, and connected horizontal compression, around the uplift center in northern Scandinavia, since the termination of the Ice Age 9,000 years ago. Geological searches for paleoseismicity show convincing postglacial earthquakes in northern Scandinavia, while indications in western Sweden around Gothenburg, and in Denmark are discussed with enthusiasm. A field trip is arranged to discuss this on site after this conference. A drastic change of the stress and strain over the last 9,000 years is here claimed to be the conclusion. The Gothenburg earthquake magnitude is here suggested as close to five and a half.

S401S1.02

S401S402S1 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

Seismic tomography in the source region of the May 29th 2008 earthquake aftershock-sequence in southwest Iceland

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On May 29th 2008 two earthquakes with moment magnitude of Mw ~6 occurred in the southwestern part of Iceland on two north-south oriented parallel faults in the Ölfus area. The second earthquake struck within only seconds after the first, on a fault ~5 km west from the first fault. The aftershock sequence was recorded by 14 seismic stations during the subsequent 34 days. Nearly 20 000 events were recorded in this time period. The recorded earthquakes were detected and located with a Coalesence Microseismic Mapping (CMM) technique (Brandsdóttir et al., 2010). The output data from this program has been used as basis for the tomography algorithm PStomo_eq, which simultaneously inverts for both P- and S-wave velocities and relocates the events. Within the study area of 46×36 km a three-dimensional velocity structure has been modeled to depths of ~10 km.

The Vp/Vs ratio varies from 1.74 to 1.82 within the study area. The velocity increases with depth starting from 2 km where the P-wave velocity is 4.6 km/s and the S-wave velocity is 2.7 km/s. At 10 km depth the P-wave velocity is 6.9 km/s and the S-wave velocity is 4.0 km/s. A high velocity area is seen in horizontal slices in the northwestern part of model. This is interpreted as a solidified magma body risen from below. Lower than normal velocities are observed above an east-west seismicity cluster (from 21.5° to 21.2° W) at depths between 2 to 4 km. We suggest it is caused by high fracture porosity within the area. The east-west seismicity cluster is itself associated with normal velocities, but with a slightly reduced Vp/Vs ratio (1.74 compared to the normal 1.78). This is possibly attributable to high pore pressures. The depth to the ductile crust, defined as a sharp cutoff in the seismicity, increases from about 7 km in the western part of the model to 9 km below the two faults.

S401S1.03

S401S402S1 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

Surface wave tomography of central and northern Europe from automated interstation measurements

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To tackle the ever increasing amount of available broadband seismic data for routine analysis, manual data processing and retrieval of certain observables (e.g. dispersive traveltimes, polarisation parameters) needs to be replaced by automated processing tools. We developed an automated routine to measure inter-station phase velocity curves of fundamental mode Rayleigh and Love waves by pairwise cross-correlating seismograms. Making use of path-specific reference models based on CRUST2.0, only three parameters that control the acceptable bandwidth of a given observation are required for our automated routine to identify and pick acceptable dispersion curves.

The procedure is applied to around one million waveforms and about 60,000 paths on permanent and temporary networks including TOR, and PASSEQ networks in central and northern Europe. The fundamental mode Rayleigh and Love wave dispersion curves are then inverted for anisotropic phase-velocity maps in the period band 10 – 200 seconds. At 15-s period, pronounced low velocity anomalies delimit the deep sedimentary basins in central Europe and around the Alps. The Trans-European Suture zone as a sharp transition from lower to higher velocities is clearly delineated at longer periods (60 and 125 s) which are sensitive to upper mantle depths. We will discuss particularly our results of variations in anisotropy across the continent.

S401S1.04

S401S402S1 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

Scandinavia: A former Tibet?

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The Himalaya and the Tibetan Plateau are uplifted by the northward underthrusting of the Indian continental lithosphere below the Eurasian continental plate resulting in lithospheric stacking. This model is based on imaging obtained from seismic tomography and S to P at the lithosphere-asthenosphere boundary (LAB). Due to the similarity of the lithosphere below Tibet and some cratons, Tibet is considered as a place where the development of future craton is under way now. S receiver functions6 along a seismic profile from central Germany to northern Scandinavia show evidence for a similar lithospheric stacking as it was found below Tibet. We observed the LAB at about 100 km depth from Germany to the Archean domain in northern Scandinavia, where it ended abruptly. We also observed the bottom of the asthenosphere (Lehmann discontinuity) deepening from 180km in Germany to 260km below Sweden. Below Sweden we found an additional high velocity mantle layer between about 130-200km depth reaching from the Archean in the north to southern Sweden where it is dipping to the south. We interpreted this zone as a part of the Baltic mantle lithosphere which was subducting at a low angle into the Laurentian asthenosphere during the Caledonian collision of Laurentia, Baltica and Avalonia 400-500 million years ago. This process resulted in lithospheric stacking which is still visible today. It could also have caused a high plateau which was eroded away in the geological epochs since then.

S401S2.01

S401S402S2 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

Upper-mantle velocity structure beneath Jutland, Denmark and northern Germany: Preliminary results

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Several temporary seismological arrays have probed the crust and lithosphere in northern Germany and southern Scandinavia (Tor, CALAS, MAGNUS and TopoScandiaDeep, see e.g. Medhus et al., 2012). In 2011-12 we measured the Jutland-Lower Saxony (JULS) profile as collaboration between Aarhus University and GFZ Potsdam. This profile crosses the southern part of the Tor array in the North German Basin and goes all the way to the northern part of Jutland (mainland Denmark). First results are presented from this new study. P-traveltime residuals were modeled with a new flexible 3D tomographic method which maximizes resolution under profile arrays (Hejrani et al., 2011).

This optimized profile yields new information on the upper-mantle velocity field beneath Jutland and parts of northern Germany. It clearly outlines a high velocity body located in the uppermost mantle beneath the North German Basin. It correlates very well with the location of a similar body located by the Tor project (e.g. Gregersen et al, 2002, 2009). The northern part of the JULS model links well with the previous results from the CALAS and TopoScandiaDeep projects (Medhus et al., 2012).

S401S2.02

S401S402S2 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

Diversity of lithospheric seismic structure in the Baltic shield

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We analyze the diversity in the seismic structure of the lithosphere in different parts of the Baltic Shield by comparing the shear velocity profiles with depth obtained by analysis of surface wave dispersion below the SVEKALAPKO, LAPNET, MAGNUS and TOR projects located respectively in southern Finland, northern Finland, southern Norway and southern Sweden. The profiles are based on depth inversion of phase velocity dispersion of fundamental Rayleigh modes. The profile under the LAPNET network is based on new data from 46 seismic broadband stations and almost 200 magnitude >6 events. The data from the other networks have been analyzed before but are reprocessed here to ensure a common procedure in the depth inversion. The comparison of the different profiles show strong variability of the lithospheric structure, despite that they are all located in the Baltic Shield. In northern Finland, we observe a well resolved low velocity zone starting at approximately 150km depth, while the shear velocities above are typical for cratonic lithosphere. Immediately south of LAPNET, in an area dominated by paleaproterozoic rocks at the surface, the lithosphere is fast to a depth of 225-250km, while cratonic lithosphere seems to be absent beneath southern Norway, where the velocities are low at 150 km depth. The low velocity zones indicates that the lithosphere beneath northern Finland and southern Norway are either modified at depth, for example through metasomatism, or that they are thinner than in the more internal part of the Baltic Shield. We discuss which mechanisms such as subduction and/or collision could potentially modify (by fluid injection) or remove (by erosion/dripping) otherwise stable cratonic lithosphere.

S401S2.03

S401S402S2 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

Role of lithosphere rheology on strain partitioning in transpressive systems: example of the Queen Charlotte margin

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We study the rheology of the lithosphere and its role in strain partitioning in transpressive systems. We use the Queen Charlotte Fault in western British Columbia as a case study. The area is characterized by transition from the Cascadia subduction zone to the Queen Charlotte transform fault, with a tectonic setting that involves interactions between various plates as well as a number of plate boundaries. Using GPS campaign data from 1993 to 2008 we derive a new crustal velocity field for Northern Vancouver Island and the adjacent mainland, and integrate it with previous velocity fields developed for Haida Gwaii, southern Vancouver Island and the adjacent mainland. We use viscoelastic models to explore what percentage of the observed deformation is transient, related to the earthquake cycle, and how much is permanent ongoing deformation, distributed off the continental margin. In a first step we calculate the effective viscosity based on heat flow and resulting geotherms, strain rate, and laboratory crustal and upper mantle rheologies. To accommodate the different values for strain rate, heat flow and crustal thickness across the margin, a suite of models has been calculated. These results provide a first order estimate of plausible effective viscosity values for the viscoelastic part of the FEM models used to calculate post- and interseismic velocity profiles in the second step.We then use the modeling results and the updated velocity field for the region to investigate how the Pacific/North America plate convergence is accommodated off Haida Gwaii. Previous authors have developed two competing end-member models assuming either internal crustal shortening or underthrusting of the Pacific plate. With the new modeling results and the updated velocity field for the region we can determine which model explains the tectonic situation most appropriatly, while also keeping in mind the recent Mw 7.7 earthquake on the Queen Charlotte fault and its mechanism.

S401S2.04

S401S402S2 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

Controls on upper plate deformation through the earthquake cycle in subduction zones

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The recent Mw 9.0 Tohoku event and other great subduction zone earthquakes over the past decade provide observations of the range of behaviors of upper plate deformation through the seismic cycle for megathrust events. This set of great subduction zone earthquakes show a diversity of deformational behavior co-seismically implying diverse inter-earthquake strain accumulation behavior. What controls this range of behavior has important consequences for our ability to use observations of pre- co- and post-seismic displacements and deformation to infer the nature, pattern and magnitude of moment accumulation on the megathrust plate boundary. The recent Tohoku earthquake provides observations (made on the upper plate) of both strain accumulation and release that allow us to explore the roles of variability of lithospheric mechanical properties, megathrust coupling, and rupture progress during the megathrust earthquake to improve our capability of linking surface observations to deformational processes along the megathrust. From a theoretical side we are systematically testing via numerical modeling the effects of variations in rheology (e.g. elastic parameters, viscosity etc.) in controlling the partitioning of deformation during the earthquake cycle. We find stark differences in the overriding plate deformation field depending on whether it is mechanically weak or strong relative to the subducting lithosphere. If relatively strong, pre-seismic surface deformation may give the false impression of the rate at which the subduction interface is accumulating slip deficit. We are using observation from these recent great earthquakes to assess how slip and moment release on the megathrust is mapped into observed co-seismic displacements; essentially determining the way in which the upper plate filters the observations of plate boundary slip.

S401S2.05

S401S402S2 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

Estimation of stress state at Saymareh dam site

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We carried out the stress state of poroelastic medium, which entails both the shear and normal stress of the rock, is influenced by pore-fluid diffusion in the underneath crust of Saymareh dam site. Saymareh dam is one of the greatest dams in Iran which is placed in the south west of Iran in Zagros Mountain. The volume of Saymareh dam is about 4.3 billion cube meters. Coulomb stress changes due to pore pressure changes in a poroelastic medium may lead to microseismic events. So the knowledge about stress state in the vicinity of dam can illustrate candidate regions to failure. In this paper, we introduce the concept of Coulomb failure stress changes as applied to the study of regional static stress changes in Saymareh dam area. Here, we show Coulomb failure stress maps for the selected area of our study.

S401S2.06

S401S402S2 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

Dislocation damping and anisotropy of seismic-wave attenuation

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Our previous forced-oscillation studies on hot-pressed and pre-deformed specimens of polycrystalline olivine prepared from fully synthetic (sol-gel) powders suggested that both intergranular (grain-boundary sliding) and intragranular processes (dislocation glide) may contribute significantly to the dispersion and attenuation of seismic waves within the Earth's deep interior (Farla et al., Science, 2012). In order to better quantify the relative contributions of these two relaxation processes we have prepared and tested a suite of polycrystals from pulverised natural (San Carlos) olivine that are significantly more coarse grained (8-17 micron) than the sol-gel specimens (3-6 micron). Like their sol-gel counterparts, the San Carlos olivine specimens – both hot-pressed and pre-deformed either in compression or torsion – have been subjected to microstrain torsional forced oscillation and microcreep tests under conditions of simultaneously high pressure and temperature. The shear moduli and strain energy dissipation measured on the hot-pressed specimen are closely consistent with a Burgers-type creep-function model fitted to similar data for a pre-existing suite of undeformed olivine polycrystals including both sol-gel and San Carlos representatives. Higher levels of dissipation and stronger modulus dispersion, observed for the pre-deformed San Carlos specimens, especially that deformed in torsion, indicate a significant contribution from dislocation glide. The more pronounced enhancement of dissipation for the specimen pre-deformed in torsion, suggests that its dislocations are generally more favourably oriented for re-activation during the subsequent micro-strain torsional oscillation test. These observations suggest that seismic wave attenuation in the Earth's upper mantle may be most pronounced for shear waves with propagation and polarisation directions suitably oriented with respect to the prevailing/fossil tectonic stress field.

S402PS.01

S401S402PS - Lithospheric structure, stress and deformation/Orogenic systems

Poster

Lithosphere-asthenosphere model beneath the Northern Apennines: Insights from seismic anisotropy into the orogenic system

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Orogeny of the Northern Apennines has been controlled by processes of syn-convergent extension related to a roll-back of the Adriatic slab and to an extension of the Tyrrhenian back-arc basin, all driven by the slow collision of the African and European plates. We image anisotropic structure of the upper mantle beneath the Northern Apennines by analyzing teleseismic body-wave anisotropy evaluated from data collected during experiment RETREAT (2003-2006). Joint analysis of anisotropic parameters evaluated from two independent data sets – teleseismic P-wave travel times and shear-wave splitting – allows us to recognize three main regions – the Tyrrhenian, Adriatic and Transition in between. Each of these regions is characterized by its own anisotropic pattern resulting from oriented fabrics both in the mantle lithosphere and in the sub-lithospheric mantle. Beneath the thin Tyrrhenian plate, a slab-parallel flow prevails in the sub-lithospheric mantle, while nearly slab-perpendicular high velocities dominate on the other side of the region, beneath the thicker Adriatic plate. This asthenospheric-flow pattern excludes a simple corner-flow model that would fit the fabric of the upper mantle in the syn-convergent extensional tectonics and thus suggests the end of the subduction roll-back. Two domains of the continental Adriatic lithosphere are characterized by their own fossil fabric with inclined symmetry axes. From careful azimuthal analysis of static terms of the relative P-wave travel-time residuals, we estimate the lithosphere thickness of the Tyrrhenian and Adriatic plates at ~50 km and ~80 km, respectively, the latter being subducted down to no more than ~200 km with indications of inherited frozen-in anisotropic fabric. The overall image of the upper mantle in the region indicates that if a potential detachment at the Northern Apennine slab exists then it would have to be narrow and in its initial stage.

S402S1.01

S401S402S1 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

The deep structure of the Scandes and its relation to tectonic history and present-day topography

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The Scandinavian Mountain Chain (the Scandes) is an intracontinental mountain chain at the western edge of the Baltic shield, and has its southern dome-like part located in southern Norway. The timing as well as the processes causing the formation of the Scandes are disputed. We bring new geophysical constraints to this issue by providing crustal and mantle models derived from seismic modelling for southern Norway, and by integrated modelling of the lithosphere and its potential deformation. The analysis has been done in the framework of the TopoScandiaDeep project, a component of the TOPO-EUROPE programme. New maps of Moho depth and crustal seismic velocities have been compiled using data from seismic refraction lines, P-receiver functions and noise cross-correlation analysis. These results show a thickening of the crust from southwest to northeast below the southern Scandes and a small crustal root not directly located below the topographic high. P-, S- and surface wave tomography infer seismic mantle velocities lower than in normal shield structure, with a possible sharp boundary close to the Oslo Graben. These low velocities are imaged in the lithosphere and in the underlying mantle down to the 410 km discontinuity. Integrated modelling of seismic models and gravity data shows that the low velocities below southern Norway are compatible with a change in lithosphere thickness from c. 100 km under southern Norway to nearly 200 km under southern Sweden, with possible additional differences in composition. The study also indicates that the topography can be largely isostatically sustained by the density distribution in the crust and lithospheric mantle. We argue that the lithospheric lateral variation has been present for at least 300 My and has had a significant influence on the localisation of the topography, independently of the mechanism for uplift.

S402S1.02

S401S402S1 - Lithospheric structure, stress and deformation/Orogenic systems

Oral

Reconstructing the growth of high topography across eastern Tibet in space and time

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How Tibet grew – when, where, and how its crust thickened and elevations rose remains one of the fundamental and hotly debated questions of continental tectonics and lithospheric geodynamics. New results indicate that the eastern margin of the present-day plateau adjacent to the Sichuan Basin, the Longmen Shan, has had a longer and more complex history of uplift than previously recognized. The consensus of the past decade that high topography in the eastern Tibetan Plateau developed largely, if not entirely, since the Late Miocene appears to be incorrect. Our recent results indicate that regions of the eastern Tibet margin adjacent to the Sichuan Basin experienced a two-stage history of rapid exhumation (and by proxy, uplift) that began in Oligocene time. This revised uplift/exhumation history is documented in one region of the plateau margin but its regional extent and tectonic significance needs to be assessed. What is not clear is whether the earlier (Eocene - Oligocene) exhumation history reflects regional crustal thickening or simply records the localized evolution of one crustal block. If the history recorded in the Pengguan massif represents regional uplift, this implies that very soon after India-Asia collision, the geographic extent of the Tibetan Plateau was similar to today. Elsewhere in northern Tibet there is documented Eocene-Oligocene deformation along the margins of the Qaidam basin, in the Qilian Shan, and in northeastern Tibet. Preliminary results from thermochronologic sampling and modeling along a transect from the Sichuan Basin margin into the interior of the plateau indicate a complex history of timing and magnitudes of exhumation (and by proxy uplift). Despite our project being limited to the eastern Tibetan plateau, our results address when large-scale continental deformation began in the eastern plateau, whether it was continual or pulsed (in space and time), and the specific rates at which exhumation (and by proxy crustal uplift) occurred.

S501PS.01

S501PS - Structures in the Mantle and Core

Poster

Measurements of inter-station phase speeds and attenuation of surface waves in North America with USArray

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Anelastic attenuation of seismic waves provides us with an insight into the distributions of temperature and water in the Earth's mantle. While a number of high-resolution seismic velocity models have been proposed, anelastic attenuation models have yet to be investigated in detail, mainly due to the intrinsic difficulties and uncertainties in the amplitude analysis of observed seismic waveforms.   We have developed a new method to measure inter-station phase speeds and amplitude ratios simultaneously, working with a fully non-linear inversion scheme for the fundamental-mode surface waves. We employed the neighborhood algorithm (NA) that enables us to explore the model parameter space so as to fit the two observed waveforms on a common great-circle path by perturbing both phase and amplitude of surface waves in a period range from 25 to 200 seconds. This method has been applied to observed data from the transportable seismic network in United States (USArray). Our preliminary analysis indicate good correlation with the conventional tomographic results of surface-wave phase speeds and attenuation in North America; e.g., significant slow velocity anomaly and high attenuation in the western United States. Our measurements also suggest the large uncertainties in the amplitude ratio between two stations, primarily due to local site effects and/or uncertainties in the reported instrument responses. Proper station-correction factors will need to be considered to compensate for the large uncertainties in the observed amplitude anomalies, when we construct tomographic models of surface-wave attenuation. The current measurement technique with a high-density seismic array enables us to gather a large number of phase and amplitude data at short distances less than 1000 km in an efficient manner, which can be of great help in improving the horizontal resolution of the regional or local scale models with intermediate- or long-period surface waves.

S501PS.02

S501PS - Structures in the Mantle and Core

Poster

Seismic images of the upper mantle velocities and structure of the European mantle lithosphere

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Tomography images of seismic velocities in the Earth mantle represent significant tool for recovering first order structural features. Regional studies, based on dense networks of temporary stations allow us to focus on structure of the continental upper mantle and to study variations of body-wave velocities in greater detail. However, the standard tomography exhibits only isotropic view of the Earth, whose structure is anisotropic in general, as shown by results of various studies exploiting a broad range of methods, types of waves and scales. We present results of our studies of seismic anisotropy in tectonically different provinces that clearly demonstrate the continental mantle lithosphere consists of domains with different fossil fabrics. We detect anisotropic signal both in teleseismic P-wave travel-time deviations and shear-wave splitting and show changes of the anisotropic parameters across seismic arrays, in which stations with similar characteristics form groups. The geographical variations of seismic-wave anisotropy delimit individual, often sharply bounded domains of the mantle lithosphere, each of them having a consistent fabric. The domains can be modelled in 3D by peridotite aggregates with dipping lineation a, or foliation (a,c). These findings allow us to interpret the domains as micro-plate fragments retaining fossil fabrics in the mantle lithosphere, reflecting thus an olivine LPO created before the micro-plates assembled. Modelling anisotropic structure of individual domains of the continental mantle lithosphere helps to decipher boundaries of individual blocks building the continental lithosphere and hypothesize on processes of its formation (Plomerova and Babuska, Lithos 2010). Fossil anisotropy preserved in the mantle lithosphere is exploited to map the lithosphere-asthenosphere boundary as a transition between the fossil and the present-day related anisotropy in the asthenosphere.

S501PS.03

S501PS - Structures in the Mantle and Core

Poster

Lithospheric and upper mantle structure across the Trans-European Suture Zone from receiver functions

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The Trans-European Suture Zone (TESZ), the border between the Precambrian East European Craton (EEC) and Phanerozoic Central Europe, has been tomographically imaged as a distinct lithospheric boundary. As such, it might also influence the thermal structure and dynamics of the sub-lithospheric mantle. Here, we trace the lithosphere-asthenosphere boundary (LAB) and the mantle transition zone (MTZ) discontinuities across the TESZ by means of a new, large dataset of P- and S-receiver functions (RFs). We used the data of the international PASSEQ experiment, which offers the densest coverage across the TESZ so far. In S-RFs west of the TESZ, a LAB conversion is found at an average depth of 90 km, similar to surface wave results. For stations in the EEC, we also observe conversions due to a velocity reduction at ~100 km depth. As this observation cannot be caused by the tomographically imaged LAB, we rather explain it as mid-lithospheric discontinuity. At some of the cratonic stations, we also observe a negative conversion of similar size that could be related to a velocity decrease at 190 km to 230 km depth, close to depth estimates for the cratonic LAB. With both P- and S-RFs, we observe significantly shorter travel times for MTZ conversions within the EEC, caused by high velocities within the cratonic root. By contrast, the differential travel time across the MTZ is normal, implying no insulating effect of the cratonic keel in the MTZ. Within Phanerozoic Europe, no widespread thermal effects of Caledonian and Variscan subduction remain. Only more recent tectonic events (i.e. Alpine subduction, Eifel volcanism) can be traced. Remarkably, we discover the signature of the TESZ in the MTZ as a linear region of ~350 km width with a 1.5 s increase in differential travel time. We relate this observation to a temperature decrease of ~80 K. Our preferred explanation for this anomaly is edge-driven convection caused by the contrast in lithospheric thickness across the TESZ.

S501PS.04

S501PS - Structures in the Mantle and Core

Poster

Effect of compositional anomalies beneath the western United States

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Much of the tectonic and magmatic activity within the western United States can be attributed to the evolution of its western margin from subduction to transform dominated. Recent tomographic studies underneath the western North America have revealed multi-scale heterogeneities that could be associated with the tectonic activity of the region. The removal and fragmentation of the flat slab during Laramide orogeny have led to the abundance of high velocity features in the sub-lithospheric mantle. However, imaged heterogeneity at very small wavelengths may not be solely due to temperature variations. In fact, the juxtaposition of high and low velocity structures at short wavelengths and strong Vp/Vs variations indicate the importance of partial melt in addition to temperature variations. In this study we seek to explain how much of the short wavelength features can be explained by temperature variations alone and how much of those are compositional in nature. The relation between density and seismic anomalies is expressed in terms of velocity-density scaling factor, $d\ln \rho / d\ln V_s$. Where chemical heterogeneity dominates, a uniform scaling factor will not be sufficient; laterally variable velocity-density scaling needs to be invoked in order to explain the anomalies. We evaluate basal tractions and the resulting stresses over North America by incorporating lateral viscosity variations arising due to slabs, keels and low viscosity asthenosphere in a global, high resolution, finite element convection code, CitcomS. We also make realistic assumptions of variable scaling factors and attempt to match the geoid and dynamic topography in addition to the stress field in that region.

S501PS.05

S501PS - Structures in the Mantle and Core

Poster

A hole of stagnant slab: Implication for volcanism, back-arc opening and trench migration

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We obtained three-dimensional P-wave velocity model with a focus on the Northeast China. We combined global data with the data of a passive broadband seismic experiment, NorthEast China Extended SeiSmic Array (NECESSArray) deployed since 2009 for two years. The result shows slow anomalies below the Cenozoic volcanoes around the Songliao basin. The slow anomalies can be traced down to 200km depth. On the other hand fast anomalies are observe below the Songliao basin in the uppermost mantle up to a few hundred km depth. In the mantle transition zone, the slab subducted form the Japan Trench meets to the 660-km discontinuity beneath the orogenic at the eastern margin of the basin. No extended flatten slab is observed to the further west beneath the basin in the transition zone while it is observed to the north and south. It looks like a hole of the stagnant slab. The volcanism around the Songliao basin has been active since about 30 Ma. At approximately the same time, the opening of Japan Sea has taken place and the Izu-Bonin Trench started to migrate rapidly eastward with a clockwise rotation as contrasted with the moderate migration of the Japan Trench. We speculate that absence of the stagnant portion of the Japan slab are caused by a slab detachment and the geological events above were related with the detachment.

S501PS.06

S501PS - Structures in the Mantle and Core

Poster

Investigating the nature of the 520-km discontinuity with P520s conversions: Case studies in South America

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Laboratory experiments have shown that a phase transformation in the olivine-normative component of the upper mantle should develop at depths of 520 km but the detection of this discontinuity has proven to be quite intermittent on a global scale. A number of studies have additionally reported that this discontinuity splits into two separate discontinuities, about 60 km apart, under some regions. Intermittency has generally been attributed to low detectability, perhaps due to lateral variations in temperature and/or composition, while splitting has been attributed to Ca-enriched lithologies.

A recent investigation of the transition zone under Africa with receiver functions has revealed that detection of the 520-km discontinuity is indeed intermittent and that P520s conversions, when observed, do not split. Lateral variations in temperature and/or water content were ruled out due to poor correlation with independent estimates of transition zone temperature and water content, and intermittency was attributed to small-scale variations in detectability (although lateral variations in Fe content could not be ruled out). The lack of splitting was attributed to low Ca contents, probably due to lack of subduction around the continent, and low sensitivity of P520s conversions to density contrasts.

To investigate the intermittency and splitting of the 520-km discontinuity further, we present a number of receiver function stacks at permanent broadband stations in South America. Contrary to the African continent, the South American transition zone is affected by subduction and probably has larger water and Ca contents compared to Africa. Our stacks reveal that, as in Africa, detection of P520s conversions is intermittent and that it does not correlate with transition zone temperature and/or water content. Interestingly, our stacks also reveal that in spite of subduction, P520s conversions do not split under South America.

S501PS.07

S501PS - Structures in the Mantle and Core

Poster

Topography of the inner core boundary inferred from frequency dependent amplitude ratio of PKiKP/PcP

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The inner core boundary (ICB) is an important region for understanding the core dynamics. The amplitude ratio of PKiKP/PcP has been used for the inference of the density jump at the ICB as well as the shear velocity at the top of the inner core. Previous studies, however, were hampered by the large scatters of the PKiKP/PcP ratios, which precluded constraining relevant parameters of the ICB structures. We observe and collect a significant volume of PKiKP waves recorded by a dense network in Japan - Hinet, to examine its frequency characteristics and relevance for understanding the core dynamics in the quasi-eastern hemisphere. We found clear PcP and PKiKP phases on high-pass filtered seismograms of 9 events with magnitude greater than 5.8 around Japan. The location of these events and the Hinet array covers epicentral distance range from 15 to 45°. After the corrections for source radiation, attenuation in the mantle, the reflection coefficients (RC) at the inner core boundary are inferred from the spectral ratios of PKiKP/PcP. We find that RCs for both 1 and 2 Hz at incident angle (IA) of 10° are close to the values predicted from AK135 and that RCs for 2 Hz are about 2 times larger than those for 1 Hz at IAs greater than 20°. A 2D finite difference simulation involving topography with wavelength and height of 1.5 km can explain the above observation. However, another observation that RCs for both 1 Hz and 2 Hz suddenly decrease at IA of 30° requires further modeling.

S501PS.08

S501PS - Structures in the Mantle and Core

Poster

Anisotropic iron-based crystal building blocks for the solid Earth's inner core texture

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Texturing in the solid Earth's core can be understood by an insight analysis of various Fe-based crystal allotropes that are stable at the extreme Earth's core conditions. An accurate study of their elastic stiffness tensors has revealed the existence of only one building block that can provide a perfect transversely isotropic velocity model. Such a model is the cubic phase (Fe-bcc), when having its fast velocity axis aligned along the Earth's spinning axis. The achieved results also show that by assuming the existence of special alignment directions for the Fe crystals, with respect to the Earth's rotational axis, the complex anisotropic behavior of the solid Earth's inner core can be addressed at its shallower part. We conclude that an approximate Earth's core-texturing model can be achieved assuming the existence of a conglomerate of Fe phases, which are locally oriented with respect to the Earth's main axis. Thermal heterogeneities and mantle convection are the likely responsible mechanisms for such a complicated inner core scenario.

S501S1.01

S501S1 - Structures in the Mantle and Core

Oral

Mapping the Australian upper mantle with multi-mode surface waves: Radial anisotropy and the lithosphere-asthenosphere boundary

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Developments of high-density seismic arrays in Australia as well as the techniques of seismic tomography in the last two decades have enhanced the horizontal resolution of seismic images of continental upper mantle. Seismic surface waves are the most powerful tool to delineate 3-D images of the uppermost mantle. While the depth resolution of the fundamental-mode surface waves is generally limited to the top 200 km, higher-mode surface waves have greater sensitivities to much deeper structure, which can enhance the potential of surface wave imaging for the whole upper mantle. We have employed a fully non-linear inversion scheme to estimate path-specific multi-mode phase speeds of surface waves to map the high-resolution 3-D anisotropic shear wave model of Australia, using permanent and transportable seismic stations deployed throughout the continent. The lithosphere-asthenosphere boundary (LAB) beneath the Australian continent is also estimated from the final 3-D model. Although surface waves are inherently not very sensitive to the sharpness of boundaries due to their long-wavelength features, the depth of LAB can be estimated from either the negative peak of velocity gradient or the slowest velocity beneath the lithosphere. The thickness of LAB (or the transition zone from lithosphere to asthenosphere) can be deduced from the sharpness of the velocity gradient. Our new anisotropic Australian model has provided us with an insight into the relationship between the lateral variations of LAB and radial anisotropy. In particular, anomalous radial anisotropy (SH>SV) are found within the lithosphere as well as beneath the LAB in central Australia, where we can find thinner transition to the asthenosphere, indicating the effects of past deformation of the lithosphere as well as horizontal flow in the asthenosphere.

S501S1.02

S501S1 - Structures in the Mantle and Core

Oral

Subduction of oceanic asthenosphere: evidence from sub-slab seismic anisotropy

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We demonstrate that subduction of the oceanic asthenosphere characterized by weak azimuthal anisotropy and strong radial anisotropy explains the essence of sub-slab shear-wave splitting patterns, where the fast splitting direction changes from predominantly trench-parallel (or sub-parallel) under relatively steep subduction zones to frequently trench-normal under shallow subduction zones. The thickness of the subducted asthenosphere is estimated to be 100 ±50 km based on the observed splitting time at global subduction zones (Song and Kawakatsu, 2012, GRL). To further validate this scenario and distinguish it from more sophisticated hypothesis such as sub-slab trench-parallel flow, we examine complicated SKS splitting patterns observed across the fore-arc central Alaska (Christensen and Abers, 2010; Hanna and Long, 2012), where the rate of trench migration is very low regardless of the mantle reference frame. Observations of the fast splitting direction vary from plate motion parallel near the trench to mostly trench-parallel beyond the 100km slab isodepth and there are strong back-azimuth variations in between these regions. After taking into account the rotation of anisotropy symmetry in the subducted oceanic asthenosphere due to the obliquity of plate motion and down-dip variations in slab dip, we reproduce a general 90-degree switch in fast splitting direction as well as back azimuth dependent splitting direction across the entire fore-arc. This validation further augments the idea that, apart from the source of anisotropy in the mantle wedge and subducting slab, the subduction of oceanic asthenosphere is probably a dominant source of seismic anisotropy in many subduction zones. This result also provides an alternative view on the anisotropic symmetry in the mantle wedge and constrains the length scale in which 3D mantle flow may be important at subduction zones.

S501S1.03

S501S1 - Structures in the Mantle and Core

Oral

Elastically accommodated grain-boundary sliding and its role in seismic wave attenuation

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Micromechanical models for grain-boundary sliding predict a two-stage process in which the grain-boundary incompatibilities arising from slip on the low-viscosity boundary are accommodated at moderate temperature and timescales by elastic distortion of the grains, and at higher temperatures and longer timescales by boundary-parallel diffusional transport of matter. Elastically and diffusionally accommodated sliding involve widely separated characteristic timescales, with distinctive dependencies on temperature and grain size. It would accordingly be surprising if the full spectrum of viscoelastic behaviour were controlled by a single master variable (frequency × Maxwell relaxation time), as has been widely advocated. However, in experimental studies of pure polycrystalline materials, the strain-energy dissipation peak predicted for elastically accommodated sliding has proved to be very elusive. In a recent attempt to reconcile the results of forced-oscillation experiments with the predictions of the theory of grain-boundary sliding, we have tentatively attributed a poorly-resolved dissipation plateau at moderate temperatures for fine-grained polycrystalline olivine to elastically accommodated sliding. Here we will examine two further lines of evidence concerning the role of elastically accommodated grain-boundary sliding: (i) forced-oscillation tests conducted at moderate temperatures in copper jackets, free from the complicating effects of the austenite-ferrite phase transition in the usual steel jackets, that provide further tantalising evidence for a broad dissipation peak of modest amplitude superimposed upon the background dissipation; and (ii) re-assessment of complementary torsional microcreep data indicates that the non-elastic strain resulting from static loading on the timescales of seismic wave periods is dominantly recoverable. We will discuss the implications for the interpretation of seismic wave dispersion and attenuation.

S501S1.04

S501S1 - Structures in the Mantle and Core

Oral

Earth's inner core: Links to the outer core and mantle

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Earth's inner core possesses radial and lateral complexity in elastic velocities, anisotropy, attenuation, and scattering. Larger scale structures (> 1000 km) may be coupled to flow in the outer core and heat transport across the core-mantle boundary, affecting properties of the geodynamo. A reduced P velocity gradient in the lowermost outer core points to the existence of a stably stratified, globally uniform, iron enriched region maintained by freezing and melting. Topography on the inner core boundary on the order of several km's height and several 10's of km wavelength is suggested by amplitude and waveform variations of PKiKP. Lateral variations in structure are concentrated in the inner core's upper half, which exhibits a quasi-hemispherical variation in P velocity, anisotropy, and attenuation. The depth extent (up to 500 km) of this hemispherical structure is difficult to reconcile with a hypothesis of constant differential rotation with respect to the mantle, favoring either oscillation or another mechanism to explain decadal variations in PKIKP travel times. The upper half of the inner core is separated by a 50 to 100 km thick transition zone from an inner inner core characterized by a change in elastic anisotropy and a strong decrease in attenuation and scattering. Models to explain the hemispherical structure of the upper half include translating/convecting models and models coupling heat transport across the core-mantle boundary. Both types of models posit that the hemispherical structural differences are due to lateral variations in freezing and melting, but predict opposite hemispheres of dominant freezing and melting. These models can be tested by merging seismic data from global, national, and temporary arrays, estimating velocities, anisotropy, and attenuation from composite media theory and mineral physics, and predicting inner core texture, deformation, and convective flow from geodynamic modeling.

S502PS.01

S502PS - Dynamical Processes in the Mantle and Core

Poster

Thermal heterogeneity of the mantle under drifting deformable continents during the supercontinent cycle

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The thermal heterogeneity of the Earth's mantle under the drifting continents during a supercontinent cycle is a controversial issue in earth science. Here, a series of numerical simulations of mantle convection are performed in 3D spherical-shell geometry, incorporating drifting deformable continents and self-consistent plate tectonics, to evaluate the subcontinental mantle temperature during a supercontinent cycle. Numerical results show that the assembly of supercontinents is accompanied by a combination of introversion and extroversion processes. The regular periodicity of the supercontinent cycles observed in previous 2D and 3D simulation models with rigid nondeformable continents is not confirmed.

The laterally averaged temperature anomaly of the subcontinental mantle remains within several tens of degrees (±50 °C) throughout the simulation time. Even after the formation of the supercontinent and the development of subcontinental plumes due to the subduction of the oceanic plates, the laterally averaged temperature anomaly of the deep mantle under the continent is within +10 °C. This implies that there is no substantial temperature difference between the subcontinental and suboceanic mantles during a supercontinent cycle. The temperature anomaly immediately beneath the supercontinent is generally positive owing to the thermal insulation effect and the active upwelling plumes from the core–mantle boundary. In the present simulation, the formation of a supercontinent causes the laterally averaged subcontinental temperature to increase by a maximum of 50 °C, which would produce sufficient tensional force to break up the supercontinent.

S502PS.02

S502PS - Dynamical Processes in the Mantle and Core

Poster

Temperature-dependence of thermal expansivity is more important than depth-dependence in mantle convection models

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Numerical models of mantle convection in 2D cylindrical-shell and 3D plane-layer geometries are used to investigate the combined effects of the temperature- and depth-dependence of the coefficient of thermal expansion on predictions of mantle convection models. While the effect of depth-dependence of the coefficient of thermal expansion is to lower heat transfer across a convecting layer, adding the temperature dependence in our models acts to increase the heat transfer across the convecting layer. For mineralogy appropriate to the mantle this increase in heat flow may match or even exceed the reduction found with depth dependence alone. In our cylindrical shell models we find adding temperature dependence to the coefficient of thermal expansion results in an increase in the predicted heat flow by 23%. Inclusion of temperature dependence also results in an increase of mean surface velocities, a proxy for plate velocities, by a factor of 62%! Our 3D plane layer models with plate-like surface velocities corroborate the cylindrical shell results. The significant change in predicted heat flow, relative to the conventional case of a depth dependent coefficient of thermal expansion, may have equally significant effects on the predictions of planetary thermal histories models which rely on the parameterization of the results of full convection models like those presented here. Similarly the substantial increase in surface (plate) velocities that occurs when temperature dependence is included has strong implications with regard to our understanding of the rates of continental dispersal and convergence in the past.

S502PS.03

S502PS - Dynamical Processes in the Mantle and Core

Poster

Possible links between subduction history, generation of of mantle plumes, true polar wander, core-mantle-boundary heat flux and core processes

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It is still an open question to what extent and in what way the core-mantle boundary (CMB) heat flux pattern influences core processes. According to current understanding, higher CMB heat flow – in particular, in near-equatorial regions – causes more magnetic field variability and higher reversal frequency. Here we compute CMB heat flux from a dynamical model of the mantle based on 300 Myr of subduction history. It includes a thermo-chemical layer at its base which – due to flow driven by subducted slabs – is shaped into piles resembling the two Large Low Shearwave Velocity Provinces (LLSVPs). Predicted CMB heat flux is spatially very variable reaching several hundred mW/m2 beneath subducted slabs, and remaining <10 mW/m2 beneath piles. Due to induced large-scale mantle flow, CMB heat flux increases beneath a new subduction zone after a few 10s of Myr, long before the slab has sunk to the lowermost mantle. But it remains high beneath paleo-subduction zones for hundreds of Myr, while the the slab sinks to the CMB and subsequently heats up.

Plumeheads detaching from the lowermost mantle, primarily at the margins of piles, due to the thermal boundary layer being pushed sideways and piled up ahead of slabs, also remove heat and locally increase CMB heat flux. Accordingly, the number of Large Igneous Provinces (LIPs), offset by 50 Myr (~ plume risetime), is correlated with reversal frequency. But since plumes themselves are triggered by slabs, their effect on heat flux variations cannot be considered separately. Thermochemical piles and regions of low heat flux beneath appear to be more stationary.

However, true polar wander (tpw) – wholesale rotation of the entire mantle relative to the core – can change core heat flux, even if the pattern remains constant in a mantle reference frame. Combining a heat flux pattern derived from LLSVPs fixed in the mantle with tpw, we compute heat flow between 10°N and 10°S through time and find some resemblance to reversal frequency.

S502PS.04

S502PS - Dynamical Processes in the Mantle and Core

Poster

Linking geodynamics and seismic observations in the lowermost mantle.

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The base of the mantle is the site of the most significant change in physical parameters in the Earth system: the core-mantle boundary. As the region which mediates core-mantle interactions and acts as the lower boundary for mantle convection understanding its properties is key to understanding the broader dynamics of the mantle. One issue is the participation of material in the lowermost mantle (often referred to as D") in whole mantle convection. This is exemplified by the questions outstanding about the origin of the large, low shear-velocity provinces observed beneath Africa and the Pacific. While the consensus view is that these are long-term, stable features which are compositionally distinct (lending them higher density than their surroundings), a dominantly thermal origin (whereby they are lower density transitory upwellings, such as clustered plumes) is favoured by a number of very recent studies.

Observations of seismic anisotropy (which results from the deformation of mantle minerals) are key to understanding the geodynamic nature of the lowermost mantle. We have produced a large, new dataset of observations which cover a broad swath of the globe. These observations show variation at a range of length scales, with some regions apparently very complex. To interpret them robustly in terms of geodynamics requires significant knowledge of lowermost mantle mineralogy.

Mineralogical information comes from both laboratory experiments and theoretical calculations; these are providing both single crystal elasticities and candidate deformation mechanisms. We have created models integrating these with predictions of strain history to generate models of general anisotropy for the lowermost mantle. We compare these with D" anisotropy in a variety of regions using raytracing and full waveform (spectral finite-element) modelling. These show the complexity of the effect of anisotropy, and motivate understanding mineralogy to make robust dynamic inferences.

S502S1.01

S502S1 - Dynamical Processes in the Mantle and Core

Oral

A Bayesian approach to infer radial models of temperature and anisotropy in the transition zone from surface wave data

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Phase transitions, upwelling and downwelling materials make the 400 - 1000 km depth range highly heterogeneous and anisotropic. The new tomographic methods involving 3D kernel computations often use, as reference models, 3D large wavelength V_P, V_S models obtained by linearized inversions. These models are based on small perturbations of 1D global models and are secondly used to derive temperature and composition distributions. From a seismological point of view, the degree of heterogeneity in the transition zone can be strong enough that the concept of a 1D reference seismic model might be addressed.

We implemented a Markov chain Monte Carlo algorithm which determines the statistical thermal state and anisotropic structure of the mantle from the fundamental and higher-order Love and Rayleigh surface wave dispersion data without computing the corresponding seismic velocity in a preliminary step. In order to both reduce the computing time and generate a self-adaptating model space with respect to the resolution power of the data, polynomial C1-Bézier curves are chosen for the parameterization. An additional advantage of this parameterization is that it is able to explore both smoothly varying models and first-order discontinuities.

The solution is described in probabilistic terms, allowing uncertainties to be fully accounted for. This methodology presents an important complement to conventional seismic tomography models. The method is illustrated with both synthetic data and actual dispersion curves. Our results indicate a complex temperature distribution in the mid transition zone beneath the Pacific ocean. The retrieved anisotropy structure agrees with previous studies indicating positive uppermost mantle anisotropy. Considering few a priori conditions, the transition zone appears to be isotropic, on the average, along the investigated path. Our results are, for the moment, strictly linked to the input phase velocities, previously computed in other studies.

S502S1.02

S502S1 - Dynamical Processes in the Mantle and Core

Oral

Significance of seismic radial anisotropy of the oceanic asthenosphere inferred from sub-slab shear-wave splitting observations

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We (Song and Kawakatsu, 2012, GRL) have recently demonstrated that the subduction of the oceanic asthenosphere characterized by weak azimuthal anisotropy and strong radial anisotropy explains the essence of sub-slab shear-wave splitting patterns, where the fast splitting direction changes from predominantly trench-parallel (or sub-parallel) under relatively steep subduction zones to frequently trench-normal under shallow subduction zones. As this model is constructed to be consistent with the observed seismic anisotropy properties for the oceanic asthenosphere, the result provides a new perspective on the nature of the oceanic asthenosphere itself. The derived model requires a strong radial anisotropy of a specific form that cannot be solely explained by the presence of melt layers in an isotropic solid as such advocated by Kawakatsu et al. (2009), and thus the solid matrix must be responsible for it, although the presence of melt-layers helps to boost radial anisotropy. The rock fabric required for the asthenosphere is more consistent with so-called girdle-type (Christensen and Crosson, 1968) or AG-type fabrics (Mainprice, 2007) observed in nature, rather than with those observed in the laboratory. Processes such as melt-solid interaction (e.g., Holtzman et al., 2003), simultaneous activation of different slip systems (e.g., Ohuchi et al., 2011) or/and transpression deformation (e.g., Tommasi et al., 1999) that may influence the solid fabric of the asthenosphere may be discussed.

S502S1.03

S502S1 - Dynamical Processes in the Mantle and Core

Oral

Is the puzzle of the Japan Sea opening resolved?

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Since the establishment of plate tectonics in early 1970’s, the solid Earth science is greatly advanced. Still there are major unresolved problems, and a cause of back-arc basin opening is one of scientific challenges. Its kinematic descriptions or images of dynamics are fairly well understood, but quantitative interpretations based on sound physical and other principles are yet missing. We present here an analysis of potential causes of the Japan Sea back-arc opening. Recent seismic tomography studies image a low velocity zone (interpreted as a high temperature anomaly) in the mantle beneath the subducting Pacific plate near the Japanese islands at the depth of about 400 km. This thermal feature is rather peculiar in terms of the conventional view of mantle convection and subduction zones. Using data assimilation we develop a model combining geodetic, geophysical, and geological data to unravel the dynamics of the Earth’s interior in the geological past. The principal finding of this study is that the anomalous hot mantle beneath the Pacific plate penetrated through the subducting part of the plate some tens million years ago and contributed to the Japan Sea development. Another part of the hot mantle migrated upward beneath the Pacific lithosphere, and the presently observed hot anomaly is a remnant part of this mantle upwelling. This result may have important implications for back-arc spreading, break-off of subducting plate, and a geochemical mixing between the rocks of the deep and shallow mantle.

S502S1.04

S502S1 - Dynamical Processes in the Mantle and Core

Oral

Stability of deep mantle structures

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Two Large Low Shear-wave Velocity Provinces (LLSVPs) in the lowermost mantle beneath Africa and the Pacific are prominent in all shear-wave tomographic models. They impose strong control on Earth's thermal, magmatic, magnetic and rotational dynamics, and their edges are the dominant sources of the plumes that generate large igneous provinces, hotspots and kimberlites. Whilst the dynamics of plumes forming at the edges at the LLSVPs is becoming clearer, the origin of the LLSVPs is less certain. Compositional anomalies clearly need to be invoked to understand their long-lived stability and seismic signatures. Whereas recycled oceanic crust of basaltic composition may be a candidate material for the LLSVPs, peridotitic materials enriched in iron and perovskite provide a better fit to the seismic properties. Linking surface and lithospheric processes to the mantle through geological time is extremely challenging but is now becoming feasible due to better constraints on deriving ancient longitudes before the Cretaceous and better understanding of the dynamics of true polar wander. We have developed an absolute Earth system model that for the first time relates motion of lithosphere or plate motions to the Earth's mantle for the entire Phanerozoic. This model demonstrate that the LLSVPs may have been stable for the past 550 million years, and the fact that on a rotating Earth, their antipodal excess masses must have remained near the equator, suggest that a very early origin for the two LLSVPs is a viable hypothesis. The dynamics of the mantle could therefore have been dominated by a degree-2 convection mode (as observed today) since Hadean times.

S502S1.05

S502S1 - Dynamical Processes in the Mantle and Core

Oral

Seismological observations of Earth's core

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Seismology is one of the most powerful tools for observing Earth's core in its current state. The seismically observable properties of the inner core, which has been growing for a significant fraction of Earth's history, can be used to gain insight into the processes taking place in the core over hundreds of millions of years.

High frequency body waves can be used to investigate regional scale structure in several different locations in the inner core. We show regional scale isotropic and anisotropic velocity models of the inner core, and compare them to the average properties of the eastern and western hemispheres of the inner core. As our observations correspond to sections of the inner core up to 360 km below the inner core boundary we are able to observe parts of the inner core which grew more than half a billion years ago. This timescale is significantly longer than the magnetic reversal time of the core, so large scale hemispherical and regional structures which have formed as the inner core grew are likely to be linked to the thermal, and not magnetic properties of the deep Earth. By better understanding the seismically observable properties of the inner core we can elucidate the relationships between the mantle and core over long parts of Earth's history.

S503PS.01

S503PS - Plate boundary processes

Poster

Seismic images of the sedimented Andaman Sea Spreading Centre

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Magmatic and tectonic processes governing the accretion of oceanic crust and the consequent structure of spreading centers affect two thirds of Earth's surface. Magma from the mantle ponds into the crust, erupts as lava flow on the seafloor through thin dikes and cools and crystallizes by hydrothermal circulation. These processes are well understood for spreading centres in the deep ocean basins. However, in marginal or young rift basins, spreading centres are generally covered with thick sediments that act as a blanket for hydrothermal circulation and hinder lava flow, and therefore are poorly understood. Here, we present high-resolution deep seismic reflection and bathymetric images across the high sedimented and young Andaman Sea Spreading Centre. The Andaman Sea Spreading Centre consists of three main spreading segments, a transform fault, and an overlapping spreading centre, between sliver strike-slip faults (Nicobar-Andaman and Sagaing Faults). Across the spreading segment, we find a 2-3 km thick upper crust consisting of strongly reflective dipping frozen sill/dike intrusions and large melt bodies, which are aligned with deep penetrating normal faults observed in the sediments above, suggesting that there is an intimate link between faulting and melt intrusions. Melt sills are also observed in the lower crust, which along with presence of large intrusive bodies suggesting that part of the upper crust is formed by off-axis melt intrusions. An axial magma chamber can be imaged at 4.5 km within the oceanic crust, above the Moho, that may provide melt supply for sill/dike intrusions above. The Moho is well imaged along whole basin, which along with the extensive presence of intrusions suggests that a significant part of the oceanic crust is formed mainly by the intrusive processes.

S503PS.02

S503PS - Plate boundary processes

Poster

Seismic structure of a recently active volcanic complex at the ultraslow spreading Gakkel ridge

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In 1999 an unusually strong, teleseismically registered earthquake swarm at the volcanic complex at 85°E/85°N marked the onset of a spreading episode at Gakkel ridge with deep submarine explosive volcanism. At this site, the rift valley hosts distinctive volcanic features which cluster on ridge-parallel faults or fissures. Activity persisted at least until 2001, seafloor imagery in 2007 showed fresh lava at volcanic cones. Three arrays of four seismometers each which were mounted on ice floes, drifted 16 days in July 2007 with a drift speed of up to 1 km/h over a region of 60 km x 70 km. We recorded over 300 local earthquakes. Of these, we used 124 earthquakes which were recorded by two or more arrays for a local tomography. They yield a dense ray coverage of the centre of the rift valley and the rift valley walls. We chose a 1D velocity starting model by selecting the best performing out of 90 randomly selected models and used the resulting hypocentres as starting locations for the tomographic algorithm. We complemented the 1D-velocity model with a 3D-water layer (v_p=1500 m/s) whose thickness varies between 2.8 and 4.3 km to take the bathymetry in the survey region into account.
Here we present the results of a seismic tomography for three-dimensional P-velocity structure in the crust and upper mantle with the algorithm FMTOMO: Most of the earthquakes cluster at a depth of 11 to 15 km, directly beneath or closely around the centrally located volcanic cones, with only slight activity in the surrounding area. The velocity variations indicate reduced seismic velocities (up to 0.2 km/s variation) in the centre of the rift valley around the site of most recent activity, stretching down from the upper crust to the assumed Moho at 11 km depth. A region of increased seismic velocities (up to 0.2 km/s variation) lies directly to the southeast, also in the middle of the rift valley.

S503PS.03

S503PS - Plate boundary processes

Poster

Crustal deformation and recent large earthquakes near Jan Mayen

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Jan Mayen is an active volcanic island situated along the mid-Atlantic Ridge north of Iceland and hosts Norway's only active volcano. It is closely connected with the geodynamic processes associated with the interaction between the Jan Mayen Fracture Zone (JMFZ) and the slowly spreading Kolbeinsey and Mohns Ridges. Several large strike-slip earthquakes have been recorded along the JMFZ, most recently events with magnitudes of 6.0, 6.1 and 6.6 in 2004, 2011 and 2012. In this presentation, we present the recent series of large events and study its impact in terms of crustal deformation, as reflected by GPS measurements. We inverted teleseismic records to obtain moment tensor and slip distributions of the events in this series. We also study Coulomb Stress transfer due to the large events, and investigate to what extent stress changes can explain the observed aftershock distributions. This will spread new light on the tectonic processes and crustal deformation in the region.

S503PS.04

S503PS - Plate boundary processes

Poster

Anisotropic mantle flow at spreading centers– seismic and rheologic effects

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Seismologists and mineral physicists have known for decades that anisotropy inherent in mantle minerals could provide a means to relate surface seismic measurements to deformation induced by plate-driven flow. Recent numerical methods explicitly incorporate constraints from rock deformation experiments into flow/deformation models. By linking these lattice-preferred orientation (LPO) results with known elastic properties of the constituent minerals, direct estimates of the associated pattern of seismic anisotropy can be compared with available seismic array data. An aspect that remains to be assessed is the possible effects of rheological anisotropy that Castelnau and coworkers have shown characterizes polycrystalline mantle aggregates with strong LPO. Initial linked micro-mega scale modeling of aggregates deformed by dislocation glide under plate-driven spreading center flow suggests that non-negligible feedbacks arise when anisotropic viscosity is incorporated. Focusing and enhanced subaxial upwelling rates begin to develop, in contrast to the dominantly passive pattern predicted when isotropic viscosity is assumed. Additional testing is required to document numerical sensitivity to discretization and boundary condition specifications. Part of this effort entails transitioning runs to FEM code developed by Dawson and Boyce, Cornell University, in which state variables evolve throughout the model space. Integration of this code with the anisotropic viscosity estimate based on Castelnau et al.'s homogenization scheme provides a means to iterate toward a fully coupled model. This presentation will outline the method, summarize the results of sensitivity tests for early anisotropic viscosity cases, and show flow pattern evolution and seismic anisotropy predictions for cases where iteration between flow, texture update, viscosity tensor calculation, and flow update have been achieved.

S503PS.05

S503PS - Plate boundary processes

Poster

Geophysical evidence for viscous decoupling between oceanic lithosphere and asthenosphere

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Geodynamic models predict that plate motions exert a viscous drag that drives flow of oceanic asthenosphere. For mid-ocean ridges, mantle flow is primarily modeled as a passive response to plate spreading, thus asthenospheric upwelling is symmetric about the ridge axis. Similarly, models of plume-lithosphere interaction presume that viscous coupling between plate motion and plume upwelling results in deflection of a plume “downstream”. We review results from fast-, intermediate and slow-spreading mid-ocean ridge settings as well as the Galapagos hotspot. These studies constrain mantle structure at a range of asthenospheric depths (100’s to 10 km depth) and each suggests that flow in oceanic asthenosphere is weakly coupled to plate motions. In particular, beneath spreading centers the seismic structure is inconsistent with ridge-centered upwelling. Instead, the axis of mantle upwelling and divergence is skewed with respect to the plate boundary. A seismic study of the Galapagos hotspot constrains the geometry of plume upwelling and lateral transport to the nearby spreading center. As the Galapagos plume shoals from 250 to 100 km depth it tilts northward toward the Galapagos spreading center, in a direction that is perpendicular to plate motion. That each of the regions discussed is associated with melt production suggests that melt accumulations at shallow mantle depths generates a lubricating layer that facilitates weak coupling between a plate and the asthenosphere. If such a layer exists, this calls into question a common assumption about plate tectonics, which is that oceanic mantle flow is driven by viscous coupling and is thus primarily a passive response to plate motions.

S503PS.06

S503PS - Plate boundary processes

Poster

Origin and evolution of the Iceland Plateau and Kolbeinsey Ridge, N-Atlantic

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Variations in crustal structure along the 700 km long KRISE-7 refraction/reflection and gravity profile, straddling 66.5°N across the Iceland Shelf (IS), Iceland Plateau (IP) and western Norway Basin (NB) are related to spreading centers which coexisted with the now extinct Aegir Ridge (AeR), prior to the initiation of the Kolbeinsey Ridge (KR) at 26 Ma. The western 300 km of the profile, across the IS, is considered to have formed by rifting at the KR, whereas the eastern 400 km, across the IP and western NB, formed earlier in association with spreading at the AeR, possibly containing slivers of older oceanic or continental crust rifted off the east Greenland margin along with the Jan Mayen Ridge. Crustal thickness increases gradually across the IS, from 12-13 km near the KR to 24-28 km near the eastern shelf edge, decreasing abruptly to 12-15 km along the IP, 5-8 km in the western NB and 4-5 km at the AeR. Lower crustal domes and corresponding gravity highs beneath the IP, mark the location of extinct rift axis, suggested to have coexisted with the AeR from the opening of the N-Atlantic. Similar lower crustal domes are associated with the currently active rift segments beneath the plate boundary in Iceland and connecting northwards with the KR. Irregularities in spreading rates within the NB where apparent fan-shaped magnetic anomaly pattern has been considered to reflect a gradual decrease spreading rate along the AeR must have been compensated by another rift axis further west, along the eastern margin of the IP, as initially suggested by Talwani and Udintsev (IODP vol. 38, 1976), forming an overlapping spreading center with the AeR or branched rift zones as in Iceland today. Such rift irregularities and associated microplates have been largely ignored, in spite of having an important role in the plate tectonic evolution of the N-Atlantic region.

S503PS.07

S503PS - Plate boundary processes

Poster

Mantle instabilities developed at a lithospheric step

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Both direct and indirect evidence for mantle instabilities have surfaced in the past decade. Direct evidence is largely from seismology and indirect inferences from geological observations, and from the geochemical argument that mafic lower crust must be recycled into the mantle in order to keep the overall andesite chemistry of the continental crust. But one of the major mechanical issues with mantle instabilities is how do they remove lower crust ? Here we show that an efficient means of removing lower crust is by the development of a mantle instability that initiates at a lithospheric step. The lithospheric step we have in mind is one formed at a continental transform system where regular and thinned lithospheres are juxtaposed. Such a system will be gravitationally unstable as pressure differences are created where regular mantle lithosphere of density 3350 kg/m^3) terminates at an abrupt edge with less dense (3300 kg/m^3)asthenospheric mantle. Such a gravitationally unstable edge will viscously deform, migrate and eventually drip off into the lower density asthenosphere providing that viscosity at the top of the mantle lithosphere is no more than 2 and 4 x10^21 Pa s, for lithospheric thicknesses of 100 and 200 km respectively. Using western North Island, New Zealand, as an example we show that a migrating edge-instability provides a credible explanation for a migrating zone of uplift and subsidence, on a 10 my time scale, providing the viscosity of the mantle lithosphere is of the order of 5 x 10^20 Pa s and its thickness ~100 km. Step instabilities may be useful in explaining other uplifted zones on different time and space scales in continental regions such as the Sierra Nevada (USA), the Transantarctic Mountains and the shoulder of the Rio Grande rift.

S503PS.08

S503PS - Plate boundary processes

Poster

Lithospheric instability beneath the Southeast Carpathians

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The damaging earthquakes that occur in the upper mantle beneath the Vrancea Zone of the South-east Carpathians represent a serious seismic hazard for Romania and surrounding countries. These earthquakes are characterised by near-vertical T-axes; they are caused by vertical stretching. The seismic moment release rate can be used to estimate vertical strain rates, which imply that the mantle at 200 km is moving downward at about 20 mm/yr relative to the surface. In order to obtain better information about the structure of the upper mantle in this region, the South Carpathian Project was undertaken by the University of Leeds, the National Institute of Earth Physics in Bucharest, the Eötvös Lor ánd Geophysical Institute in Budapest, and the Seismological Survey of Serbia in Belgrade during 2009-11. The tomographic images of the upper mantle beneath the Pannonian – Carpathian region thus obtained (Ren et al., EPSL, 2012) illuminate the upper mantle over a wide region, and shed new light on the unique geological structure which is responsible for the strong seismicity. The earthquakes occur at the NE end of an asymmetric sub-vertical high-velocity body, bounded by slow anomalies to the NW and SE. With increasing depth, the fast region becomes more circular in cross-section until about 400 km where the fast anomaly fades out. The main mass of fast (presumably dense) material is located directly beneath the seismic activity. The depth distribution of seismic-moment release rate is explained if this high velocity structure is produced by a Rayleigh-Taylor instability acting on an unstable stratification of mantle lithosphere above asthenosphere. Numerical experiments suggest that the drip-like structure that we image may be a natural consequence of a Rayleigh-Taylor instability triggered by recent convergence of Adria and Europe and the focusing of stress and strain in the hinge zone between the relatively rigid East-European platform and the Moesian block.

S503PS.09

S503PS - Plate boundary processes

Poster

Mantle lithosphere around the TESZ – a diffuse paleoplate boundary between the East European Craton and the Variscan orogenic belt

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The Trans-European Suture Zone (TESZ) manifests a broad transition between the Precambrian and Phanerozoic Europe. To contribute to better understanding of the structure of the upper mantle, we analyse anisotropic parameters of teleseismic body waves. Specifically, we examine lateral variations of P-wave travel-time deviations from about 100 teleseismic events, selected to provide good azimuthal coverage, and evaluate shear-wave splitting parameters from about 20 events recorded during passive seismic experiment PASSEQ (2006-2008). We model in 3D large-scale olivine fabrics of mantle lithosphere domains on a transect from the eastern limit of the Bohemian Massif (BM) towards the Teisseyre-Tornquist Zone (TTZ) - the NE limit of the TESZ - and through the Polish Paleozoic Platform to the East European Craton (EEC).

Variations of anisotropic signal around the central part of the TESZ are surprisingly moderate:

(1) There is no distinct change of the P-residual pattern and shear-wave splitting parameters across the surface trace of the TTZ.

(2) The most distinct change of the anisotropic signal occurs to the southeast of the TTZ at the northern boundary of the BM.

(3) Regional changes in the shear-wave splitting parameters are larger along the TTZ than the changes across this laterally heterogeneous zone.

We observe a sharp change of the mantle lithosphere fabrics at the NE rim of the BM. Week changes of the mantle lithosphere structure across the TESZ suggest a south-westward continuation of the EEC beneath this broad and diffuse paleoplate boundary. Inferences from seismic anisotropy indicate that this laterally heterogeneous pervasive shear zone probably contains blocks of EEC mantle lithosphere that were partly deformed during the amalgamation of the Variscan orogenic belt.

S503PS.10

S503PS - Plate boundary processes

Poster

Revisited block boundaries in South America - a study of intraplate deformation

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In plate reconstruction modeling we rely mostly on magnetic lineations on the seafloor to constrain our models in time and to deduce the velocities at which the plates move. These lineations occur due to the reversal of the Earth's magnetic field and are recorded during the opening of a mid ocean ridge. However, the reliability of this approach becomes limited during a period where no magnetic reversal has been recorded. One of these periods is the Cretaceous Superchron, an almost 40 Ma era with no recorded magnetic reversal. Particularly for reconstructing the opening of the South Atlantic this era poses a problem, since it took place between ca. 120 and 83 Ma, a time when rifting between South America and Africa had just begun. Most existing plate models are predominantly based on geometrical constraints in order to achieve the best-opening fit, which leads to intraplate deformation in South America accommodated very differently from model to model. We choose, in addition to the classical approach, to use strong geological and geophysical constrains to better define zones of intraplate deformation and hence the most viable block boundaries. This work consists of three parts: First, we compare the various existing plate reconstruction models, with focus on where and how much intraplate deformation is accommodated within South America. In a second step we study available data like gravity, crustal thickness, geology, major faults zones, basement age and changes of the dip angle of the downgoing slab of the Peru/Chile trench to investigate current tectonics and strain distribution. Based on this analysis we postulate an updated block geometry for South America. In a third step, we reconstruct the opening of the South Atlantic using the updated block model and rotation file for South America. We analyze the result by comparing it to the pre-opening fit of the existing plate models.

S503PS.11

S503PS - Plate boundary processes

Poster

Toward an overall understanding of Deep Low-Frequency Earthquakes

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Deep low-frequency earthquakes (LFEs) are small earthquakes that radiate low frequency seismic waves. LFEs in western Japan are categorized into three types: tectonic, volcanic, and semi-volcanic LFEs. Tectonic LFEs occur on plate boundaries and volcanic LFEs occur around the Moho beneath active volcanoes. Recently, we examined semi-volcanic LFEs that occur far from active volcanoes but which are otherwise similar to volcanic LFEs [*Aso et al.*, 2011; 2013].

First, we characterize the seismicity of 3 types of LFEs after event detection and precise relocation using waveform correlation. The results about magnitude frequency statistics, tidal sensitivity, and hypocenter distribution show that semi-volcanic LFEs are more similar to volcanic LFEs than to tectonic LFEs, which is the reason why we named them «semi-volcanic LFEs».

Next, we worked on focal mechanisms. While tectonic LFEs are thought to be thrust events, the mechanisms of (semi-) volcanic LFEs have not yet been firmly established. We used waveform inversion to estimate focal mechanisms of semi-volcanic LFEs in eastern Shimane. The moment rate functions determined from our inversions oscillate between positive and negative values. The focal mechanisms for many LFEs are found to be dominated by a CLVD component, with their symmetry axes parallel to the lineation formed by the source distribution. Finally, we tried to understand physical source models of LFEs. Since tectonic LFEs are usually thought to be slow faulting on plate boundaries, we need a new explanation for (semi-) volcanic LFEs that occur as CLVD type of deformation. For these LFEs, we developed a new model related to the cooling process of magma that involves three steps: stress accumulation, stress release, and oscillation excitation.

S503PS.12

S503PS - Plate boundary processes

Poster

Analysis of detailed crustal strains due to the dense GPS array in the Tokai region, central Japan

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The Tokai region, central Japan, is an area of scientific interest where the Philippine Sea plate subducts beneath the Japanese Islands and is expected to generate a large interplate earthquake in the near future. We established a dense GPS array in the region and started observation in around 2004 for monitoring the crustal deformation. The array is an augmentation of the GEONET, the nationwide GPS array established by the Geospatial Information Authority of Japan (GSI). The network consists of more than 50 GPS sites and is denser with 5-10km baseline lengths relative to the 20km spacing array of GEONET. The data taken by the network has been used to monitor the strain accumulation in the area. Matsumura et al. (2008), for example, suggested that the change in the areal strain could be a good indicator for monitoring the change of coupling along the subducting plate interface. Recent analysis of GEONET data suggest that GPS dense array is capable of detecting short-term slow slip event with a few millimeter of amplitude (e.g., Satomura et al., 2011). Ochi (2011) introduced a new model of the Tokai slow event that lasted about five years since 2000. The presentation reviews the study made through the analysis of the data taken in the GPS dense array in Tokai for the period of about 10 years and finds recent progress of strain accumulation in the region, from which we discuss interaction of the plate coupling along the northern margin of the Philippine Sea plate.

S503PS.13

S503PS - Plate boundary processes

Poster

Three-dimensional seismic structure in the Southwest Indian Ocean Ridge (37iã50iäS): Implication for active hydrothermal circulation

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The southwest Indian Ridge (SWIR) is a major plate boundary separating Africa and Antarctica with an ultraslow-spreading rate of 14-16 mm•a-1. Many characteristics along SWIR, such as the mean axial depths, the obliquity of the ridge axis, the present day small-scale segmentation, the presence or absence of transform and non-transform discontinuities, were got to know based on the multi-beam bathymetry data, gravity data and magnetic data. The complicated three-dimensional (3D) seismic structures on the ultraslow ridges are the key area to studying interplay among magmatism, tectonics, and hydrothermal circulation. The 3D seismic survey for the first time was carried out at the SWIR during DY115-21 global cruise from January to March in 2010. We use airgun shots recorded by twenty ocean bottom seismometers (OBSs) to generate a 3D P-wave tomographic velocity model of the segment 28 (37iã50iäS). Our results in the cross sections show strong asymmetric crustal structure across the ridge axis. Hydrothermal activity identified in the study region is closely associated with asymmetrical accretion. Our results yield lateral variation of P-wave velocity along the axis too. Layer 2 relatively keeps constant both in thickness and velocity, while Layer 3 changes greatly in velocity. A low-velocity anomaly in the eastern side beneath the active hydrothermal vent, maybe acts as heat source to sustain long-term hydrothermal circulation.

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S503S1.01

S503S1 - Plate boundary processes

Oral

Hydrothermal seismicity beneath Lucky Strike volcano (37°N, Mid-Atlantic Ridge)

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We present seismological evidence for along-axis hydrothermal flow feeding the Lucky Strike hydrothermal field (37°N, Mid-Atlantic Ridge), which is controlled by the permeability of the upper crust and the topography of the underlying magma chamber. The seismicity has been measured since 2007, using a local network with repeated year-long deployments. Relative relocations of the first two years of the data reveal two clusters of small but continuous seismicity extending north and south along-axis from the hydrothermal field. The events are tightly limited across-axis: to the north they fall beneath a narrow surface graben whose southern end contains the hydrothermal field. This northern cluster contains most of the events and is focused a few hundred meters above the volcano's axial magma chamber (AMC) reflector. The southern cluster is about 600 m shallower, but the events are again clustered near to its lower depth limit. The events have small magnitudes (ML -1.2 to 1.6) and they are not aligned along any fault-like structures. The northern cluster's lower limit deepens by 50 to 100 meters during a 3-month long event swarm, during which two other event clusters beneath the vent field were activated.

We interpret the events as being caused by thermal stress at the bottom of along-axis hydrothermal cells, and the swarm as a period of enhanced flow corresponding to hydrothermal penetration towards the AMC or drop in the AMC lid. We present two and three-dimensional numerical and physical models that reveal that the observed kilometer-scale hydrothermal circulation cells are consistent with the combination of a narrow upper crustal permeable zone and an axial magma chamber topography that shallows beneath the vent field.

S503S1.02

S503S1 - Plate boundary processes

Oral

Imaging the transition from asthenospheric to lithospheric structures beneath the endeavour segment, Juan de Fuca Ridge

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We report on results from a multi-scale seismic tomography experiment of the Endeavour segment of the Juan de Fuca Ridge. In August 2009 we deployed 68 four-component ocean bottom seismometers (OBSs) at 64 sites throughout a 90x50 km2 area to record seismic energy from 5567 shots of the 36-element, 6600 cu. in. airgun array of the R/V Marcus G. Langseth. The experimental geometry utilized 3 nested scales and was designed to image (1) crustal thickness variations within 25 km of the axial high; (2) the map view heterogeneity and anisotropy of the topmost mantle beneath the spreading axis; (3) the three-dimensional structure of the crustal magmatic system and (4) the detailed three-dimensional, shallow crustal thermal structure beneath the Endeavour vent fields. Results to date include tomographic inversion of first-arriving P waves that sample the upper- and mid-crustal regions, characterization of off-axis magma bodies via travel time and amplitude anomalies of crustal phases, estimation of regional-scale crustal thickness variations from analysis of PmP arrivals and imaging of mantle structure using Pn to constrain mantle flow and melt distribution. The mantle and crust of the Endeavour segment is surprisingly heterogeneous. Three features, in particular, suggest that we are imaging the transition from structures dominated by asthenospheric processes (mantle divergence and melt transport) to those controlled by lithospheric stresses. These features include: The trend of shallow mantle and mid crustal structures, both of which are rotated anticlockwise with respect to the axis of spreading; the presence of numerous off-axis magma bodies that overly regions where the mantle low-velocity zone is located off axis; and the trend of isotropic and anisotropic structures in the shallow crust which closely parallel seafloor morphology. We discuss the implication of our results for the pattern of magma and energy transport between the mantle and the seafloor.

S503S1.03

S503S1 - Plate boundary processes

Oral

Initial surface wave tomography of the upper mantle beneath the Juan de Fuca spreading center

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The Juan de Fuca Ridge is an intermediate-rate spreading center that has gradually changed its orientation through a series of propagating rift events as the ridge approaches the subduction zone beneath western North America. The Juan de Fuca plate and subduction zone are the primary targets of the Cascadia Initiative, which includes a multi-year deployment of broadband ocean-bottom seismometers (OBS) and land stations. The Cascadia Initiative is a community experiment with open access to the data. Instruments are spaced about 70 km apart from the subduction zone out to and slightly beyond the spreading center. The first year deployment of ~ 60 OBS covered the northern part of the Juan de Fuca plate and provided the data for the preliminary tomographic images of shear wave structure beneath the ridge that are reported here. The second year deployment, currently recording, covers the southern Juan de Fuca and Gorda plates, augmented by an independent experiment focused on the Blanco fracture zone. To extend the period range of Rayleigh waves with good signal-to-noise ratio, we subtract the gravity-water wave noise from the vertical component by predicting the noise from the differential pressure gauge (DPG) records. Noise predictions are made using empirical transfer functions between pressure and vertical component during Rayleigh-wave-free times. Coherence between pressure and vertical displacement during those times is > 0.95 between periods of 50 and 140 s for deep water deployments, reaching a maximum of ~ 0.99 between 60 and 80 s; thus a large fraction of the vertical noise can be removed. Tomography was performed using the two-plane-wave technique to account for the first-order effects of multi-path propagation between the teleseismic sources and the receiver array. The preliminary results reported here for the northern Juan de Fuca ridge are based on the six month recording period when all OBS were deployed simultaneously.

S503S1.04

S503S1 - Plate boundary processes

Oral

Anisotropy beneath fast- and slow-spreading mid-ocean ridges caused by melt channels

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The oceanic crust is created at mid-ocean ridges (MORs) by melt, drawn upwards from below the axis in high-porosity channels which form by reactive flow. These channels have very different seismic properties to the surrounding mantle, having the potential to explain widespread observations of anisotropy in surface and body waves travelling through MORs and the oceanic lithosphere.   To investigate these processes, we use a 2D numerical model of coupled magma-mantle dynamics in a two-phase system with two components in local thermodynamic equilibrium. One component is more fusible than the other, and a network of magma-rich channels are nucleated when more fusible heterogeneities are introduced. We model ridges with full spreading rates of 40-160 mm/a.   Shear wave splitting measurements at MORs show increasing lag time with distance from the ridge axis, and with increased spreading rate. Surface wave studies show horizontally-polarised waves (SH) travel faster than those polarised vertically (SV) at 50-100 km depth. These observations cannot be wholly explained by alignment of crystals due to flow. We convert the ridge model to elasticity using effective medium theory, with porosity as a proxy for melt, and melt flow lines for the orientation of the elasticity. We then predict shear wave splitting and surface wave anisotropy.   We find at slow spreading rates, low porosities concentrate melt-induced anisotropy near the ridge axis (<50 km), whilst faster ridges show significant splitting further away (>250 km). Channels dip away from the axis more steeply at slow ridges (>45 deg) than fast ones (~30 deg). Melt-rich lenses with horizontal long axes are carried away from the axis and may explain the Vsh>Vsv signature in surface waves. Melt alone is unlikely to explain the overall splitting measured at ridges: we find a better fit to observations when previous models of mineral alignment are included in our calculations alongside our new models.

S503S1.05

S503S1 - Plate boundary processes

Oral

Wide versus narrow rifts: insights from numerical models on the relative role of heat, strain rate, and crustal heterogeneities

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While continental rifting is commonly accommodated along a narrow region, the rifting can be accommodated diffusely across a wide region, or may evolve from a diffuse to narrow style. These different styles of strain may be due to changes in far-field stresses, or due to the naturally evolving strength profile of the lithosphere. Here we use a 2-d finite element model to examine how the evolution of strain in rift systems is related to the initial thermal structure, strain rate, and crustal heterogeneities. We begin with the geometry of a paleo-convergent zone with a thick crustal welt adjacent to a «cratonal» lithosphere with a thick lithosphere and normal crustal thickness. Model results indicate that the initial thermal structure of the lithosphere has first-order control on the rifting evolution and subsequent rupture, while stretching rate and crustal heterogeneities places a second-order control on the rifting evolution. Two different aspects of the evolution from rift to rupture are recognized: the location of rupture (near or far from the craton), and how wide the rift region is prior to rupture. These two aspects of the rift evolution are primarily controlled by the initial thermal structure of the lithosphere, while strain rate and crustal heterogeneities play secondary roles. The initial thermal structure places first order control on the rifting evolution such that: cooler upper mantle temperatures ($<\sim 700°C$) are associated with rifts that rupture far from the craton, while warmer temperatures in the upper mantle result in rifts that rupture near the craton. Rifts with less heat initially conducted from the asthenosphere (thicker initial lithosphere) accommodate extension across a narrow region and after minimal amount of extension, while rifts with significant heat initially conducted from the asthenosphere (thin initial lithosphere) accommodate extension across a wide region, and accommodate significant extension prior to rupture.

S503S1.06

S503S1 - Plate boundary processes

Oral

Along-axis variations of the seismicity of ultraslow spreading ridges

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At mid-ocean ridges, the lithospheric plates drift apart, magma fills the gap to form new crust. This engine splutters at ultraslow speeds of less than 20 mm/y: Isolated volcanoes pierce the seafloor of ultraslow spreading ridges; between the volcanoes, there are long stretches without volcanism. The morphology and the mode of seafloor production at ultraslow spreading ridges differ fundamentally from all faster spreading ridges. The reasons for the uneven distribution of melts at ultraslow plate boundaries are still poorly understood as their main representatives, the Arctic ridge system and the Southwest Indian ridge, are difficult to access.

We analysed the teleseismically recorded seismicity in 11 sections of ultraslow spreading ridges spanning altogether 7200 km. Epicentres located within 30–35 km of the rift axis were extracted from the catalogue of the International Seismological Centre for a time period of 35 years. The typical stripe-and-gap seismicity pattern of slow spreading ridges is not discernible at ultraslow spreading rates. Here, volcanic centres often have an increased seismicity rate relative to the background rather than appearing as seismic gap. In contrast, amagmatic segments of ultraslow spreading ridges are seismically only weakly active. Asymmetric accumulations of earthquakes at segment ends that are related to detachment faulting at slow spreading ridges do not exist at ultraslow spreading ridges. Local and teleseismic earthquakes at ultraslow spreading ridges occur down to depths of 20 km below seafloor, confirming the existence of a cold and brittle lithosphere. Underneath Logachev Seamount at Knipovich ridge, microearthquake hypocentre depths from a 10 days seismicity study with ocean bottom seismometers yield for the first time direct evidence for an undulating lithosphere-asthenosphere boundary which has often been postulated as one possible way to channel melts towards the centres of focussed magmatism.

S503S1.07

S503S1 - Plate boundary processes

Oral

Structure of Atlantis Massif, oceanic core complex from waveform inversion

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Downward continuation of multichannel seismic (MCS) data used in conjunction with travel time tomography and full waveform inversion (FWI) is proving to be a robust and reliable means of imaging young, unsedimented oceanic crust in detail. Downward continuation of sources and receivers to a seafloor datum isolates refractions and wide-angle reflections in a wedge shaped region ahead of the seafloor reflection in gathers, while simultaneously improving the signal to noise ratio of these often weak arrivals. Isolation of refractions as first arrivals combined with the collapse of triplications simplifies the picking of travel times for tomography, while all arrivals in the wedge can be used for elastic FWI. Starting from the tomography model, FWI typically converges in 30-40 iterations with final misfits ~30% of the data size and correlation coefficients of 0.7-0.85. Atlantis Massif is a core complex located at the intersection of the Mid Atlantic Ridge and Atlantis Transform. Inversion of the 5 existing MCS profiles reveals a high velocity core extending from the central dome onto the southern ridge. Ground truth from IODP Hole 1309D indicates that this body is primarily of gabbroic composition. It is juxtaposed to an older, intermediate velocity body that outcrops on the southern wall of the Massif where serpentinized peridotites and pervasively altered gabbros are observed. The FWI results indicate that the contact between these seismically, relatively homogeneous bodies is almost planar, dipping at ~30° away from the spreading axis. We interpret it as a fault plane, conjugate to the main detachment fault and associated with the initiation of core complex formation. FWI also reveals some large, sub-horizontally elongate velocity anomalies at ~1 km depth within, but near the edges of the gabbroic core that could represent heavily altered ultramafics, thicker versions of the altered intervals seen within 1309D.

S503S2.01

S503S2 - Plate boundary processes

Oral

Crustal formation along the Eastern Lau Spreading Center: influence of slab-derived water

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The Eastern Lau Spreading Center is a key region over which mantle source composition, melt supply, and the general geological and geophysical character of the crust vary in a manner consistent with decreasing "subduction-influence" of slab volatiles on mantle melting. One of the key observables is the physical structure of the crust in that it records the changing nature of the mantle as the location of the ridge migrates away from the arc. Using data from the L-SCAN active-source seismic experiment, we construct 3-D tomographic images that reveal crustal and mantle structure and the present location and form of the magmatic system beneath ~110 km of the spreading center. When the ridge was closer to the arc, a relatively thick crust was produced with an abnormally thick low velocity upper crust and an abnormally high velocity lower crust. This can be explained by excess melting in the presence of high water content and a subsequent higher degree of crustal differentiation in the presence of water in the crustal magmatic system. As the ridge moved away from the arc, a step-like transition occurred to more normal crustal velocities and thicknesses, indicating a rapid drop in mantle water content. Located everywhere beneath the spreading center is a prominent, but narrow, seismic low velocity volume (LVV), presumably due to high temperatures and melt in a crustal magmatic system. The top of the LVV closely follows the ridge axis and steps across 3 overlapping spreading centers. As the offset of the overlap increases, the LVV becomes increasing discontinuous across the ridge limbs. The largest offset, at only 8 km, acted as a major boundary between melts derived from distinct mantle domains for 0.31 Myr.

S503S2.02

S503S2 - Plate boundary processes

Oral

Imaging mantle melting beneath backarc spreading centers and island arcs

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Arrays of land and seafloor seismographs image melting processes in the Mariana and Tonga-Lau mantle wedges, where active arc volcanism, backarc spreading occur and intermediate/deep seismic zones provide optimal source distribution. Ocean bottom seismograph deployments in the Mariana Islands (2003-2004) and Tonga-Lau (2009-2010) provide large datasets for detailed imaging. At both, we find significant slow velocity and high attenuation anomalies in the upper 100 km of the mantle beneath the volcanic arc and the spreading center. In Mariana, the anomalies are separated by a high velocity, low attenuation region at shallow depths (< 80 km), implying distinct arc and backarc melting regions; anomalies coalesce at greater depths possibly allowing material interchange. The maximum anomaly in the backarc is shallower (~30 km) than in the arc (~ 65 km), consistent with geochemical indications on the depth of melt production. The anomaly beneath the backarc spreading center is narrow (~ 70 km) and extends from close to the moho to 80 km depth. The magnitude of the backarc spreading center anomaly is slightly greater than the arc anomaly for both attenuation and seismic velocity.

Preliminary results for Tonga-Lau project show similarities to the Mariana images. Extremely low seismic velocity and high attenuation are found within a 100 km wide region beneath the spreading center in the upper 80 km, with minimum Qp of about 50. Deeper, the anomalies are displaced westward, suggesting that partial melting occurs within upwelling that originates beneath the far backarc. Rayleigh wave tomography shows a much stronger anomaly along the Central Lau Spreading Center compared to the Eastern Lau Spreading Center. Attenuation and velocity anomalies in both the Mariana and Lau regions are larger than expected for temperature effects alone. We infer that they delineate the extent of partial melting but that only small melt fractions (< 1%) are required.

S503S2.03

S503S2 - Plate boundary processes

Oral

Back-arc extension along the Andaman Sea plate boundary: Spreading and transtensional processes imaged by earthquake swarms

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The geometry, kinematics, and mode of back-arc extension along the Andaman Sea plate boundary are refined using relocated hypocenters, global CMT solutions, and high-resolution bathymetry. By applying cross-correlation and double-difference algorithms to regional and teleseismic waveforms and arrival times from ISC and NEIC bulletins (1964-2012), we resolve the fine-scale structure of active faults in the Andaman Sea. The new data reveal that back-arc extension is primarily accommodated at the Andaman Back-Arc Spreading Center (ABSC) at ~10°N, which hosted 3 major earthquake swarms in 1984, 2006, and 2009. A deficit in seismic moment indicates that spreading by intrusion and the formation of new crust make up for the difference. A spatio-temporal analysis of the swarms show that dike intrusions are the primary driver for brittle failure in the ABSC.

A change to E-W extensional faulting mechanisms along the West Andaman Fault after the Mw=9.2 Sumatra-Andaman earthquake of Dec. 2004 indicates a substantial stress change in the back-arc of the 2004 rupture. In Jan. 2005, with a delay of a month, the Nicobar-Island earthquake swarm occurred at ~7.9°N in the back-arc region. The most energetic earthquake swarm ever observed globally, it had >600 teleseismically recorded earthquakes in the first five days of activity. A detailed view of the seismogenic structures active during the swarm emerges after relocation. It is located along the Seulimeum strand (SEU) of the Sumatra Fault. CMT solutions for earthquakes prior to the 2004 event indicate dextral motion along the forearc-back-arc boundary, particularly along the SEU fault, and a gap of seismicity is observed at the location of the future swarm. The center of the swarm is dominated by NE-SW striking normal-fault mechanisms, whereas the NE and SW tips are dominated by strike-slip mechanisms. The observed pattern suggests a crustal pull-apart associated with a 15-20 km right step or bend along the dextral SEU fault.

S503S2.05

S503S2 - Plate boundary processes

Oral

Impact of subducting bathymetric features on earthquake and tsunami potential along the Sumatra subduction zone

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Bathymetric anomalies present on the subducting plate have long been recognized as influencing segmentation but their role in earthquake generation remains a matter of debate. Bathymetry along the Sumatra subduction zone reveals the presence of a diversity of high-relief features on the subducting Indo-Australian plate: seamounts, ridges, and fracture zones, including the Investigator Ridge, the Wharton Ridge, and the Ninetyeast Ridge. The extinct Wharton Spreading Center (WSC) marks the boundary between two morphological provinces on the subducting plate: smoother, with a thicker sediment cover, and a small number of large bathymetric features in the north; rougher, marked by the presence of abundant seamounts and thin sedimentary cover, in the south. Associated with this contrast in seafloor morphology is a contrast in rupture properties along-strike: in recent years, the southern portion of the margin has ruptured as small distinct patches (September 2007 (Mw ~8.5 and 7.9), October 2010 (Mw ~7.8)), while the northern segment has ruptured in much larger events (December 2004 (Mw ~9.3), March 2005 (Mw ~8.5)). Given the large seismogenic and tsunamigenic potential of this region, it is crucial to understand controls on rupture processes.

We examine the role of subducting bathymetric features in rupture segmentation and earthquake generation along the margin. We use bathymetry data and relocated seismicity, complemented by seismic reflection images across the subduction zone down to depths of 60 km, to understand the relationship between the subduction of bathymetric features and earthquake behavior. Based on our observations, the relationship between the subduction of features and earthquake behavior appears to depend on the nature, size, and depth of subduction of the feature, as well as the sediment thickness on the subducting plate. We clarify this relationship through a quantitative analysis.

S503S2.06

S503S2 - Plate boundary processes

Oral

Structure downdip of deep low-frequency earthquakes in Shikoku, western Japan, revealed by later P and S arrivals with slow apparent velocities

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Based on observations of later P and S arrivals with slow apparent velocities, we suggest that deep low-frequency earthquakes (LFEs) in Shikoku, western Japan occur either between the oceanic and the island arc crust or between the oceanic crust and the overriding mantle of velocity reduced drastically. For P waves traversing from slab earthquakes within the oceanic crust of the subducting Philippine Sea plate around Shikoku, we observe later arrivals with a slow apparent velocity at stations on the downdip side. The apparent velocity is in a range of crustal P-wave speed. Dominant S waves also propagate by an apparent velocity as slow as in the crust. The observations suggest the presence of a low-velocity region connecting between the slab earthquakes and the stations. By computing theoretical seismograms, we show that the observations can be explained by two models. In one model, the subducting low-velocity crust lies in contact with the bottom of the thick low-velocity island arc crust. The other model is attributed to significant velocity reduction at the corner of the mantle wedge, for instance, owing to the hydration reaction. In either model, deep LFEs are located updip of the connected low-velocity region. This means that the high-velocity mantle wedge, in other words, the flow of the mantle, is not located close to the zone of LFEs. The present result can influence determination of the temperature where deep LFEs occur. It is generally difficult to understand the forearc mantle wedge structure because the region is often located below the ocean. This study demonstrates that seismic waves guided by the low-velocity crust can provide improved knowledge for the structure as well as the shape.

S503S2.07

S503S2 - Plate boundary processes

Oral

Structural factors controlling slip in magathrust earthquakes

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Coseismic slip in a large megathrust earthquake is not uniformly propagated along a plate boundary. For example, magnitude-8 class megathrust earthquakes in the Nankai Trough, SW Japan, are well knows as clear segmentation of a slip zone in the eastern (Tonankai segment) and the western part (Nankai segment). Moreover, a complicated slip distribution is recognized even in one segment. In the Japan Trench, NE Japan, coseismic slip of the 2011 great Tohoku-oki earthquake (M=9) extends over 500 km x 200 km area along the trench. The most characteristic slip behavior is an extremely large slip reaching to the trench axis. In addition, a seismological study shows unusually large stress drop concentrated in a small region near the initial break of the slip. We have been investigating whether the aforementioned complex slip distributions are just coincidence or there are any distinct structural factor controlling the slip behaviors by means of active-source seismic imaging technique. In the Nankai Trough, subducted seamounts and ridges, which may control the lateral propagation of coseismic slip during the 1944 Tonankai and 1946 Nankai Earthquakes, are successfully imaged. Following those studies, compiling recent deep seismic studies by densely distributed profiles provides a fine-scale 3D plate geometry of the entire Nankai trough. This realistic plate geometry applies to a numerical simulation to examine if the observed slip distribution can be reproduced. In the Japan Trench area, seismic reflection image clearly shows subduction of large scale horst-and-graben structure near the trench axis. Furthermore, significantly strong reflectors composed of a step-like interface is imaged around the initial break area of the 2011 earthquake. In this presentation we review active-source seismic studies in in the Nankai Trough and the Japan Trench and discuss structural factors controlling slips in megathrust earthquakes.

S601PS.01

S601PS - Educational Seismology in Schools, Universities, and Informal Settings

Poster

Using school seismology resources as the focus of an open ended inquiry base science project

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Observational seismology in schools has been proven to be an effective tool for teachers and learners to stimulate interest in sciences and geosciences. Simple and inexpensive mechanical seismometers with PC based datalogging systems can be installed and operated by schools themselves (see www.bgs.ac.uk/ssp for more information). The data recorded by these instruments is of sufficient quality to detect seismic signals from large (>M6.5 -7) earthquakes anywhere in eth world as well as smaller local events. One of the pedagogical advantages for schools of using this system is that it works well within the context of open-ended learner-led inquiry based science projects. In the UK a national competition (called the Big Bang) for such projects is run on an annual basis with finalist invited to attend a large conference showcasing their work. This poster showcases one such project submitted to the competition by a student, Edward Duckworth, from the Thomas Hardye School in Dorchester, UK. The project was carried out with assistance from an acoustic engineer, Jim Nicholson, who volunteers from his work at QinetiQ to assist at the school as part of the Science Ambassadors scheme. The project was based on observations of tidal signals from the nearby coastal zone on spectrograms of the background noise recorded by the sensor.

S601PS.02

S601PS - Educational Seismology in Schools, Universities, and Informal Settings

Poster

Seismo@School in Switzerland: high-school diploma work projects

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In the framework of the Swiss Seismo@School program, and due to the active engagement of numerous secondary school teachers, an increasing number of high school students in Switzerland choose seismology-related topics for their graduation diploma work projects. In these projects the students make active use of the materials provided through Seismo@School.

We present a selection of the project works from the last year, spanning a wide variety of topics such as tsunamis, nuclear explosions (interactions with local subsurface and developments in seismology), the relation between eigenfrequencies of the subsurface and buildings, calibration of pendulum seismographs, etc.

S601PS.03

S601PS - Educational Seismology in Schools, Universities, and Informal Settings

Poster

Raising awareness towards seismology in Portugal

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Portugal is a country exposed to moderate and large earthquakes, as evidenced by its historical records. However the tectonic rates in Portugal are slow, resulting in long recurrence intervals between earthquakes. For this reason, most Portuguese are vaguely aware of seismic risk. In this presentation we will give an overview of a few activities carried out in Portugal over the last years with the goal of raising populations awareness toward seismology and seismic risk. In particular we will focus on 1) visits to historical observatories, 2) seismology at school programs, and 3) congresses of young scientists. Both in Lisbon and Coimbra, students have the possibility to visit the historical seismic observatories. Station COI, located in Coimbra, hosts the oldest seismograph in Portugal. This station is visited yearly by hundreds of students. During the visits students are given a brief introduction to seismological concepts, and then take a tour through the different generations of seismometers and seismograms. Seismology at school programs started in Portugal during the 1990s. These programs enable the deployment of didactic seismometers at schools, which are used as an aid in courses like Physics and Earth Sciences. Finally, The Earth Sciences Department of the University of Coimbra has been promoting since 2005 the Congress of Young Geoscientists. During its seven editions, high school students have presented and discussed their own research studies on Earth sciences, including earthquakes and associated hazards and risks. In a few editions the students had the opportunity to participate in exploratory, hands-on activities about soil liquefaction and tsunamis. This research was supported by European and Portuguese funding (FP7-PEOPLE-IRG-2008, PTDC/CTE-GIX/122262/2010).

S601PS.04

S601PS - Educational Seismology in Schools, Universities, and Informal Settings

Poster

Building diverse seismology workforce: Role of historically black colleges and universities

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This paper will present a model for increasing diversity in seismology profession based on experience and efforts at North Carolina Central University (NCCU), a Historically Black College/University (HBCU) located in Durham, North Carolina. Established in 1909 as the first public liberal arts college in the United States for African Americans, NCCU has current minority enrollment of more then 90%. Throughout its history NCCU has been a major producer of minority science graduates and was from 1997 to 2006 nationally among top five public master's universities of baccalaureate origin for science doctorate recipients who are African-American. Two graduate programs closely related to seismology, Master of Science in Earth Science and Master of Science in Physics, were established in 1995 and 2007. However, it was only after National Science Foundation Computational Center for Fundamental and Applied Science and Education was created on NCCU campus in 2008 that interdisciplinary graduate research program in seismology was developed. A multipronged approach that includes collaboration with major research universities, development of bridge-to-PhD programs, internships and networking opportunities and partnerships with geoscience associations will be described. We will discuss the impact of major external funding from National Science Foundation, National Aeronautics and Space Administration and National Geospatial Intelligence Agency on the quality of earth science program and will present overview of seismology related research accomplishments by NCCU masters students. Finally, we will argue that cultivating physics and earth science degree programs at flagship HBCUs is important step for improving representation of African Americans in seismology. Furthermore, we will also assert that geoscience organizations and unions should more actively support physics and geoscience programs at HBCUs and more energetically promote seismology profession to minority students.

S601S1.01

S601S1 - Educational Seismology in Schools, Universities, and Informal Settings

Oral

The Australian Seismometers in Schools Network: A multipurpose network primarily aimed at promoting careers in geoscience

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The Australian Seismometers in Schools Network (AuSIS) is half way through its initial 4-year program and has already received over 125 expressions of interest from schools. By 2015 we will build a network of 40 seismometers in high schools across the nation to provide real-time monitoring of the Australian continent and raise awareness of geoscience through observing our dynamic earth in motion. This is a multipurpose network that uses professional seismometers to provide research quality data to the seismological community, including both monitoring and research agencies. Data recorded by AuSIS is publically available through the IRIS Data Management Centre. The data quality has exceeded expectations with schools recording local earthquakes down to magnitude 1, and large distant earthquakes. The AuSIS project's educational aims are to: raise community awareness of earthquakes; raise awareness of seismology and geoscience, as a field of study; promote science as a possible career; and provide a tool to assist in teaching physics and earth science.

The project also involves an online education portal allowing students to access earthquake recordings in their own and other schools. Some students participate in the program by looking up earthquake locations on maps and learning about geography, while more advanced students have been investigating the frequency characteristics and sources of noise at their school. Both students and the schools are particularly proud that their seismometer is contributing to the global scientific community and are actively incorporating seismology into the school curriculum. A growing community of volunteers is forming to support the program within their local area. Over the duration of the project these volunteers will enhance the project through provision of technical expertise as well as promotion within the education sector. AuSIS is funded by the Education component of AuScope Australian Geophysical Observing System.

S601S1.02

S601S1 - Educational Seismology in Schools, Universities, and Informal Settings

Oral

Integrating European school seismology networks

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Encouraging students in secondary schools to study sciences and geosciences in particular is a common objective of many national educational systems. Experience has shown that providing stimulating and relevant contexts within which basic physical concepts can be explored is a powerful tool for encouraging an interest in sciences. Seismologist are fortunate in that Earthquakes are a topic which holds a natural fascination for most young people and is a topic which renews its relevance and topicality with sometimes disturbing regularity. Seismologists across Europe have discovered that providing schools with the tools and resources to set up functioning seismic observatories within their own grounds, either with professional quality instruments or even simple “homemade” mechanical sensors can provide a continuous stream of stimulating and topical data that teachers and learners can use to ensure that their science and geosciences lessons are always stimulating and relevant. Since 2010 school seismology groups from UK, France, Italy and Switzerland have been working together under the NERA FP7 project (www.nera-eu.org) to share their educational resources and integrate the data recorded by schools across the continent. This presentation will provide an update on the progress of this activity and show how any school user can access and interpret the data recorded by schools in this network or linked school networks in Ireland, USA and Australia.

S601S1.03

S601S1 - Educational Seismology in Schools, Universities, and Informal Settings

Oral

Increasing access to IRIS educational seismology resources and data

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IRIS Education and Public Outreach has developed a robust collection of resources to support seismology-related instruction at the middle, high school and university levels, and to satisfy public interest in earthquakes. Resources include animations, short video lectures, data visualizations, classroom demonstrations and labs, Teachable Moment summaries of large earthquakes, and computer software to display and explore seismic data. IRIS InClass, a new web-portal to be released this Spring, will improve the ability to find resources within the collection. It suggests related resources that may also be of interest and link resources together into instructional sequences of varying duration and depth of content. In the future, IRIS InClass will also offer asynchronous professional development. Through a combination of video and text, the system will increase instructors' content knowledge while also easing hurdles to implement IRIS resources in the classroom. To increase access to seismic data, IRIS has developed two new products. The first is a public display (Earthquake Channel) of recent earthquakes that has been optimized for large format HD displays and offers a customizable cycle of world and regional map views. The second is data acquisition and analysis software (jAmaseis) that allows educational users to record and display seismograph data locally, and stream this data over the Internet to other jAmaseis users. jAmaseis also allows users to display and record data from any station stored at the IRIS Data Management Center, and to perform simple analyses on the data including determining earthquake location and magnitude. An online interface enables schools with an educational seismograph to share and use seismic data while communicating with other users. Collaborations with UK and Ireland networks has resulted in web-based tools that leverage the IRIS database to allow educators to easily establish an online presence for their own regional networks.

S601S1.05

S601S1 - Educational Seismology in Schools, Universities, and Informal Settings

Oral

An interactive earthquake experience at ETH Zurich, Switzerland

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1 ETH Zurich, Swiss Seismological Service, Switzerland

Since 2008 ETH Zurich hosts an educational earthquake simulator as collaboration of the Swiss Federal Office of Environment FOEN, the Department of Earth Sciences public information center *focus*Terra, and the Swiss Seismological Service (Schweizerischer Erdbebendienst SED). The earthquake simulator can seat up to 10 people and replay actual recorded or synthetically generated waveforms, with some limitations in maximum displacement, velocity and acceleration, and in only one horizontal direction. Nevertheless, the shaking experience provides an excellent context to demonstrate various important phenomena associated with exposure to earthquakes, like the dependence of perceived shaking on distance, magnitude, soil type, or building height. In addition to the earthquake simulator we developed and set up a series of hands-on experiments that also demonstrate specific earthquake phenomena: the randomness of earthquake occurrence, the effect of the eigenfrequency of a structure on exciting resonant behavior, and the principles of earthquake-proof construction. The experiments and the program played in the earthquake simulator, which is accompanied by simultaneous visual projection of relevant information, relate to each other and enhance the educational impact of the experience.

In close collaboration with engaged teachers of secondary schools in Switzerland pedagogic concepts were developed that allow teachers to prepare the visit to the simulator with their classes beforehand, guide the visit, and provide material for further treatment of specific issues afterwards.

Currently we are starting the development of a second installation of a simulator and experiments in a joint project with the canton of Valais, which exhibits the highest seismic hazard in Switzerland. With funding from the canton an educational center for earthquake preparedness will be set up within the next 2 years, ready for the EU FP7 NERA seismo@school conference in 2014.

S602PS.01

S602PS - Seismo-Sociology

Poster

Turning earthquake's eyewitnesses' into real time ground motion sensors!

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1 EMSC, France

The Internet and social networks have dramatically changed the way the seismological community interact with the public. The first change is the speed of interactions.

At the EMSC, the first indication of a felt earthquake's occurrence does not from seismic networks, it comes from the eyewitnesses: they rush on the Internet to find out the cause of the shaking they have just been through causing instantaneous and easy-to-detect traffic surge on our website.

We have shown in past studies that the automatic processing of these traffic surge, an approach called Flash-sourcing, offers unique mapping capacities such as the mapping of the felt area and, in certain cases, the mapping of damaged regions.

Using the Virginia earthquake, we will demonstrate that the visits on our website are triggerred by arrival times of the seismic waves at the eyewitnesses locations by locating its epicentre using traffic analysis only. Eyewitnesses can then be considered as real time ground motion detectors: they feel the ground shaking and report it by hitting our website.

Beyond this analysis, we will discuss on the new interactions EMSC has been developing with the public both on its website and on social networks. We will advocate for a a revision of the way we deliver public earthquake information to better answer the needs of the citizens.

This work has been partially funded under the FP7 REAKT project.

S602PS.02

S602PS - Seismo-Sociology

Poster

Civilian monitoring video records for earthquake intensity: A potentially unbiased on-line information source of macro-seismology

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Traditional measures for macro-seismic intensity survey using media accounts or public reports suffered from the bias caused by the lack of professional training of the public and the media. Considering the long recurrence period and the unexpected nature of earthquakes, such training is practically hard to conduct, which means that for traditional media accounts and public reports, artificial effect is almost inevitable. Previous investigation showed that earthquake effects can be exaggerated in media accounts, and the exaggeration depends on the local intensity level. This situation is facing to a significant and maybe historic change: Since recent years, with the development of economy and society, there have been more and more civilian monitoring videos deployed, mainly for security purposes. Some of the videos happened to record the scenes of earthquakes and can be used for the macro-seismic intensity survey. In the emergency response to the 2008 Wenchuan earthquake, there were numerous volunteers sharing video materials on-line. We collected some of these on-line-shared civilian monitoring videos and estimated the local intensities by visual inspection of the playback video recordings. Comparing to traditional media accounts, these video records have the unbiased feature in obtaining local intensity due to their dynamic and repeatable characteristics, independent of the seismological training of the provider. With proper guidance for providing the necessary information of the location and time when sharing these data on-line, civilian monitoring videos are potentially useful in the citizen-powered macro-seismology.

S602PS.03

S602PS - Seismo-Sociology

Poster

Epidemiological trends in the face of hazards and natural disasters

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Examining epidemiological trends a very critical in as far setting health priorities is concerned. Traditional sources of information about the descriptive epidemiology of diseases, injuries and risk factors are generally incomplete, fragmented and of uncertain reliability and comparability. Lack of a standardized measurement framework to permit comparisons across diseases and injuries, as well as risk factors, and failure to systematically evaluate data quality have impeded comparative analyses of the true public health importance of various conditions and risk factors. As a consequence the impact of major conditions and hazards on population health has been poorly appreciated, often leading to a lack of public health investment. As a result, dementia and injuries, for which non-fatal outcomes are of particular significance, were identified as being among the leading causes of disease/injury burden, with clear implications for policy, particularly prevention. The survey investigated incidences, prevalence's and mortalities, by age, sex and Region. Inadequate cost-effective data collection systems in low income economies, is a key priority for public policies to promote health. Keywords: Epidemiological, trends, Hazards, Natural disasters

S602PS.05

S602PS - Seismo-Sociology

Poster

Earthquake activity update in northeast India Himalaya for assessing and managing risk

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The northeast India Himalaya and its adjoining regions represent a seismically complex tectonic regime. Assessment of earthquake risk is very multifarious in this region due to different earthquake occurrence scenario. For the purpose region is segmented into five active zones as (i) Eastern Syntaxis; (ii) Arakan-yoma fold belt; (iii) Shillong plateau; (iv) Himalayan Frontal arc; and (v) Southeastern Tibet with the aid of spatial distribution of seismicity and tectonic features. Statistics of occurrence of, large to great earthquakes in Himalayan thrust zone evidenced that, it have been triggered by the major thrusts but the occurrence patterns of smaller events are observed to be controlled largely by the southeast flow of Tibetan plateau, northward movement of Indian plate and westward drift of the Burmese arc. The data set has been critically examined for b-values, the spatio-temporal patterns of seismic activity, the focal depth distribution of events, and the energy release pattern. It has been observed that Arakan-Yoma region is seismically most active compared to other delineated regions. Localized zones with intense seismic activity have also been observed in some regions especially in Eastern Syntaxis and southeastern Tibet regions. The region is characterized by 71% shallow focus activity and 29% intermediate activity when events with cutoff magnitude (mb $\geq$4.3) are considered. The Arakan-yoma region exhibits almost equal annual frequency of both the shallow and the intermediate events whereas mostly shallow events have occurred in other regions. Increase in focal depth of earthquakes from west to east up to depth 180 km has been observed in Arakan-yoma region. The paper presents the various seismological aspects to evaluate the present seismicity scenario of the region which could be useful for managing earthquake risk in the region.

S602S1.01

S602S1 - Seismo-Sociology

Oral

The L'Aquila trial

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The first step of the trial in L'Aquila (Italy) ended with a conviction of a group of seven experts to 6 years of jail and several million euros refund for the families of the people who died during the Mw 6.3 earthquake on April 6, 2009. The experts participated to the meeting of the National Commission for Forecasting and Predicting Great Risks (CGR) held 6 days before the main shock. The basic point of the accusation is that the CGR suggested that no strong earthquake would have occurred (which of course was never mentioned by any seismologist participating to the meeting); this message would have convinced some of the victims to stay at home, instead of moving out after the Ml 3.9 and 3.5 earthquakes few hours before the mainshock.

This verdict has a tremendous impact on the scientific community as well as on the way in which scientists deliver their expert opinions to decision makers and society. The verdict's reasons ignore the absence of prevention and the inability of the Italian system to manage hazard information on vulnerability and seismic risk in the medium and long-term. In contrast with the judge's opinions, we believe that the prevention is the main way to reduce the seismic risk, in terms of reduction of buildings vulnerability.

In this presentation we describe the role of scientists in charge of releasing authoritative information concerning earthquakes and seismic hazard and the conditions that led to the verdict, in order to discuss whether this trial represented a prosecution to science, if errors were made in communicating the risk and who was in charge of the risk management and the definition of actions for risk reduction. Documents, articles and comments about the trial are collected in the web site http://processoaquila.wordpress.com/. We also discuss the role of the media in this complex matter and how they dealt with this issue in the days preceding and following the earthquake, contributing to affect the risk perception.

S602S1.02

S602S1 - Seismo-Sociology

Oral

The 'internet intensity' of earthquakes?

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In recent years, earthquakes have started to affect the internet and in turn affect our everyday life, raising a new question of how to describe the seismic destruction to this special network. Based on the phenomenological and currently qualitative analysis of several cases, the influence of earthquakes on the internet can be divided into three different levels. The first level is the 'felt level', and there have been rich experiences in the perspective of 'citizen seismology' and the 'community internet intensity map', providing a new tool for the fast and interactive report of earthquakes. The second level is the 'destruction level', at which the internet itself is destructed by the earthquake. At this level, the statistical physical properties of the internet have to be taken into account. Considering the recent development of the physics of networks, we suggest that the maximum betweenness centrality of a destroyed vertex could be considered as the simplified measure to define the destruction of the internet, or the 'internet intensity' of an earthquake. The third level is the 'interaction level', at which the internet and the real world would interact with each other, causing catastrophic changes by a cascading process. The 'internet intensity' is important in defining the economic and social losses of earthquakes and in designing the internet security systems. Study of the influence of earthquakes on the internet calls for the collection and analysis of more cases of earthquakes and more cases of the internet disruption, and calls for more works on the related statistical physics modeling.

S701PS.01

S701PS - Mathematical problems in seismology

Poster

Enhanced velocity tomography: The method of combining velocity and attenuation parameters

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Acoustic (ultrasonic) tomography is a well developed method for investigating the internal structure of Earth's structure, rock masses in mines, or rock samples studied in laboratory experiments. In this presentation we discuss the approach which combines the robustness of velocity tomography and the sensitivity of attenuation tomography resulting in Enhanced Velocity Tomography. The theoretical considerations are illustrated by a computer simulation, application to data from a granite sample subjected to induced damage by heating and tomographic imaging in mines. We have find out that the Enhanced Tomography is more sensitive to the internal rock structure than classical velocity tomography and overcomes instability problems characteristic of attenuation tomography. Simultaneously it can be performed using most of the existing tomography software.

S701PS.02

S701PS - Mathematical problems in seismology

Poster

Two qualitatively different fault slip behaviors generated by modified porosity evolution law

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We have studied effects of interaction among shear heating, fluid pressure and inelastic pore creation on dynamic fault slip and found two nondimensional controlling parameters Su and Sú about the interaction. The parameter Su represents the relative dominance of the effect of inelastic pore creation on the fluid pressure change over that of heating, while Sú is associated with the dominance of fluid flow effect over the effect of shear heating. We have succeeded in explaining many aspects of dynamic earthquake slip behavior by the parameters. However, in the framework, there exists a problem that we have assumed simple form of inelastic porosity evolution; inelastic porosity change rate was assumed to be proportional to slip velocity, while porosity in natural faults is suggested to have an upper limit, ϕ_∞, from observational and experimental viewpoints.

We introduce the third nondimensional parameter, Su^{ul}, to describe the effect of the upper limit. We neglect here fluid flow; that is, Sú=0. If we assume Su>1, fluid pressure reduction due to inelastic pore creation at an initial stage of slip reduces slip velocity. After the initial stage, two qualitatively different behaviors of slip appear. For some parameter ranges of Su and Su^{ul}, slip accelerates in the later stage. This behavior occurs because inelastic porosity approaches to ϕ_∞ and effect reducing the fluid pressure (and the slip velocity) due to pore creation vanishes. Diversity observed for the time when the slip acceleration begins can be explained in terms of two parameters; larger Su^{ul} leads to smaller ϕ_∞, which results in earlier acceleration. On the other hand, for the other parameter ranges, slip velocity approximately approaches to zero. Both high speed slip and spontaneous slip cessation can be understood in a single framework.

S701PS.03

S701PS - Mathematical problems in seismology

Poster

Unified modeling of nearfield tsunami and seismic waves using a three-dimensional earth model

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We present a new scheme for calculating of nearfield tsunami and seismic waves for a three-dimensional earth model with a sea layer. We use a gravitational elastodynamic equation simplified by assuming that the acceleration of gravity is constant in time and uniform over the computational region, and by ignoring the buoyancy term. We formulate the equation as a set of the first-order equations to apply a time-domain staggered-grid finite-difference method which is often employed for strong-motion simulation. This scheme can simultaneously model all of the seismic waves and static deformation in the solid earth and acoustic and tsunamis waves in sea from sub-oceanic earthquakes. We also derived a convolutional PML equation for our tsunami-coupled seismic equation and implemented numerically stably to eliminate artificial reflections of both seismic waves and tsunami from the sides of the computational domain. We have numerically checked and confirmed our scheme is stable even for very long time computations more than one million time steps. In the presentation we will show the numerical scheme and some computational examples including an application to events around the Ryukyu trench, Japan, where the Philippine Sea Plate subducts northwest beneath the Eurasian Plate.

S701S1.01

S701S1 - Mathematical problems in seismology

Oral

Multi-scale full waveform inversion for crustal and upper-mantle structure

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We present a tomographic model of the crust and upper mantle beneath Europe and western Asia, constrained by the full waveform inversion of complete teleseismic and regional seismograms in a broad period range (8-200 s). Our method combines the spectral-element modelling of seismic wave propagation, adjoint techniques and the quantification of waveform differences via time-frequency phase misfits. To resolve both crustal and mantle structure, we simultaneously solve multiple regional- and continental-scale inverse problems. The inverse problems on different scales are coupled via 3D non-periodic homogenisation which induces apparent anisotropy that needs to be accounted for in the forward modelling. We assess tomographic resolution using curvature information obtained via second-order adjoints. Regions where resolution is particularly high compared to previous studies include the North Atlantic, the western Mediterranean and Anatolia, where lateral resolution length drops below 30 km within the lithosphere. The multitude of geologically interpretable features include the Iceland plume which clearly extends into the lower mantle. Furthermore, we observe two low-velocity fingers that extend from the Iceland plume into the North Atlantic asthenosphere, where they correlate with regions of Neogene uplift. Western Anatolia is characterised by the extension-related updoming of lower-crustal material. The deep expressions of volcanic provinces in central Anatolia and the North Anatolian Fault Zone are clearly imaged.

S701S1.02

S701S1 - Mathematical problems in seismology

Oral

Seismic tomography with sparsity penalties, at the global and the exploration scale

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Seismic tomography leads to often gigantic systems of linear equations, and as data volumes increase, every effort has to be made to reduce the inversion problem to manageable size. At the same time as achieving a reduction of computational complexity, new sparsity-seeking methods should be able to give additional insight into the nature of the problem itself, and the character of the solution. Practically speaking, this means that if we are solving systems that relate data (functionals of seismograms) to model parameters (the physical properties of the Earth) through the use of sensitivity kernels (partial derivatives of the measurements with respect to the unknown Earth parameters), we have opportunities for dimensional reduction on the data, the model, and the kernel side. In this presentation I discuss strategies to make inroads on all three sides of the seismic tomographic inverse problem, using one-, two- and three-dimensional spherical wavelets, and l2-l1 combination misfit norms. My examples are drawn from global seismic tomography, where the benefits of learning about the structure of the Earth through physically sensible parameterizations are at least as important as finding the best-fitting families of models themselves, and from seismic tomography at the exploration scale, where the sheer data volume and the complexity of the subsurface that is being imaged necessitate strategies to make converging, stable inversions at all possible.

S701S1.03

S701S1 - Mathematical problems in seismology

Oral

Probabilistic seismic source location through the time reversal method

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The spatial location of sources of acoustic/seismic waves is one of the first tasks when acoustic/elastic transient waves are analyzed in many branches of physics, including seismology, acoustics, oceanology, to name a few. It is well recognized that there is no single universal location algorithm which performs equally well in all situations. Source activity and its spatial variability in time, the geometry of the recording network, the complexity and heterogeneity of wave velocity distribution are all factors influencing the performance of location algorithms. In this presentation we propose the new location algorithm which combines the speed of calculation typical for the classical gradient-optimization based algorithms with the robustness, flexibility and generality typical for the probabilistic (Bayesian) approaches. The proposed algorithm exploits the reciprocity and time-inverse invariance property of the wave equation and combines it with the modern finite-difference type eikonal solver. The algorithms constructs the full aposteriori probability distributions as classical probabilistic approach performing only a few (nonlinear) forward modelings. In particular the proposed approach allows the full, nonlinear error analysis without loosing the speed of the algorithm. However, being a single-event type location algorithm it inherits all features of the classical location algorithms, especially the strong dependence on the velocity model is the most important. The performance of the algorithm is illustrated with a few synthetic tests. In one of them we explore the most advanced feature of the algorithm to analyze a performance of the Bayesian Evidence and the Shanons measure in the context of a designing an algorithm for the simultaneous location and velocity inversion through the Reversible Jump Markov Chain Monte Carlo tech.

S701S2.01

S701S2 - Mathematical problems in seismology

Oral

Quantifying model resolution in non-linear inverse problems

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We consider the definition of model resolution in non-linear inverse problems, and describe some practical methods for its quantification. In particular, we describe a simple extension of the adjoint method that enables the calculation of higher-order Fréchet derivatives, and show how they can be employed in estimates of model resolution. We illustrate this theory through a simple 2D tomographic problem.

S701S2.02

S701S2 - Mathematical problems in seismology

Oral

Beyond conventional geophysical inversion and new observations from the crust to the core

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Obtaining a too simplistic (or a too complex) geophysical model is one of the consequences of utilizing a conventional geophysical inversion requiring various subjective decisions. Some of the issues of traditional techniques are inadequate parameterization of a problem and an inaccurate knowledge of data noise. A trans-dimensional Bayesian inverse method has the excellent property of treating the number of model parameters (e.g. number of basis functions in tomography, number of layers in receiver function inversions and number of changes in differential travel times trends) as an unknown in the problem. Furthermore, in a hierarchical extension of the trans-dimensional framework, the level of data noise can be relaxed to become a free parameter in the inversion. This level is critical because it effectively quantifies the usable information present in the data, and therefore determines the complexity of the solution. We will show the application of the Bayesian method to problems in global observational seismology. The presentation will include application to joint inversion of receiver functions and surface wave dispersion, travel-time tomography and full waveform modeling of structures in the lowermost mantle, and recent advances in modelling of the rotational dynamics of the inner core. The obtained results have profound consequences for the dynamics and the interpretation of the Earth's interior.

S701S2.03

S701S2 - Mathematical problems in seismology

Oral

Potential resolution of earthquake rupture processes with a block-by-block low-cost strong motion network

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An emergent strategy to build extremely dense seismic networks involves low-cost micro-electromechanical system (MEMS) sensors and citizen seismologists. The Community Seismic Network (CSN) aims at deploying sensors on a block-by-block basis in southern California. We assess here how CSN recordings could complement the Southern California Seismic Network (SCSN) to improve our understanding of earthquake physics. Our analysis is based on a simulated Mw7 earthquake scenario on the Sierra Madre fault system, which is within the urban area potentially covered by the CSN. The scenario includes a 3D velocity model of southern California (SCEC CVM-H). We conduct source inversions based on the ground motions that would be recorded by the CSN and/or the SCSN. Due to the large number of stations and the complexity of the wave propagation medium, the source inversion is computationally challenging. We apply our recently developed source inversion method based on adjoint principles. It enables a computationally efficient evaluation of the gradient of the cost function needed in an iterative gradient-based optimization strategy. The density of the CSN is expected to resolve the details of the rupture process (e.g. position of asperities, peak slip velocity) significantly better than the SCSN. We will report on the comparison between our results of source inversions based on SCSN recordings and the combined SCSN and CSN dataset.

S702PS.01

S702PS - Advances in seismic data handling: from acquisition to data services, analysis and products

Poster

Ensuring waveform data integrity

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Obviously, the core part of a seismological data center is its waveform data, mainly collected from continuous online channels. This steadily growing data set is stored permanently and is made available to the user by various interfaces. In order to always deliver proper data, one of the challenging tasks of the data center is to ensure the integrity of the complete waveform data set at all times. In our environment, recommendable strategies for achieving this goal are: (i) do not rely on a single storage medium (ii) maintain checksums of data to be able to identify integrity problems (iii) regularly verify the checksums on all online and backup media At the waveform data center at the Federal Institute for Geosciences and Natural Resources, Hanover (BGR), the data archive consists of currently about 15TByte of mainly broadband waveforms. For ease of data management the whole set is chopped into pieces of a few GBytes each. The waveforms are stored on disk storage systems (NAS), the backup data are on a tape robot system and on USB disks. Via internal an explicit redundancy of these storage media up to seven redundant physical different storage locations can be realized. The storage and backup locations including their integrity verification status is controlled by databases. The goal is that each copy of every data piece is revisited at least once a year to warrant a reliable data recovery in case of storage failures. This highly redundant system with frequent integrity status checks minimizes efficiently the risk of data loss.

S702PS.02

S702PS - Advances in seismic data handling: from acquisition to data services, analysis and products

Poster

Web service of seismic activity fields

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Currently, there are many sites on which seismological observations are provided. In the report the web service project for visualization of fields of seismic activity is considered. Seismic observations to calculate the fields will be automatically read from the ISC site. Time series of seismic activity fields during T_1 (background seismic activity) and during T_2 (the observed seismic activity), as well as the field of seismic activity changes (normalized difference of the background and observed seismic fields) will be presented to the user. The results are automatically updated once a week. Algorithm is as follows. Pre-specified: the region and the magnitude for the fields of seismic activity; regular grid of 3D spatio-temporal fields with Δx, Δy, and Δt steps on the longitude, latitude and time coordinates; parameters of the kernel function: R and T are decreasing kernel function decrements by geographical distance and in time, ε is the threshold that defines the border, after which the kernel function is assumed to be 0. It is assumed that b-value is the same over time and space of the region. Let the web-service reads the catalog of earthquakes within the time interval ($T_1 + T_2$). Spatial 2D field of minimum earthquake magnitudes is calculated by the catalogue. Then 3D field of earthquake epicenter density is calculated by the earthquakes with the magnitudes greater than the minimal magnitude. The field of earthquake density is converted to two 3D fields of seismic activity for the time intervals T_1 and T_2. Further output fields are evaluated: A_1 and A_2 are time-averaged at the intervals T_1 and T_2 2D fields of seismic activity, and $\Delta A=(A_2-A_1)/\sigma$ is the field of statistics, which indicates normalized value of seismic activity change, where σ is the field of standard deviations of $A_2(n)-A_1(n)$, n is a number of the grid node. Web service prototype is open at http://www.geo.iitp.ru/server/over.html

S702PS.03

S702PS - Advances in seismic data handling: from acquisition to data services, analysis and products

Poster

Automatic pickers performances in the case of the Emilia sequence of May-June 2012

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The automatic processing of seismic data, whether for real-time seismic warning system or to reprocessing large amount of seismic recordings, is increasingly being demanded by seismologists especially in case of emergency as for the Emilia sequence in may-june 2012. In this study is presented a comparison between the AutoPicker (DipTeRiS, University of Genova) a new method used for automatic accurate onset phase picking for both P and S wave arrival based on the Akaike's information criterion (AIC), a solid and tested picker as the STA/LTA in Antelope software and the manual pickings. In order to construct the database used for the relocation of Emilia sequence, the RAN strong motion database has been merged with the available velocity and acceleration data extracted from the EIDA database (European Integrated Data Archive) and velocity data recorded by the Southeastern Alps Integrated Network (DMG, OGS, ARSO and ZAMG). The fault system of the Emilia earthquake area is complex and it is not easy to assess which fault has moved. A precise localization of the sequence is essential. The manual pickings, the equivalent locations and the choice of the most appropriate velocity model (“Iside”) used in this study are the results of a work done in collaboration with Università di Chieti and DPC, not described here. The main problem of the AutoPicker and Antelope software is to discriminate events that occur very close to each other in time. The best way to solve that issue is choosing the best setup of both techniques to minimize the problem. Then we are implementing the AutoPicker technique on the Antelope system routinely used by DMG for the real-time data analysis. In addition we use automatic locations and manual locations to produce a travel time tomography of the field near the generating fault of Emilia sequence 2012 and compare the different results in order to study how much the location's errors influence the tomography's results.

S702PS.04

S702PS - Advances in seismic data handling: from acquisition to data services, analysis and products

Poster

Integration design and development of python based toolboxes for data download and analysis

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The increase of seismological data and the increment of archiving data-centers providing waveforms with automated methods - web-pages and/or web-services - allow for the application of standardized seismological analysis to a previously unthought amount of events. Unfortunately, web-services and web-page based data requests have not yet reached standardized syntaxes and, although these differences are generally small, they are enough to oblige users to apply different request procedures to obtain data from the different data-centers for the same earthquake.

We present here a possible solution to the problem above by introducing wavesdownloader (called here Wd), an open source python based seismological software toolbox for data discovering, downloading and pre-processing. The tollbox makes extensive use of the obspy software libraries. Wd integrates access to web-services of different data centers simultaneously to request and download waveforms using a single procedure and syntax. Moreover, wd features the exporting of the downloaded data into the most commonly used seismological data formats, and their pre-processing for additional analysis (e.g., phase onset picking, PGMs parameters for ground shaking analysis). Wd is thus designed to be coupled with other commonly and widely used softwares. The modular design of wd allows for the seamless addition of new modules required, for example, by other software analysis tools.

We then developed a python based toolbox for the time domain moment tensor inversion of small local and regional earthquakes - pyTDMT. The pyTDMT is designed to be integrated with wd, using waveforms and metadata downloaded with wd and does not need the preparation of specific file format.

wd and pyTDMT show how simple and straightforward can be the design of seismological analysis toolboxes and how they can be combined to provide complete and standardized earthquake data and parameters to be used also for seismic hazard and risk products.

S702PS.05

S702PS - Advances in seismic data handling: from acquisition to data services, analysis and products

Poster

Automatic event relocation using optimized SeisComP3 software settings in Central Alborz (Iran)

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SeisComP3 is one of the few softwares used nowadays for real-time data processing including earthquake location. It obtains continuous waveforms of stations from the internet as an input, automatically filters the input signal and by the use of a Short Term Average to Long Term Average ratio (STA/LTA) filter as its picker algorithm, the P phase are picked. When a sufficient number of picks are ready, location is done by use of a grid format file and pre-defined travel-time tables in a LOCSAT format. By default SEISCOMP3 uses predefined and similar filters and STA/LTA parameters for all stations worldwide, a global grid and iasp91 velocity model for locating earthquakes. These setting might be adequate enough for detecting teleseismic earthquakes which might cause tsunamis, but with these settings definitively many local events are missed inside the network. It is also possible to detect micro-seismic events using SeisComP3 by manipulating its settings. In this study, we have used SEISCOMP3 in offline mode in order to optimize and relocate local events occurred in the year 2010 in Central Alborz (Iran). The region included 16 short period (SS1) stations, consisting of 223 GB Yiles. First a database of Mini-SEED daily files were created, then different filters, triggers, STA/LTA ratios, velocity models and time tables were implemented. Grid file of SeisComP3 was also modified and instead of using global grid, a condensed grid file suitable for Alborz region was implemented. Local velocity model for the area was used instead of iasp91 and travel time tables for all phases were generated in LOCSAT format. After offline execution of SEISCOMP3 our results show a great improvement in number and precision of located events, moreover micro-seismic events that were not detected in the IGUT routine bulletin for the year 2010 were found.

S702PS.06

S702PS - Advances in seismic data handling: from acquisition to data services, analysis and products

Poster

Fast automatic strong motion data analysis for Civil Protection purposes: the 2012 Ferrara earthquake example (Northern Italy)

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A fast seismic data analysis is essential to provide useful information to Authorities which make decisions immediately after a strong earthquake occurrence. During a strong earthquake, the modern accelerometers are the only instruments which can provide near source high-quality data that are important both for scientific and for civil protection purposes. Automatic and fast techniques have been developed by the University of Trieste for the automatic real-time strong motion data analysis. These techniques have been installed and optimized in the data acquisition centre of the Department of Civil Protection of Italy (DPC) to process the quasi real-time data of the National Accelerometric Network (RAN). RAN counts more than 450 stations covering all the Italian territory. Two local networks, the Friuli Venezia Giulia Accelerometric Network (RAF), located in NE Italy, and the Irpinia Seismic Network (ISNet), contribute their data into the RAN data acquisition system. 148 stations of the integrated RAN triggered the main shock of the Ferrara arc 2012 sequence. The RAN stations recorded the strong motions of the ML 5.9 mainshock, as well as of the major ML 4.1 foreshock and of nearly 35 aftershocks of magnitude ML ¡Ý 4.0. Soon after the mainshock, the DPC installed 15 temporary stations to increase the network coverage in the epicentral area. The performance of the network and of the fast automatic strong motion data analysis during the 2012 Ferrara sequence is analysed. The value of the strong motion parameters calculated by means of the automatic procedure immediately after the events show small differences with respect to the visual inspection procedure. Other aspects related to the seismic source, attenuation of seismic waves, directivity effects and to the comparison between distribution and attenuation of earthquake engineering parameters and observed damage are discussed, highlighting the robustness of the proposed automatic procedure.

S702PS.07

S702PS - Advances in seismic data handling: from acquisition to data services, analysis and products

Poster

Strong motion network in Greece: Current status and contribution

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To date EPPO-ITSAK operates a nationwide motion network more than 230 'free field' that provide large number of reliable strong motion recordings open to the public. These accelerographs are installed mainly in highly populated settlements, in various special borehole arrays and on structures. Thus, in case of a strong event all acquired strong motion data can significantly contribute to microzoning for reconstruction and rehabilitation studies of the affected infrastructure and citizens. During the period 1982-2007 ITSAK operated about 80 'free field' accelerographs in Greece. In 2007, the permanent network upgraded and enhanced with additional 28 'free field' high resolution digital recorders and 5 borehole accelerometer arrays. In 2008 with additional funding by the Hellenic Earthquake Planning and Protection Organization(EPPO), ITSAK further enhanced its strong-motion network by procuring and installing throughout the Greek territory an additional number of 118 latest-generation broadband digital accelerometers. The aim of the project, was to enhance density of the Hellenic strong-motion network that may adequately monitor seismic response of all the major urban areas in Greece and – in certain cases – the diversified seismic response of various soil formations within a certain urban area. Early in 2013 installation of the new 24-bit broadband accelerometers is going be completed. Communication and data transfer is accomplished in real-time and continuously through internet making use mainly of the SYZEFXIS public network. The large amount of incoming data are stored to dedicated servers while a semi-automatic procedure has been designed to retrieve seismic recording based on reliable earthquake catalogues. Strong motion data of the network are used in seismic hazard assessment by studying source, path and site effects of all triggering events. Due to real time data acquisition a tools has been developed to estimate 'shake maps' in case of a strong earthquake.

S702PS.08

S702PS - Advances in seismic data handling: from acquisition to data services, analysis and products

Poster

Curvature attributes to delineate faults in offshore Iran

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Curvature attribute maps have been very successful for delineating fault zones in sedimentary basins of offshore Iran. Each of the individual curvature attributes gives a slightly different insight into the mapped surface. The major objective was to delineate the fault zones through a comparison between various curvature attributes and has been made in order to highlight the main differences between them. Several curvature attributes such as most positive, most negative, dip, strike, curvedness, Gaussian, maximum, minimum and mean curvature attributes were calculated for a 3D seismic volume. The curvature attribute studies reveal that maximum curvature and dip curvature showing high sensitivity relating to the fault zones. The positive curvature values discriminate from negative curvature values in maximum curvature attribute. Point of view of geometry, as positive curvature values represent upthrown side and negative curvature values represent downthrown side of the fault therefore, comparison between the maximum curvature and other curvatures show that maximum curvature attribute is very effective in orientation of the fault dip. Both magnitude and direction of the faults are preserved with dip curvature attribute. Surface orientation independent is one of the useful properties of curvature attributes as the curvature values have a large contrast. In addition, in areas with the high background dip, values reveal more detail as smaller faults appeared with more clarity. Curvature attributes provide a powerful insight into mapped surfaces revealing a lot of extra information relating to faults, lineaments and the local shape of horizons.

S702PS.09

S702PS - Advances in seismic data handling: from acquisition to data services, analysis and products

Poster

Analyze of full waveform acoustic logs when there is borehole instability in order to obtain reliable formation properties

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In this study we investigate the borehole instability and try to achieve trustworthy formation properties. Data from a well in south of Iran has been studied. There are rock failures in wall of the borehole which they are well known as drilling induced fractures. Some of them are classified as small scale failures in the borehole wall and the rest of them should be considered more. We use conventional logs including lithology, density, dipmeter and full waveform acoustic logs. The DSI dipole shear sonic imager, combines monopole and dipole sonic acquisition capabilities for the reliable measurement of compressional, shear, and Stoneley slownesses. We cannot use the standard processing methods in these kinds of boreholes because of the borehole wall is under failure. The density log shows we need extra correction steps when the diameter size is seriously more than the bit size. The effects of failures on full waveform acoustic logs such as refracted P and S and Stoneley are evaluated by theoretical models. We modify P and S wave velocities from other waves which are least affected and next we try to obtain density from P wave data by using the correlation between density and P wave velocities. Finally we obtain the dynamic elastic moduli and, through known relationships, the static ones.

S702S1.01

S702S1 - Advances in seismic data handling: from acquisition to data services, analysis and products

Oral

Virtual Earthquake and Seismology Research Community e-science environment in Europe (VERCE)

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The nature of science in seismology is changing – new discoveries will emerge from the statistical analysis and the modeling (inversion, assimilation) of large amounts of complex data generated from dense observational and monitoring networks and from large-scale wave propagation simulations. In many cases our ability to acquire observational and synthetic data outpaces our ability to process them. Addressing these challenges requires a new and holistic approach.

VERCE is a four years FP7-INFRASTRUCTURE project, with a consortium of ten partners from seismology and computer sciences. It is a major contribution to the e-science infrastructure of the European Plate Observatory System (EPOS), the ESFRI initiative of the solid Earth community in Europe. The aim of VERCE is to provide a data-intensive e-science environment enabling innovative statistical data analysis and modeling methods of the seismology research community.

The VERCE e-science environment is built upon a service-oriented architecture and a platform of work/data flow tools and services integrating European computing and Data infrastructures, private resources together with the community Data archives. Another important goal is to provide intellectual ramps that provide safe and supported means for researchers and users of the community to engage in data-intensive research. VERCE

We report here the progress of VERCE after one year and half. Selected data-intensive analysis and modeling pilot use cases will be detailed and analyzed in terms of work/data flow requirements and e-science environment. First enabling steps will be reported as well as the next VERCE roadmap.

S702S1.02

S702S1 - Advances in seismic data handling: from acquisition to data services, analysis and products

Oral

The European Seismological Research Infrastructure and EPOS: status and developments

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NO COUNTRY SELECTED -

Europe is currently investing heavily in coordination of its seismological research infrastructures (RIs) and the products and services they provide through a wide variety of European and national projects. The current status and on-going developments can be described within roughly three categories:

- Seismological data, including primary waveforms, metadata and primary measures (arrival times and amplitude of seismic waves) and building on existing network coordination initiatives within the ORFEUS (www.orfeus-eu.org) framework.
- Seismological products, including earthquake parameters (location, magnitude), seismic bulletins and (historical) catalogues, earthquake alerts and building on existing coordination efforts within the EMSC (www.emsc-csem.org) framework.
- Products and services in seismic hazard and risk, including base date for modeling (catalog of active faults, GMPEs, building vulnerability functions, etc) and modeling tools, hazard & risk maps and scenarios, and building on on-going initiatives in SHARE and NERA and within the EFEHR (www.efehr.org) framework.

The breadth of the developments is illustrated by the many on-going projects. During 2013 the coordinating organizations are structuring those developments into a comprehensive European seismological RI, well embedded in the international framework to ensure compatibility and, specifically, in the general European earth science RI of EPOS. This includes a long-term planning of integrated services based on a scientific research vision in earth sciences.

S702S1.03

S702S1 - Advances in seismic data handling: from acquisition to data services, analysis and products

Oral

The EPOS architecture: Integrated core services for solid earth science

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The European Plate Observing System (EPOS) is a long-term plan to facilitate integrated use of data, models and facilities from existing and new distributed research infrastructures for solid Earth science.EPOS will make possible innovative multidisciplinary research leading to a better understanding of the physical processes controlling earthquakes, volcanic eruptions, unrest episodes and tsunamis,and those driving tectonics and Earth surface dynamics. EPOS mission requires integration of the existing European research infrastructures (RIs) in the solid Earth sciences and this will result in increased accessibility and usability of the many types of data acquired by the existing monitoring networks. We present the EPOS e-Infrastructure architecture and illustrate the initial suite of services that EPOS will provide to users.

The e-Infrastructure is being developed along 3 parallel tracks:(a) an inventory of assets offered by organisations within the EPOS community,the Research Infrastructure Database for EPOS (RIDE),(b) an iterative process of refining an architecture to meet the requirements (c) a prototype in one domain (seismology) to provide assurance that the architecture is valid.

To the purpose of sustainability of its infrastructure, EPOS is taking into account (i) issues about the interoperability with other geoscience systems, (ii) interoperability with other European environmental research infrastructure projects which present sustainable solutions for data management (e.g. EUDAT), (iii) concepts and architecture proposals which might possibly become the standard in data management,as Research Data Alliance (RDA).

We will describe the use-cases identified thus far that will allow stakeholders and potential future users to understand and interact with the EPOS infrastructure.We also discuss the global perspectives for data infrastructures in order to demonstrate the relevance and coherence of the EPOS plans, and show how EPOS is at the cutting edge.

S702S1.04

S702S1 - Advances in seismic data handling: from acquisition to data services, analysis and products

Oral

The European Integrated seismic waveform Data Archives (EIDA)

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ORFEUS is the non-profit foundation that coordinates and promotes digital broadband seismology in Europe. Since 1987 the ORFEUS Data Center (ODC) has been its jointly funded data center. During the last years new opportunities and challenges arose to revise the European data archiving structure. The rapid growth in the amount of seismic stations operated by European organizations as well as the diversification of data types put new demands on data archive management. Preservation of data, up-to-date metadata management, data quality monitoring tools, as well as provenance tracking are key elements in providing enhanced services to the scientific community to properly discover, access, process and cite the data. To cope with the new demands on data management as well as to further extend the services to the users, ORFEUS revised its data archiving infrastructure into a coordinated distributed data archive system. A major component of this is the establishment of the European Integrated waveform Data Archives (EIDA). The founding group of EIDA nodes, formed in 2013, is responsible for steering and maintaining the technical developments and organization of the European distributed waveform data archive. The EIDA Founding nodes are ODC/ORFEUS, GFZ/Germany, SED/Switzerland, RESIF/France, INGV/Italy and BGR/Germany. This group has been formed within ORFEUS to ensure sustainability of the EIDA system and implementation of new developments. Currently, ArcLink is the protocol which technically connects the distributed archives and provides uniform access to the data archives. With regard to the new challenges in data management, quality assurance, provenance and services in a distributed archive, new developments will be implemented in the EIDA framework. This includes global coordination within the International Federation of Digital Seismograph Networks (FDSN). The EIDA infrastructure and organization will be presented with emphasis on on-going developments and challenges.

S702S1.05

S702S1 - Advances in seismic data handling: from acquisition to data services, analysis and products

Oral

The Swedish National Seismic Network (SNSN)

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Over the last ten years, 67 new, permanent, digital, broadband seismological stations have been deployed in Sweden, from Lappland in the North to Skåne in the South. The network operates largely automatically, and is now essentially complete. The primary objective of the network is to monitor local seismicity. Seismometers with high gain (20,000 Vs/m) are used to ensure monitoring of true ground motion at higher frequencies. With the current station spacing of about 100 km, completeness magnitude close to “M_L=0” is assured within the network. This magnitude corresponds to very small movements, for example to a motion of 0.01 mm over a fault area with a radius of about 50 m. Several hundred Swedish earthquakes are detected every year. Only a few (5 to 10) of these are so large that they are felt by people living close to the epicenter. While Sweden is a low seismicity area, the high sensitivity of the system means that ongoing deformation processes in the crust can be monitored in detail. As a larger data set is gradually acquired, it is also possible to use information from these events to elucidate structures within the Swedish crust. In addition, the network records signals from larger distant (teleseismic) earthquakes, and also regional events of sufficient magnitude. These data are analysed to reveal details of the structure within the crust and upper mantle below the recording stations in addition to source complexities.

S702S1.06

S702S1 - Advances in seismic data handling: from acquisition to data services, analysis and products

Oral

A streaming processing model for efficient computations of large continuous data sets

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Many traditional software processing models are not well suited to the large continuous, real time data streams from observatories and data centers around the world that are readily available today. Traditional software processing has tended to treat data as discrete sets that were processed in a batch mode. This has been especially true with active source exploration processing software and passive seismic event oriented processing software. The treatment of data in these traditional batch oriented software modules is not well suited to processing continuous data. This has led to a certain segregation in processing software development; continuous real-time processing vs. discrete batch processing. We present a software design methodology that provides researchers with a substrate that can be used to effect both continuous real time and discrete batch processing using the same software source coding. The software substrate consists of a set of interoperable dynamically linked modules, each running in its own thread and communicating with the other modules through specialized real time packet pipes. We provide a standardized set of import and export software modules that regularize the inner computational modules so that they can process both real time continuous and discrete data sets without the need for separate code versions. This software design methodology also provides inherent threading, transparent to the application programmer, to provide maximum leverage of modern multiprocessor computer systems. We show real examples of this methodology, including seismic array processing, data resampling and real time spectra estimation.

S702S2.01

S702S2 - Advances in seismic data handling: from acquisition to data services, analysis and products

Oral

Recalibrating the Global Seismographic Network

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As part of ongoing work to assess and improve the quality of data collected from instruments deployed at the 150+ stations of the Global Seismographic Network (GSN), particular attention is being directed at improving the metadata that characterize sensor responses. Details of the overall quality assessment program are described on IRIS' website at www.iris.edu/hq/programs /gsn/quality. One very important component of this effort focuses on recalibrating existing instruments at each site. A portable broadband sensor whose stable response can be verified in the laboratory is installed in close proximity to the in situ GSN sensors and operated for a duration of several hours or days. From these waveform data, a very precise estimate of the sensitivity and orientation of the GSN seismometers may be obtained. Observations that indicated a need for this program are reviewed. This study also highlights the opportunity provided by the occurrence of the 2011 Mw 9.0 Tohoku earthquake as well as several other large events since 2004 to evaluate the impact of the new calibration procedures on the metadata accuracy. Receiver stripping techniques are used to collect information about the amplitudes of long period modes excited by these large events. The resulting data set is then examined for patterns that would indicate errors in the metadata. Sensors whose recordings consistently fall along the tails of the amplitude distributions are identified as candidates for further study. The subset of observations from sensors whose sensitivity has been verified by co-located, calibrated, portable sensors generally show a narrower distribution, which suggests the new calibration procedures are effective in improving metadata quality.

S702S2.02

S702S2 - Advances in seismic data handling: from acquisition to data services, analysis and products

Oral

SeisComP 3 - Where are we now?

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Originally a seismological acquisition and archival software, SeisComP has evolved within the last approximately 10 years into a fully featured real-time earthquake monitoring software.

The development of the of the 3rd-generation SeisComP, also known as «SeisComP 3», was driven by the needs of the German-Indonesian Tsunami Early Warning System GITEWS, funded by the German government following the disastrous tsunami of 2004, as well as global earthquake monitoring at GFZ Potsdam. Automatic processing modules include a phase picker, global associator and locator as well as modules for data quality control. Several modern graphical user interfaces are available for rapid event review and visualization. Communication between the modules is achieved using a a TCP/IP infrastructure that allows distributed computing and remote review. For seismological metadata exchange export/import to/from QuakeML is avalable, which also provides a convenient interface with 3rd-party software.

SeisComP is the primary seismological processing software at GFZ Potsdam. Especially since the first public release of SeisComP 3 in 2008, the software has been successfully adopted by numerous regional and local seismic networks world-wide. The growth of its active user community has resulted in significant external funding of new capabilities that make SeisComP particularly attractive for local and regional monitoring. For instance, event relocation in 3-D velocity models is now transparently possible through an interface to the popular relocator NonLinLoc. In addition to seismological aspects, the issue of configuration has been addressed by a completely new configuration framework, which features an easy-to-use, graphical configuration tool.

In our presentation we provide an overview on the current status of SeisComP 3 five years after its first public release, as well as possible future developments.

S702S2.03

S702S2 - Advances in seismic data handling: from acquisition to data services, analysis and products

Oral

Observations for large scale networks based on operations of the NSF USArray Transportable Array

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Since 2004, the Transportable Array component of the USArray Instrumentation Network has collected high resolution seismic data in near real-time from over 400 geographically distributed seismic stations. The deployed footprint of the array has steadily migrated across the continental United States, starting on the west coast and gradually moving eastward. As the network footprint shifts, stations from various regional seismic networks have been incorporated into the dataset. In 2009, an infrasound and barometric sensor component was added to existing core stations and to all new deployments.

One class of difficult problems faced in the USArray project is related to the dynamic nature of the moving array including maintaining accurate and up-to-date metadata, and developing a variety of web-based tools to support field operations based on the changing requirements of the field teams. A second class of problems are based on the scaling of the data bandwidth, server processing power, and storage requirements which are driven by the requirements of acquiring data in near-real-time, generating the most complete data set possible by creating the union of real-time data with the on-site storage, and by adding new channels of scientific and SOH data.

The ongoing success of the project can be attributed to a number of factors, including reliable communications to each site, on-site data buffering, largely homogenous data logging hardware, and a common phase-locked time reference between all stations. Continuous data quality is ensured by thorough human and automated review of data from the primary sensors and over 24 state-of-health parameters from each station. The staff at the Array Network Facility have developed a number of tools to visualize data and troubleshoot problematic stations remotely. In the event of an emergency or maintenance on the server hardware, data acquisition can be shifted to alternate data centers through the use of virtualization technologies.

S702S2.04

S702S2 - Advances in seismic data handling: from acquisition to data services, analysis and products

Oral

Reconstruction of the Icelandic SIL seismic data base to facilitate fast access to quality checked seismic data and products

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In the new environment of cross-border networking of research infrastructures to enable access to data and derived products, the data base of the Icelandic national seismic network, SIL will be reconstructed. The Icelandic Meteorological Office (IMO), which archives geophysical data from the Icelandic national networks, is taking steps to reconstruct the seismological data base and connecting it to other, new or existing geophysical data bases at IMO. Two on-going infrastructure projects are at the core of this development; a national research project Volcano Anatomy, providing the initiative for the seismic data base reconstruction, and the FP7 Icelandic volcano supersite project, FUTUREVOLC, providing construction of a multiparameter data base and access at the supersite to data products relevant to volcanic hazard. Activities in the on-going FP7 seismic hazard infrastructure project NERA, will also establish streaming of seismic broadband data to Orfeus, as well as introduction and access to crucial processes for automatic quality checking of the seismic data. The data service resulting from these projects is expected to become a key data node in the large scale European Plate Observing System (EPOS), providing access to Icelandic volcanological data and services.

The emphasis of the SIL seismic analysis system is on automatic, real-time processing. The system operates and stores its parameters, earthquake locations, mechanisms and ShakeMaps in Unix tree file systems. This structure allows only one solution to be stored for each event, which makes all post processing and re-analysis at the data centre very cumbersome and difficult to keep track of. Presently the parameter data is copied into a relational data base that has hitherto had limited use beyond basic data viewing, does not allow search of the waveform data base, or provide automatic outside access to the data. Reconstruction of this data base is required to facilitate data access at the supersite.

S702S2.05

S702S2 - Advances in seismic data handling: from acquisition to data services, analysis and products

Oral

ODC: developments to meet the future data challenges

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European seismological waveform data archives need to address several challenges in the near future: integrate distributed data archives and computational resources, handling an exponential growing amount of diverse data. provide metadata describing data and QC parameters, long-term archival security, affordable services and maintenance, and diversified services for a broad earth science community. Orfeus Data Center is therefore improving its services, using new (web) technologies for data and product services, data management and integration European Integrated waveform Data Archive (EIDA) and FDSN developments. This investment is mostly funded through EC-projects NERA, VERCE, and contributions from different ORFEUS participants and EMSC, IRIS-DMC collaborations. We implement standardized web services, experiment with data management at different levels (a.o.MonetDB), spanning from data acquisition and description to quality assessment, preservation and integration with other domains (IRODS, Dublin Core, CERIF). We coordinate relevant activities in projects like VERCE, EPOS, NERA and ENVRI to ensure a common direction in the infrastructure implementation European seismology and benefit from experience and existing relevant knowledge in projects like EUDAT, COMMIT and COOPEUS. These project investigate, experiment and implement the best technical approaches to data and metadata management and standards. In VERCE we participate in integrating data archives and computational creating a virtual research environment. Large volumes of data and computational complexity necessary to create new data products require new processing techniques. Therefore we work together with the EGI and PRACE communities and the related projects (SCI-BUS), to implement user friendly access strategies to the computing infrastructure supporting the user with services and portals.

SP1PS.01

SP1PS - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Poster

Assessment of tsunami hazard for the coast of the Okhotsk Sea

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Okhotsk Sea is the large marginal sea in the north-western Pacific region, located tectonically within the Okhotsk microplate bounded on the north by the North American Plate, on the east by the Pacific Plate and on the west by the Eurasian Plate. Its long western coastline stretches along the Kolyma coast for more than 2500 km and until recently was considered as having low risk of tsunami impact. However, after the destructive Mw9.0 Tohoku earthquake and tsunami, the decision was made about addition of this coastline to the zone of responsibility of the Tsunami Warning System acting in the Far-East region of Russia. This part of the Okhotsk coast does not have nearby seismic zones capable to generate destructive tsunamis, however, its exposure to the tsunamis originated in the main Kuril-Kamchatka seismic zone remains questionable. The earthquakes on the northern shelf of the Sakhalin Island can be also potentially dangerous for the Kolyma coast. The paper deals with assessment of the long-term tsunami hazard for the Okhotsk coast by means of numerical modeling of tsunami generation and propagation from model sources representing typical tsunamigenic earthquakes in subduction zones. Several possible scenarios with model earthquakes having Mw magnitudes from 7.8 to 9.0 and placed at different locations along the Kuril-Kamchatka seismic zone were considered. Energy radiation patterns and distributions of maximum wave heights at the Kolyma coast were obtained and compared with available historical data on tsunami observations in this area. It was found that Mw9.0 mega-quakes are capable to produce dangerous waves with heights up to 4-6 meters at many locations along the Kolyma coast. Several places at this coast have increased tsunami heights as compared to the neighboring parts due to wave energy focusing by topographic features of wide western shelf of the Okhotsk Sea.

SP1PS.02

SP1PS - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Poster

Tsunami waveform inversion by the truncated SVD approach and its application to the 2011 Tohoku event

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This paper proposes an approach to solving the problem of reconstructing an initial tsunami waveform in tsunami source area by the inversion of the remote measurements of water-level data. It is well known that this inverse problem is ill-posed and imposes some restrictions on the use of mathematical techniques. In the present study, tsunami wave propagation is considered within the scope of the linear shallow-water theory. Numerical simulation is based on the finite difference algorithm and the method of splitting. The unknown function of water surface displacement in the source area has been represented as a series of spatial harmonics with unknown coefficients. The proposed method is raised on singular value decomposition (SVD) and r-solutions techniques. In this method, the inverse operator is replaced by its restriction on a subspace spanned by a finite number of the first right singular vectors. The quality of the solution is defined by relative errors of the tsunami source reconstruction. How accurately a tsunami source can be recovered using records at a given data network? Is it possible to improve the quality of reconstructing a tsunami source by distinguishing the most informative part of the initial observation system? To answer these questions there has been carried out a series of numerical experiments with synthetic and real bathymetry of Peru(1) and Kurile Trench(2) subduction zone. By analyzing the characteristics of a given tide gauges network, the above-proposed method makes possible to control numerical instability of the solution and therefore to obtain an acceptable result in spite of the ill-posedness of the problem. It has been revealed that the accuracy of tsunami source reconstruction strongly depends on the signal-to-noise ratio, the azimuthal and temporal coverage of assimilated monitoring stations relative to the target area and bathymetric features along the wave path.

SP1PS.03

SP1PS - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Poster

Tsunami-induced electromagnetic fields in the ocean

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Electric and magnetic (EM) fields are generated within ocean currents moving through the earth's magnetic field, and tsunami flows are also considered to generate EM fields in the ocean although its signal levels are very low. Recent advances in high precision measurements of EM fields enabled the seafloor measurements of the tsunami signals. In order to extract useful information from the offshore measurements of tsunami EM signals and utilize them for the tsunami warning at coast, we need an appropriate theory, which relate the EM signals observed at seafloor to tsunami parameters. Results of the theoretical examination demonstrate that the observations of the three components of the magnetic field and the two horizontal components of the electric field at a single seafloor station can reveals, (1) variations of the sea level change associated with tsunami flows, (2) propagation direction of tsunami waves, (3) frequency dependence of phase velocity of tsunami propagation, and (4) frequency dependence of apparent electrical conductivities observed at seafloor. We will show that these theoretical relations are verified by the results of the first simultaneous observation of the 2010 Chilean earthquake tsunami and applicable to the 2011 Tohoku earthquake tsunami. Recently we have just developed a new tsunameter equipped with an electromagnetometer to estimate the directions as well as a pressure gauge to measure the amplitudes of tsunamis, which is called «vector tsunameter».

SP1PS.04

SP1PS - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Poster

Tsunami hazard of Canada: a first-order assessment

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We present the first tsunami hazard assessment of the Canadian coast, accounting for local and far-field, earthquake and large landslide sources. Our probabilistic analysis uses historical, paleotsunami and paleoseismic data, modelling, and empirical relations between fault area, earthquake magnitude and tsunami runup. We consider geological sources with known tsunami impacts (e.g., Cascadia subduction zone; 1755 Lisbon tsunami source; continental slope failures) as well as potential sources with previously unknown impact (e.g., Explorer plate subduction; Caribbean subduction zones; crustal faults). The cumulative hazard for potentially damaging runup (1.5+ m) of the outer Pacific coastline is estimated at ~40-80% in 50 y, respectively one and two orders of magnitude greater than the outer Atlantic (~1-15%) and the Arctic (< 1%). For larger runup with significant damage potential (3+ m), Pacific hazard is ~10-30% in 50 y, again much larger than both the Atlantic (~1-5%) and Arctic (< 1%). For the outer Pacific coast, far-field subduction sources dominate the 1.5+ m runup hazard, but the probability of runup exceeding 3 m is highest for local megathrust sources, particularly the Cascadia subduction zone. Thrust sources along the Explorer and Queen Charlotte margins are also significant for the adjacent coastline; runup data from the 2012 Haida Gwaii tsunami provide a useful validation of our methods. For the more sheltered inner Pacific coast (Juan de Fuca and Georgia Straits), the hazard at both levels is contributed mainly by the Cascadia megathrust. Tsunami hazard on the Atlantic coastline is dominated by poorly-constrained far-field subduction sources; a lesser hazard is posed by near-field continental slope failures similar to the 1929 Grand Banks event. Tsunami hazard on the Arctic coastline is poorly constrained, but is likely dominated by continental slope failures; a potential thrust earthquake source beneath the Mackenzie River delta requires further study.

SP1PS.06

SP1PS - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Poster

The meteorological tsunami of 1 November 2010 in the Strait of Georgia

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On 1 November 2010, an unusual marine event occurred in the area of Point Atkinson in the southern Strait of Georgia, British Columbia. On this day, fast-moving muddy water surged back and forth along a shoreline channel, creating significant local damage. An examination of nearby tide gauge records revealed that this was a tsunami-like wave event. The event was clearly observed at tide gauges at Point Atkinson, West Vancouver and Patricia Bay, the latter being located roughly 70 km from the other sites and on the opposite side of the strait. Precise atmospheric pressure records for the region indicated that the observed phenomenon was likely caused by a major atmospheric disturbance that propagated over southern part of Vancouver Island and the nearby mainland coast. Sea level oscillations associated with the event were similar to those from meteorological tsunamis that occurred in this region on 9 December 2005, 13 July 2007, and 28 February 2008. Meteorological tsunamis resemble seismically generated tsunamis but have an atmospheric, rather than seismic, origin. An analysis of coincident 1-min sea level data and high-frequency atmospheric pressure data confirms that the 1 November 2010 event originated with atmospheric pressure jumps and trains of atmospheric gravity waves with amplitudes of 1.5 to 2.5 hPa. The estimated speed and direction of the disturbance were in close agreement with high-altitude steering winds (the jet stream), indicating that the atmospheric disturbances generating the tsunami-like sea level oscillations were likely wind-transported wave trains rather than freely propagating atmospheric gravity waves.

SP1PS.08

SP1PS - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Poster

Meteorologically-generated anomalous sea level oscillations in the Port of Kholmsk (southwestern Sakhalin Island)

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The Port of Kholmsk is the main sea gate of Sakhalin Island. Loading and unloading of ferries are highly dependent on the intensity of resonant oscillations in the port. For this reason, the Institute of Marine Geology and Geophysics, FEB RAS, in 2006 deployed a bottom pressure recorder in the head of the port (close to the ferry pier) to provide continuous monitoring of harbour oscillations. These measurements stopped in the end of 2008 but in 2009 the Sakhalin Tsunami Warning Center installed a telemetric tsunami recorder at the same site. In addition, a high-precision microbarograph was installed in Kholmsk in winter-spring 2012 to measure simultaneous atmospheric fluctuations. Several events of anomalous tsunami-like sea level oscillations with wave heights of 40-50 cm were recorded in the Port of Kholmsk (October 4,2010; May 25,2011; February 20,2012) . The fundamental (zeroth) harbour mode with the period of about 8 min and the nodal line near the harbour entrance was found to play the key role in formation these oscillations. The amplification of this mode leads to strong currents near the entrance which are the reason of major problems for ferries and port activity. The first mode with period of about 3 min that produces strong currents in the central part of the harbour was also found to be important, especially during strong storms. Examination of simultaneous records of sea levels and atmospheric fluctuations indicated that anomalously strong harbour oscillations are mainly associated with atmospheric disturbances propagating over the southern part of Sakhalin Island in autumn and winter. This study was supported by the RFBR grant 12-05-00757- á.

SP1PS.09

SP1PS - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Poster

Atmospherically generated anomalous event (meteotsunamis) observed on the Kuril Islands

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Atmospherically induced tsunami-like events are now and then observed on the coast of the Kuril Islands. They have very similar spatial and temporal scales as ordinary seismically generated tsunamis and can severely affect some bays and inlets. A number of precise bottom pressure recorders were deployed between 2009-2011 by the Institute of Marine Geology and Geophysics off the coasts and in the bays of Shikotan, Kunashir, Iturup and Urup islands. In addition, the Russian Hydrometeorological Committee installed permanent tide gauges at Severo-Kurilsk (Paramushir I.), Malokurilsk (Shikotan I.), Yuzhno-Kurilsk (Kunashir I.), and Kurisk (Iturup I.) for the Tsunami Warning Service. These instruments measured several anomalous non-seismic events enabling us to investigate their physical properties and generation mechanisms. A spectacular event occurred on 21 March 2010 at Severo-Kurilsk during a cyclone passage. A train of generated waves had maximum wave height of 110 cm and looked quite the same as tsunami waves induced at this site by the Kuril Islands earthquake of 28 February 1973. The 2010 Severo-Kurilsk event together with some other events recorded at various sites of the Kuril Islands were spectrally examined and compared with seismic tsunami events recorded at the same sites. We separated topography and source effects and found that the former are responsible for the similarity of various recorded events, while the latter are responsible for specific peculiarities.This study was supported by the RFBR grant 12-05-00757-a.

SP1PS.10

SP1PS - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Poster

Integrated 4D-analysis of seaquake tsunami sources

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The most tsunamis occur as a result of seaquakes. Non-profit organization WAPMERR has a historical database of alleged tsunami sources around the world which is based on the information about seaquakes. However, there are other ways of tsunami occurrence, such as landslides, meteotsunamis, falling large celestial body, explosions, etc. We compare different types of tsunami sources and wave height measured by different stations (DART records, satellite wave-form images, etc). The main idea is to classify tsunami sources with the help of solving the inverse tsunami problem. Using the additional information about the wave height we expand and refine the database of tsunami source types and for operative and accurate prediction of hazards and assessment of risks and consequences. For solving the inverse tsunami problem we use singular value decomposition to estimate the degree of ill-posedness, optimization and regularization methods.

WAPMERR offers a comprehensive solution of tsunami prediction as well as evaluation of the consequences of destruction based on the problem investigation with the help of mathematical tools. Also we present 3D visualization of real-time tsunami wave propagation and loss assessment, characterizing the nature of the building stock in cities at risk, and monitoring by satellite images using modern GIS technology Integrated Tsunami Research and Information System (Imp.ITRIS) developed by WAPMERR in collaboration with the Institute of Computational Mathematics and Mathematical Geophysics SB RAS. The special scientific plug-in components are embedded in a specially developed GIS-type graphic shell for easy data retrieval, visualization and processing.

This work was partially supported by the Russian Foundation for Basic Research (project 12-01-00773) and by SB RAS interdisciplinary project 14 «Inverse Problems and Applications: Theory, Algorithms, Software».

SP1PS.11

SP1PS - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Poster

The 2002 submarine slide in north-eastern Rhodes: numerical simulation of the slide dynamics and of the generated tsunami

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In March 24th, 2002 an around 33 million m3 slide detached along the submarine slope off the north-eastern coast of Rhodes Island (Greece), provoking unusual waves reaching 3-4 m height that caused some damages in the city of Rhodes. The event was very surprising for the eyewitnesses and in general for the population, because it was not associated to any earthquakes that are considered the main source for tsunamis. Subsequent marine surveys found many scars in the detachment area at about 300-400 m depth, which suggests that repeated events might have occurred with generation of waves comparable to the 2002 event. In this work we simulate the landslide and the tsunami using respectively the codes UBO-BLOCK1 and UBO-TSUFD, that were developed by Tsunami Research team of the University of Bologna. The tsunami propagation and the impact on the coast of Rhodes and on the neighboring coast of Turkey shows that the tsunami had a quite local character consistently with the observations. This case is an example of a tsunami source very close to the coast and poses a great challenge for the implementation of adequate tsunami warning systems. It further shows that for a proper tsunami hazard assessment for the island of Rhodes and in the southern Aegean sea not only tectonic sources but even submarine landslides must be taken into account. This study has been conducted in the frame of the European funded project NearToWarn that addresses the problem of devising suitable protection and warning actions against tsunamis generated very close to the coast.

SP1S1.01

SP1S1 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Tsunami sources along Japan Trench: 2011 Tohoku, 1896 Sanriku and 869 Jogan earthquakes

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The temporal and spatial slip distribution of the 2011 Tohoku earthquake was estimated by inversion of tsunami waveforms recorded offshore bottom gauges (Satake et al., 2013, BSSA). The result shows that fault slip started near the hypocenter and very large (> 25 m) slip occurred on the deep plate interface near the hypocenter within ~ 2.5 min, then huge (up to 69 m) slip occurred at the shallow part near the trench axis and propagated to the north. The average slip on a 550 km long and 200 km wide fault is 9.5 m, and the total seismic moment is 4.2×10^{22} Nm (Mw 9.0). The total volume of displaced water (both uplift and subsidence) is ~ 2×10^{11} m^3, and the potential energy is ~ 2×10^{15} J.

The 1896 Meiji Sanriku earthquake is known as a «tsunami earthquake,» which produces weak ground shaking but large tsunami. The largest seismic intensity and the felt area were much smaller than those of the 2011 earthquake, while the maximum tsunami height (~ 40 m) was similar. Comparisons with the waveforms on coastal tide gauges and the coastal heights indicate that the slip was limited in a 200 km × 50 km fault along the trench axis with the average slip of about a half of the 2011 earthquake. The seismic moment is ~ 3×10^{21} Nm (Mw 8.2). The displaced water volume is ~ 2×10^{10} m^3 and the potential energy is ~ 9×10^{13} J; both are an order of magnitude smaller than the 2011 tsunami.

Damage from the 869 Jogan earthquake and tsunami were described in a historical document. In addition, the distribution of tsunami deposits was mapped in Sendai and other plains (Sawai et al., 2012, GRL). By matching the distances of computed inundation and the tsunami deposit, the minimum size of the Jogan earthquake is estimated as 200 km × 100 km fault with 9 m slip, and the minimum moment magnitude Mw is 8.5. The water volume is ~ 9×10^{10} m^3 and the potential energy is ~ 7×10^{14} J, both are between the 1896 and 2011 tsunamis.

SP1S1.02

SP1S1 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Lessons learnt from the 2011 Great East Japan tsunami: failure modes of coastal defense structures due to high-energy impact

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Tsunamis are among the world's most dreadful natural disasters. The 2004 Indian and 2011 Pacific (Great East Japan) tsunamis are extraordinary examples of proving its destruction power that witnessed from the damage to coastal structures and a large number of fatalities. Japan is known as a well-prepared country for tsunami-threat as it possesses advanced technology to predict impending tsunamis, sophisticated communication systems to distribute tsunami-warnings among people and engineered coastal defense structures along the coast, especially the northeast coast, to protect from tsunamis. However, the energy released by the 2011 tsunami was massive and exceeded the predicted and design limits; except a few, almost all the defense structures (seawalls, embankments) at the northeast coast of Japan were partially or fully destroyed thus they acted passively. A field survey was conducted along the coasts of Iwate and Miyagi Prefectures to observe the damage to coastal defense structures in August 2011. The damage was classified as primary or secondary type based on the extent and nature of damage to the structures: breaking (or crushing), overturning, and scouring as the primary type and cracking, and surface chipping as the secondary type. The mechanism behind the damage is varied greatly with type of structure (structural shape/dimensions), local characteristics of the tsunami (flow depth, flow velocity, and density of flow), and the structure-ground interaction during and after the quakes due to ground subsidence and liquefaction of soil. This presentation discusses the possible theory behind each damage mode with the help of photographs taken during the field survey and implies adjustments to the design-formula of such structures.

SP1S1.03

SP1S1 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Cause of traveltime difference between observed and synthetic tsunami waveforms at distant locations

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Pressure gauges deployed at deep open oceans recorded trans-Pacific tsunami from the 2010 Chile and 2011 Tohoku-Oki earthquakes. The observed distant tsunami waveforms show two characteristics different from the synthetic waveforms based on the long-wave simulation. The observation delays up to 15 min relative to the simulation. The delay time increases with the traveltime. Another feature is the negative phase before the main positive peak with the amplitude up to 10 % of the main peak. This initial phase was not observed near the tsunami sources, hence not related to the source process. Numerical tsunami simulation tests with various bathymetry datasets indicate that the inaccuracy of the ocean bathymetry cannot account for the waveform discrepancy.

The phase velocity of the observed tsunami waveforms were measured and compared with that of the tsunami mode branch computed for a 1D spherical earth model (PREM) with a 4km ocean layer. The depth-normalized measured phase velocity is explained well by the tsunami branch of PREM. The measured phase velocity is slower than that of linear gravity wave by more than 1 % at period longer than 2,000 sec, and the shows reverse dispersion at period longer than 1,000 sec. Since the normal mode solution for PREM automatically includes the effects of elasticity of the solid earth, compressibility of seawater, and the gravity potential change associated with the mass motion during the passage of the tsunami, these effects are the main cause of the waveform difference.

Finally we computed synthetic distant tsunami waveforms by taking into account the phase velocity reduction at long-periods predicted by PREM. Comparison with the observed tsunami waveforms shows improved waveform fit for both earthquakes; the traveltime difference becomes less that 5 min and the initial negative phase is reproduced. The large discrepancy between the observed and synthetic distant tsunami waveforms now disappeared.

SP1S1.04

SP1S1 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

The 2011 Tohoku tsunami at Jayapura, Papua, Indonesia: Effects of far-field focusing and receiver-bay resonance

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The 2011 Tohoku tsunami was unexpectedly severe in the Bay of Jayapura (2 S; 140 E), in the Easternmost part of the province of Papua, Indonesia, where it resulted in one of only three known casualties of the tsunami in the far field. The most remarkable aspects include (i) The location of Papua outside of the main lobe of directivity from the source; (ii) the run-up reaching 2.8 m in the Southern part of the bay (destroying several houses in an ocean village, a river bridge on a coastal road, and moving large shipping containers more than 100 m inland), even though it did not exceed 80 cm in the port of Jayapura itself; and (iii) the apparent delay (by at least 2 hours and possibly up to 7) of the main destruction, relative to the first arrival of the wave under the shallow water approximation. On the positive side, a successful evacuation took place following an official warning by BMKG. We present a number of simulations which justify the large amplitudes in Jayapura as due to focusing by shallow bathymetry along the Bonin-Mariana Island Arc and the fossil Caroline and Eauripik Ridges, and explore the resonance of the large shallow dipping Southern Bay to high-frequency components of the tsunami, traveling outside the shallow-water approximation.

SP1S2.01

SP1S2 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Is near-field tsunami forecast possible: lessons from the March 11, 2013 Japan tsunami

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During the devastating 11 March 2011 Japanese tsunami, data from two DARTs were used to determine the tsunami source within 1.5 h of earthquake origin time. For the first time, multiple near-field tsunami measurements enabled accurate real- time flooding forecast system for Hawaii as part of the NOAA forecast system upgrade. To test the accuracy of the same forecast system in the near field, a total of 11 numerical models with grids telescoped to 2 arcsec (*60 m) were developed to hindcast the propagation and coastal inundation of the 2011 Japanese tsunami along the entire east coastline of Japan. The computed tsunami runup height and spatial distribution are consistent with post-tsunami survey data collected along the Japanese coastline. The computed inundation penetration also agrees well with survey data, giving a modeling accuracy of 85.5 % for the inundation areas along 800 km of Japan coastline. Comparison of tsunami sources inferred from different indirect methods shows the crucial importance of deep-ocean tsunami measurements for real- time tsunami forecasts.

SP1S2.02

SP1S2 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Tohoku tsunami of 11 March 2011 as observed on the Russian Far East Coast by deep-sea and coastal gauges

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The source region of the catastrophic Tohoku tsunami of 11 March 2011 was located close to the Russian Far East coast. The Sakhalin Tsunami Warning Center at Yuzhno-Sakhalinsk issued an Alarm for the coasts of the Kuril Islands and Kamchatka. The tsunami was clearly recorded by a number of coastal tide gauges on the coast of the Kuril Islands, Kamchatka Peninsula and Sakhalin Island, and by several deep-sea bottom pressure stations. The data from the DART buoys located near Japan and along the Aleutian Islands were used for the comparison. These data enabled us to estimate the principal characteristics of the tsunami waves: arrival times, maximum heights, duration of the signals, spectral properties and dominant periods. This analysis indicated significant difference in wave features and spectral characteristics between tsunami waves propagating eastward toward the coast North America and northwestward in the direction of the Russian Far East. The main spectral peaks of the eastward propagating tsunami waves were relatively high-frequency (periods ranging from 6-8 min to 15-20 min), while those propagating in a northwest direction were mainly low-frequency (ranging from 25-40 min to 60-80 min). Additionally, pronounced spectral peaks with similar long periods were found in the near-field records at Hanasaki (the northeastern coast of Hokkaido Island), Yuzhno-Kurilsk (Kunashir Island) and Malokurilskoe (Shikotan Island). In contrast to the deep-sea records where the first waves were highest, at the Russian coastal sites the highest waves occurred several hours after the arrival of the first wave. At far-field stations, spectral peaks associated with local topographic resonant effects were strongly predominant. The numerical model of the Tohoku tsunami waves penetrating into the Kuril Straits was constructed and matched well the observations.

SP1S2.03

SP1S2 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

On spectral properties of major 2009-2011 tsunamis in the open ocean and near the coast

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Three recent major tsunamis (2009 Samoa, 2010 Chile, and 2011 Tohoku) propagated across the Pacific Ocean and were recorded by hundreds of coastal tide gauges and deep-ocean DART tsunameters. Of great importance, these three tsunamis were probably the first in history to provide a basin-wide synoptic and temporal look at a tsunami in the deep-ocean where observations are free from distortion by topographic and non-linear effects. With these observations, we evaluated “pristine” characteristics of tsunami waves and examined spatial and temporal evolution of tsunamis in the open ocean. High-resolution (15-sec) data internally recorded by tsunameter sensing instrumentation were downloaded after instrument recovery and used in the present study: 24 for 2009 Samoa, 23 for 2010 Chile and 18 records for 2011 Tohoku tsunamis. The combination of coastal and open-ocean time series records allowed us to estimate the energy content and spectral properties of tsunami waves to separate the influence of source and topography on recorded tsunamis, and, in each case, to reconstruct the spectral properties of the source. Investigation results from different instruments were mutually consistent: the main energy of the 2010 Chile and 2011 Tohoku tsunamis was found to be concentrated at periods of 4 hrs to 2 min with peak values at 1.5 hrs to 3.5 min; the 2009 tsunami was much less energetic and characterized by much shorter periods, 30 min to 2 min with the peak values at 6 to 10 min. The spectra of coastal records were strongly affected by coastal resonance, however, the reconstructed “source spectra” (after suppression of the topographic influence) had almost the same periods of open-ocean tsunami spectra.

SP1S2.04

SP1S2 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Post-tsunami field survey following the October 27 2012 Haida Gwaii event

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The October 27 2012 Haida Gwaii tsunami is the largest locally-generated earthquake tsunami to occur in written history (the last ~150 years) on the Pacific coast of Canada. The tsunami was sourced by an M_w 7.7 earthquake with a predominantly thrust-faulting mechanism on a NW-striking, eastward-dipping fault plane beneath the seafloor off western Moresby Island, British Columbia. Documentation of the tsunami effects is crucial for constraining models of the earthquake source mechanism and tsunami generation. It will also advance understanding of much larger future events on the Cascadia subduction zone with massive potential impacts over widespread populated regions. Although the closest tide gauge recorded a peak-to-trough wave amplitude of only 52 cm, tsunami waves in excess of 3 m (extremely destructive on populated coastlines) were likely on the unpopulated west coast of Moresby Island. Several inlets that are relatively sheltered from storm waves may have natural resonant periods close to the ~30-minute period of the tsunami, promoting runup amplification. A helicopter-based post-tsunami survey was undertaken in mid-November, with a follow-up survey planned in Spring 2013. Landing sites were based on preliminary tsunami model predictions and initial observations from the air. Evidence for significant runup (up to ~6 m above the state of tide) was found at the heads of inlets from Blue Heron Bay in the north to Gowgaia Bay in the south. Debris, including plastic (e.g., bottles and sheeting), polystyrene, fishing floats, seaweed, dead fish, and driftwood logs, was found in elevated positions alongside creek beds as well as on the forest floor and draped over fallen trees, up to tens of metres from the shore. Freshly disturbed windfall logs indicate a variety of flow directions; log footprints are often lined with bark and filled with seaweed. Seaweed draped over tree branches indicates minimum flow depths of up to 2.2 m above the ground.

SP1S2.05

SP1S2 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

The Haida Gwaii tsunami of 28 October 2012: Observations and modelling in the deep ocean and on the coast of British Columbia

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On October 28, 2012, a major earthquake (Mw 7.7) occurred offshore from Moresby Island on Haida Gwaii (formerly the Queen Charlotte Islands). This was the strongest earthquake in British Columbia since 1949. The earthquake caused a trans-oceanic tsunami which was clearly observed throughout the northeast Pacific Ocean, from the Hawaiian Islands and California in the south to Alaska and the Aleutian Islands in the north. The tsunami was recorded at 11 CHS tide gauges along the coast of British Columbia with maximum heights (trough-to-crest) at Henslung Cove, Langara Island (53.5 cm), Winter Harbour (47 cm) and Port Alberni (43 cm). It was also recorded at four cable geophysical NEPTUNE-Canada stations on the shelf off southern Vancouver Island. To determine the tsunami source region and to construct a high-resolution numerical model of this event, we used the USGS finite fault earthquake model. The location of this source was subsequently adjusted using tsunami arrival times at open-ocean DART and NEPTUNE stations. The main “searchlight” rays of tsunami energy were found to be directed southwestward towards the Hawaiian Islands, where maximum wave heights up to 1.5-2 m were recorded. A significant portion of the wave energy also impacted Moresby Island. Simulated maximum tsunami runup in some bays and inlets was as high as 5-6 m above the normal tide level. Although the tsunami occurred at a low (but rising) tide, the results of the numerical model show that the tsunami runup in some bays was well above the the high tide level and could therefore be detected by a post-tsunami field survey. Subsequent surveys in six bays on the west coast of Moresby Island in mid-November of 2012 showed clear evidence of the recent tsunami runup of up to 2.2 m above the high tide, in good agreement with the numerical results.

SP1S2.06

SP1S2 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Submarine landslide assessment and research in Canada

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Scientists have identified submarine landslide hazards on all three of Canada's Pacific, Atlantic and Arctic oceans. The responsible authority for identifying and minimizing geohazard risk is the Geological Survey of Canada. A national scale exercise is currently under way to assess the hazard of submarine landslides to lives and infrastructure in the country. This exercise aims to advise the government on several key aspects: 1) details of all known submarine mass movements, published and unpublished, 2) the level of effort required (fieldwork, assets and person power) required to better constrain the timing and recurrence intervals of these events, 3) suggestions for targeted research programs that would improve the knowledge of triggers and conditioning factors, and 4) the required steps which will translate our knowledge of these events to a useful measure of hazard. On the issue of improving our knowledge of triggers and conditioning factors, the Geological Survey has partnered with Ocean Networks Canada to deploy a high bandwidth real time observatory on an active prograding delta. This observatory is able to examine most of the forcing factors which lead to pore pressure increases, and thus unstable slopes, and is also able to detect the failures themselves. So far half of the planned instrumentation is deployed and the observatory has measured earthquakes, groundwater flows, gas escape, strong currents, storm waves, high deposition and oversteepening rates and other factors which alter pore pressure and bed stability. The following work outlines the progress of the National Assessment Exercise as well as providing novel and exciting results from the Delta Dynamics Laboratory.

SP1S3.02

SP1S3 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Earthquake vs. landslide generation of tsunamis along the eastern Sicily-Messina Straits area (southern Italy)

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The identification of the source responsible for the generation of tsunamis is one of the most common problems in tsunami research. A classical situation is the one in which a tsunami occurs following a significant-magnitude earthquake, but the final distribution of the tsunami effects is not consistent with a pure tectonic generation. In these cases, a contribution to the generation by a submarine landslide is frequently invoked, even in absence of direct evidence of slide occurrence. The situation is dramatic for historical tsunamis, for which the information on the possible parent earthquake is based only on macroseismic reconstructions and the evaluation of the tsunami effects is often limited to qualitative data. A set of criteria has been published by Okal and Synolakis in 2004 (OS04) to solve the problem. They are based on a number of non-dimensional parameters and thresholds and they have been introduced assuming a linear coastline and a simplified ocean bathymetry. The OS04 criteria have been applied by different authors to the largest historical tsunamis (1693, 1783, 1908) hitting the eastern coasts of Sicily in southern Italy, but with contradictory results. The aim of our study is to follow the theoretical approach proposed by OS04 and to show how complicated coastline configurations and bathymetry can influence tsunami propagation and run-up distribution. We run a number of numerical simulations for tsunamis generated by both earthquakes and landslides, varying the main source parameters in the attempt to find a new OS04-like formula and a new threshold for source discrimination, adequate to the tsunamigenic sources in the eastern Sicily area. We comment on the possible need to evaluate the main historical tsunamis in light of the obtained results.

SP1S3.03

SP1S3 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Forgotten catastrophe – October 9, 1963 Vajont Dam overtopping wave

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In October of 2013, there will be a 50-year anniversary of one of the most dramatic events in the whole 20th century history of natural and man-made catastrophes – Vajont Dam tragedy. In the late evening of October 9, 1963, the northern slope of the Monte Toc collapsed into the Vajont reservoir with accumulated 0.17 km^3 of water. The landslide with estimated volume of 0.26 km^3 completely filled up the narrow basin just in front of the dam and resulted in 250-m water splash on the opposite slope. About 0.05 km^3 of water overtopped the dam as 150-m wave and rushed downstream the valley killing in minutes from 2000 to 3000 people in Langarone and several other villages. The northern slope of the Monte Toc was carefully monitored by geologists and landslide occurrence was expected but its volume, speed and resulted wave turned out to be much beyond of all prognoses and estimates. In 2008 UNESCO cited the Vajont tragedy as one of cautionary tales caused by the failure of engineers and geologists to understand the nature. Pretty similar situation, but on much greater scale, exists now for the 500-m depth Sarez Lake, located at the altitude 3250 m in high-mountain area of Tajikistan. The lake formed in 1911, after a great earthquake that triggered a massive 2.2 km^3 landslide that blocked the Murghab River and formed the Usoi Dam of 560 m high. At present, the lake contains 16 km^3 of water and its level rises on 0.2 m annually. The dam is unstable and can collapse if another strong earthquake occurs nearby. Steep northern coast of the lake has potential of great landslide whose volume may be up to 1.2 km^3. Overtopping the Usoi Dam may result in highly destructive mud-and-water flood that can go downstream along the valleys of the Bartang, Panj and Amu-Darya rivers and potentially affect 6 million people inhabiting there. Based on the details of the Vajont Dam disaster, paper analyses the possible scenario of the impending Sarez catastroph

SP1S3.04

SP1S3 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

The large tsunami of 1956 in the South Aegean Sea: tectonic or landslide origin?

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On 9 July 1956, an earthquake (M7.5) associated with normal faulting, generated a destructive, 15-m-high tsunami in the South Aegean. The wave was reported from remote coastal sites and recorded by two near-field tide-gauge stations and a far-field station in Yafo, Israel, with small amplitude. Numerical simulations performed so far, assuming either a tectonic or a landslide origin of the tsunami, underestimated drastically the wave heights observed mainly in the near-field domain. We calculated the «slowness» factor characterizing the seismic slip in the earthquake fault (Ebelin and Okal, 2012), which is a seismological criterion for tsunami source discrimination. The value obtained is -4.68, which implies that the earthquake do not exhibit the exceptionally slow source behavior (<-6.0) expected for «tsunami earthquakes», i.e. for earthquakes whose tsunamis were disproportionately large with respect to their seismic moment (Kanamori, 1972). Then, the discrepancy between observed and theoretical wave heights could be explained either by inadequate source mechanism or by overestimation of the wave heights observed or both. To reexamine the case, we updated a data set initially published in 2005 and containing tsunami runup observations and arrival times. Several scenarios for the source mechanism, involving alternatives for both mechanisms, the tectonic displacement and the submarine landslide, were introduced to perform tsunami numerical simulations using the GEOWAVE software package. Simulation results indicated that the far-field wave parameters are well reproduced by co-seismic normal fault displacement in the seismic rupture zone. In the near-field, however, wave heights were again underestimated, while one of the hypothetical co-seismic landslide scenarios reproduced better the observed wave heights. The generation mechanism of the 1956 tsunami remains open.

SP1S3.05

SP1S3 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Modeling of tsunami generation by an underwater landslide

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A high-resolution model solving for dynamics of a stack of shallow layers in curvilinear co-ordinates has been developed for simulating landslides that can serve as a source of tsunami waves. The model relies on the reduced-gravity approximation and solves nonlinear, hydrostatic or nonhydrostatic equations for horizontally inhomogeneous, viscous fluid layers on an f-plane. The dynamical equations are discretized by the finite-difference method and integrated on a rectangular grid, which is the map of the curvilinear grid generated by the elliptic method.

Tsunami generation, wave propagation and flooding of a coastal zone are processes when both frequency dispersion and non-linear effects play an important role. For this reason the landslide model needs to account for nonhydrostatic effects.

Numerical examples are provided to illustrate this statement.

SP1S3.06

SP1S3 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Propagation pattern of landslide-generated tsunamis from Ischia flanks (Italy)

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The island of Ischia at the north-western end of the Gulf of Naples, Italy, is a volcanic complex characterized by a powerful block resurgence, causing steepening of the Mount Epomeo (the highest relief in the island) and triggering mass collapses along its flanks, as evidenced by subaerial and submarine deposits observed during marine surveys carried out recently all around the volcanic edifice. In this work, basing uniquely on geomorphological considerations, we elaborate three landslide scenarios for the northern, western and southern flank of the volcano respectively, and simulate their dynamics via the numerical code UBO-BLOCK1 that implements a Lagrangian model. We compute further the corresponding tsunamis by making use of the in-house developed finite-difference code, UBO-TSUFD, that solves the shallow water equations. The tsunamis attack the island of Ischia and Procida and the neighboring coasts of Campania, including the Gulf of Naples. The main interest is to study the propagation pattern of the tsunamis and, by noting similarities and differences, to qualitatively discriminate between the influence of the source and of the bathymetric features of the Tyrrhenian sea basin surrounding Ischia, which includes the Gulf of Naples. This is the first step of a research to evaluate hazard for the Campania coasts from tsunamis induced by mass failures along the flanks of Ischia.

SP1S4.01

SP1S4 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Revisiting the slip distribution of the 22 May 1960 (Mw 9.5) Chile earthquake

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The great Chile earthquake on 22 May 1960 with magnitude of 9.5 is unique in aspects such as magnitude, foreshock setting, rupture initiation, and rupture process. The slip distribution of the event is disputed among seismologists. Barrientos and Ward (1990) found two separate sets of trench parallel asperities mirrored along the north-south axis of the Longitudinal Valley, 73 degrees W, with negligible slip over the valley. However, Moreno et. al. (2009) using a curved geometry for the plate interface found only the shallow set of asperities and suggested that the deep set of asperities were likely an artifact of planar geometry. We analyzed the rupture area of the event using the measure of “trench parallel Bouguer anomaly, TPBA”. Positive-TPBA patches in the forearc settings show the location of interpolate asperities. However, for the 1960 earthquake the main western set of asperities to the south of 38.5 degrees S fall in the negative-TPBA area; this area was expected to show positive-TPBA. Based on TPBA distribution and other seismological evidences we propose a scenario for the 1960 Chile earthquake. We also discuss the slip distribution of the 25 March 2012 (Mw 7.1) Maule earthquake along the coasts of Chile that supports the slip distribution by Barientos and Ward (1990).

SP1S4.02

SP1S4 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Characteristics of small Pacific tsunamis: two case studies of the El Salvador and Philippines tsunamis of August 2012

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We compare the characteristics of small tsunamis within the Pacific Ocean with those of large tsunamis using numerical modeling of tsunami waves and sea level data analysis. In addition to large tsunamis which occur once in some decades within the Pacific Basin, this region experiences some small tsunamis annually. Although most of the attention of the scientific community is devoted to the analysis of large basin-wide tsunamis, it is worth characterizing small tsunamis occurring in the Pacific Ocean. As a case study, we report and analyze two small tsunamis generated by the El Salvador earthquake of 27 August 2012 (Mw 7.3) and the Philippines earthquake of 31 August 2012 (Mw 7.6) within the Pacific Basin. The characteristics of the aforesaid tsunamis are compared with those of the 11 March 2011 Japan mega-tsunami (Mw 9.0). Statistical, spectral ad wavelet characteristics of the sea level records of the tsunamis are compared with each other, and their powers to attack far-field coasts are examined using numerical modeling. Results show that while the tsunami energy is limited to the period band of 5-30 min for small events, it reaches the value of around 120 min for large basin-wide tsunamis. The duration of small events is around 10 h whereas the oscillations caused by the 11 March 2011 Japan tsunami lasted more than 4 days within the Pacific Basin. Numerical modeling of tsunami showed that the small events are extremely localized in terms of far-field propagation compared to the March 2011 tsunami which affected the entire Pacific Ocean coastlines.

SP1S4.03

SP1S4 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

An overview of the earthquake activity and associated hazards in South-America and the socio-economic impact of severe earthquakes in this region

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Most of the population of the South-American countries is settled along a seismic belt that has generated many destructive earthquakes in historical and recent times, occasionally accompanied by tsunamis, great landslides and other earthquake-induced natural phenomena. The ~70 mm/a to ~80 mm/a east-northeast subduction of the Pacific plate beneath the South-American continent has resulted in several of the largest earthquakes known to mankind, with a toll of over 100.000 deaths and hundreds of thousands of people injured and homeless during the period of instrumental seismology, billions of US dollars in economic losses, and rather commonly wide-spread damage by discrete earthquakes to individual countries impacting big cities and towns, industries, public buildings, the educational and health sectors, electrical and power lifelines, commerce and infrastructures of communications, the most recent disaster being that generated by the giant (Mw 8.8) Chilean quake of February 2010 and its large tsunami. The statistical analysis of tsunami generation by large earthquakes along the coast of the continent shows that every single great shock of Mw larger or equal that 7.8 known to have occurred along the Pacific-South American interplate boundary zone since the colony times has generated a tsunami. This observed law will help seismologists and authorities to avoid cases like in Chile 2010 (Mw 8,8), when the tsunami alarm was called off by the authorities and shortly after the tsunami waves arrived generating a great amount of human losses and casualties, many of which could have been avoided.

SP1S4.04

SP1S4 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Seismic and nonseismic tsunamis in the Black Sea. Models and results

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The tsunamigenic potential of different sources located in the Black Sea is investigated as a part of the project 'Nonseismic tsunamis in the Baltic and Black seas'. Models of tsunami generation from different seismic (strong earthquakes) and nonseismic (submarine and surface slides, meteorological effects, etc.) sources are performed. The results demonstrate strong dependence on bottom bathymetry and coastal topography to the tsunami waves propagation. Some of the coastal areas (for example, cities of Varna, Balchik and Kavarna) are specifically vulnerable to tsunami hazard due to strong focusing effects caused by the bottom bathymetry and coastal topography. Several maps of the tsunami parameters are generated for these cities. They present tsunami heights, tsunami currents velocities and tsunami run ups and run offs. The special vulnerability and risk maps are constructed according to the special developed methodology. The results are presented to the decision makers and local administrations to support their everyday practice.

SP1S4.05

SP1S4 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

A survey of strong high-frequency sea level oscillations along the U.S. East Coast between 2006 and 2011

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A systematic survey of high-frequency sea level oscillations (< 6 h) measured between 2006 and 2011 along the U.S. East Coast is performed on raw 1-min resolution sea level data. After performing data quality check, the most intense events, with maximum recorded wave heights ranging from 40 to 100 cm, are identified. Focusing on three of these events enables us to recognize three different generation mechanisms: (i) topographically-trapped edge waves which are found to be a significant contributor to the strongest observed oscillations, (ii) standing waves, which occur over enclosed shallow waters and result in significant wave heights of up to 100 cm, and (iii) meteotsunami waves, that are occurring over tsunami frequencies. The selected tsunami-like waves were accompanied with strong air pressure disturbance, that occasionally preceded to the observed ocean waves. The waves were generated by the passage of an energetic atmospheric disturbance through Proudman resonance, as the average shallow water wave speed of ~15-20 m/s matches well the observed speed of the air pressure disturbance estimated between 16 and 25 m/s. The disturbance was found to propagate offshore during all events. The observed temporal difference between the forcing and the sea level record was explained by a reflection of the offshore propagating forced ocean wave on the shelf edge, resulting in a free wave propagating toward the coastline. Estimated pathway of the forced and the reflected free ocean waves seem to be coherent and match quite well the time differences observed at tide gauge stations.

SP1S4.06

SP1S4 - Tsunamis, particularly due to submarine slides: cases, experiments, observations and warning

Oral

Meteo-tsunamis along the west Australian coastline

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Analysis of tide gauges records from different locations along the coastline of Western Australian (WA) revealed the regular occurrence of tsunami like events of non-seismic origin. The events corresponded with meteorological data and the larger events (amplitude > 0.25 m) were found to be associated with summer thunderstorms and could be classified as meteo-tsunamis. In this study, their generation mechanism is investigated with observations and numerical simulations. Spectral analysis of sea levels from coastal tide gauges records revealed that both shelf and local bay seiche frequency band oscillations were enhanced by the meteo-tsunamis. A barotropic hydrodynamic model equipped with pressure and wind forcing was applied to investigate meteo-tsunami generation mechanisms along the WA Coast. Initially, experimental model runs were performed to examine the sensitivity to the travelling speeds of pressure jumps and strong winds associated with thunderstorms. Results revealed that tsunamis on the coast were generated through Proudman and Shelf resonance, whereas the magnitude of tsunami oscillation at the coast was determined the magnitude of the pressure jump, its travelling speed and direction.

SP2PS.01

SP2PS - From surface heat flow mapping to geodynamic analysis and geothermal energy

Poster

Specific heat flow around the German Deep Continental Drilling (KTB) from numerical modeling and high resolution seismic data

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The surrounding of the Continental Deep Drilling (KTB) site in Germany is used as a case study for a geothermal reservoir. Based on new filtering methods for seismic reflection data, various rock units including two roughly parallel fault zones (SE1, SE2) are identified and provide the basis for a 3D numerical model to investigate temperature and fluid flow. Variations of seismic reflectivity are quantified and attributed to variations in fissure density. Associating these fissures with fluid pathways, rock permeability variations are attributed and calibrated by log data. Porosities are inferred considering lithological differences between the rock units. Permeabilities and porosities are low and do not exceed 10^{-4} D and 4 %, respectively. Thermal conductivity and heat production of the rock units are deduced from literature. Using this information on thermo-hydraulic rock properties, numerical calculations are done with Shemat-suite, a FD-code solving the coupled differential equations for heat and fluid transport in porous media. For the lower boundary condition the bottom heat flow is estimated to 54 mW m-2 ±2.1 mW m-2 by fitting the observed temperature gradient; topography is used at an upper boundary condition. Fluid flow does not exceed 1mm/a and is mainly occurring within the two fault zones. Our model confirms the finding (Kohl & Rybach 1996) that diffusive heat transport is the dominant process. The fit of the observed temperature gradient demands a paleoclimatic contribution in accordance with mainly heat conduction and 1 mm/a downward flow. Two heat flow regims are identified down to 7 km separated by the Franconian Line with high heat flow up to 90 mW m-2 in the eastern part and about 60 mW m-2 on the western side. Concerning the Southern German Crystalline as a geothermal reservoir, we find temperatures suitable for geothermal energy production, but the low permeabilities and flow rates would demand an engineered stimulation.

SP2PS.02

SP2PS - From surface heat flow mapping to geodynamic analysis and geothermal energy

Poster

Inferring the mid crustal heat flux for the geothermal reservoir 'Guardia Lombardi' using stochastic and deterministic inversion

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A region in Campania (southern Italy) centered around the "Guardia dei Lombardi" area (province of Avellino) was identified as a possible target for a medium enthalpy geothermal resource by the VIGOR group (Italy). This 20 km^2 large area is characterized by a local heat flux maximum of about 90 mW m^{-2}. Based on about 20 seismic profiles and a number of hydrocarbon exploration wells, an integrated 3D geological model was established identifying the main stratigraphic units of this fractured carbonate reservoir. The model clearly reveals the upper surface of the cretaceous Apulian platform as an anticline unconformity between 1100 m and 2300 m depth overlaid by dense partly clay-rich sediments. The available bottom hole temperatures were corrected to extrapolate the temperature to static conditions together with the 95% confidential bounds. The 17 formation temperatures from 9 wells at depths about 300 m to 3.5 km show reservoir temperatures exceeding 100 °C. Based on the geological model, the temperature observations, and the mean surface temperature distribution, we invert for the heat flux at the base of the reservoir at 6 km depth assuming conductive heat transport. Thermal conductivity values for the various lithological units and their uncertainty are deduced from laboratory measurements on rock samples together with logging interpretation. The inversion is carried out using a deterministic Bayesian approach and a stochastic approach with a Monte Carlo ensemble varying basal heat flux and thermal conductivities in the various layers according to their uncertainties.

SP2PS.03

SP2PS - From surface heat flow mapping to geodynamic analysis and geothermal energy

Poster

Effective thermal conductivity of heterogeneous rocks from lab experiments and numerical modeling

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Studying heat transfer processes in sedimentary crustal rocks requires the correct thermal conductivity of the respective rock type. Often a single value is used for a given rock type, obtained from the measurements on homogenous samples. We demonstrate how variations in rock layering and micro-fractures on the sub-centimeter scale may influence thermal conductivity values at much larger scale. We obtain thermal conductivity images from lab measurements on two different, heterogeneous samples performed with an optical thermal conductivity scanner in two directions. We study different spatial averaging methods for parameterizing the structural heterogeneities and the associated variation of thermal conductivity within the samples. For each of these structural simplifications we set up a numerical model for a numerical heat transfer experiment in order to determine effective thermal conductivity values in two directions. We compare these values and the mean thermal conductivities obtained from different mixing laws and find that, in heterogeneous rocks, effective and mean thermal conductivity may differ substantially. This may cause significant errors in reservoir-scale simulations of heat transfer with associated severe consequences for estimated heat flow and temperatures.

SP2PS.04

SP2PS - From surface heat flow mapping to geodynamic analysis and geothermal energy

Poster

Monitoring fluid induced fracture propagation in the lab

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This work is part of a joint project on the design of deep geothermal fracture systems. A numerical fracture propagation code is under development and will be compared to and optimized by laboratory scale hydraulic fracturing experiments of square-cut dense rock specimens under triaxial compression. Fracture propagation is being monitored using ultrasonic transducers. Acoustic emission events are registered and analyzed. After a short introduction to the overall project we will focus on presenting the acoustic emission analysis of fracture propagation.

SP2PS.05

SP2PS - From surface heat flow mapping to geodynamic analysis and geothermal energy

Poster

Subsurface temperatures under different types of the ground surface – results of a long-term monitoring in Czechia

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Temperature of shallow subsurface is a parameter that strongly influences performance of the heat pump - ground heat exchanger systems. This temperature is determined mostly by the mean annual temperature of the ground, which depends mostly on the mean annual air temperature, but also on the character of the surface. We present results of the long-term monitoring of the air-ground temperature coupling based on the ten year (2003-2012) long soil- and air-temperature series from the observatory Prague – Spořilov located at the campus of the Institute of Geophysics in Prague (50 02’ 27’’ N, 14 28’ 39’’ E, 274 m a.s.l.). The soil temperatures under different types of surfaces (grass, sand, bare soil, asphalt) at the depths of 2, 5, 10, 20 and 50 cm, as well as the air temperatures (SAT) at 5 cm above each of the surface types and at 2 m above the background grass surface were recorded every 5 minutes together with other meteorological variables (solar radiation, humidity, soil moisture, precipitation and wind speed).

The mean annual temperatures indicate the ground warmer than the air (2 m above surface) at all experimental plots over the whole observational period. The mean annual difference between ground and air temperatures depends strongly on albedo and insulation (snow, vegetation cover) of the given surface and intensity of solar radiation during the year. The highest difference, 4.0 - 4.8 °C, was observed for surface covered by asphalt and can be explained by asphalt’s low albedo. In the case of sand, bare soil and grass, the ground – air temperature differences were in the range 1.5 – 2.3 °C, (sand), 1.3 – 1.9 °C (bare soil) and 0.6 – 2 °C (grass). The by far most favourable type of surface, from the point of view of the ground heat exchanger performance, is asphalt (the mean difference 4.2 °C), followed in large distance by sand (the mean difference 1.9 °C), bare soil (1.4 °C) and grass (1.1 °C).

SP2PS.06

SP2PS - From surface heat flow mapping to geodynamic analysis and geothermal energy

Poster

Long-term temperature-time monitoring at the experimental Borehole Site Sporilov-1 at Prague (The Czech Republic)

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Borehole-based subsurface temperature-time monitoring site has been running at the Sporilov campus of the Institute of Geophysics in Prague since 1993. The obtained records were analyzed to identify the existing systematic patterns (cycles). Data series were processed with help of the Fast Fourier Transform and Recurrence Quantification Interval analysis. The results proved considerable similarity for all investigated depth levels. In addition to the obvious annual wave all measured series contain certain 8-year and 11-year-long periodicities. The results were compared with similar analysis of the meteorological air temperature series. The potential dynamics explaining the occurrence of the 8-year wave is briefly discussed. As the site presents a typically urban environment, the numerous repeated temperature-depth logs provided suitable material for the climate reconstruction studies. The gradual year-to-year increase of temperature below the “seasonal-variation zone” amounts to 0.03 K/yr, while another observational site at the rural site Kocelovice (southern Bohemia) gave lower value of 0.02 K/yr.

SP2PS.07

SP2PS - From surface heat flow mapping to geodynamic analysis and geothermal energy

Poster

Heatflow assessment in the Eastern Alps with focus set on the Tauern Window

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The thermal regime of the Eastern Alps is dominated by the crustal build-up with respect to the collision of the European and African plate. However, the general background geothermal regime, which is dominated by steady-state conductive heat transport, is in some regions overprinted by non-conductive, non-steady-state heatflow phenomena. At the region of the Northern Calcareous Alps for example a significant lowering of the overall heatflow density down to below 40mW/m2 is shown by temperature measurement in hydrocarbon exploration wells. Referring to an average heatflow density at the Eastern Alps region of approximately 70 mW/m^2, this lowering can be seen as a consequence of massif inflow of meteoric surface waters in highly permeable carbonates. In opposite to this regions of elevated heatflow densities have been observed in some Central Alpine regions within or nearby the so called Tauern Window zone of uplifted deeply buried crustal blocks belonging to the Penninic tectonic units. However, the geothermal pattern of the Central Alpine region shows locally strongly varying geothermal conditions with small to moderate spatial wavelengths of the observed heatflow patterns. In order to investigate the reason of these variations of heatflow densities and in order to achieve a better understanding of the geothermal conditions at the Central Alpine region the study THERMTEC, financed by the Austrian Academy of Science, has been launched in 2008. It was aimed to investigate and numerically proof the existence of heat excess due to rapid exhumation and erosion of deeply buried Penninic crustal blocks, as indicated for example by Sachsenhofer (2001). In this context, it has to be kept in mind, that the Penninic Units belong to oceanic crust, which in general shows lowered radiogenic heat production. As a consequence the thermal evolutional history of the Tauern Window area has a strong time-dependent, transient nature.

SP2PS.08

SP2PS - From surface heat flow mapping to geodynamic analysis and geothermal energy

Poster

Global heat flow without invoking the Kelvin paradox

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Use of modern techniques in handling geospatial data sets and in manipulating detailed geologic information have allowed advances in outlining tectonic age patterns in a large number of crustal blocks in continental and oceanic regions. The procedure adopted is based on specifying tectonic age polygons for 64800 cells that constitute a system of 10 x 10 degree equal longitude grid. Estimates of heat flow have been assigned for such polygons, based on the empirical relation between heat flow and age. In some of the earlier works estimated values of heat flow, assigned for young ocean crust, have been derived using the half-space cooling model. This model is essentially the same as that employed by Kelvin in his historic attempt at estimating the age of the Earth. Use of this model has lead to appearance of spurious heat flow anomalies, incompatible with observational data in areas of young ocean crust. In the present work, we circumvent this problem by making use of the recently proposed finite half-space model, which allows for the effects of latent heat and provides at the same time physically reasonable account of ocean floor bathymetry variations. Such estimates have been used along with the updated data set of observational heat flow (slightly over 43000 values) in deriving new global maps with spatial resolution of about 100km for grid averaged data. We propose that the practice of using half-space cooling model, which gave rise to the well-known Kelvin Paradox of the 19th century, be discontinued in deriving modern global heat flow maps.

SP2S1.01

SP2S1 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

A new picture of the geothermal features of northern Italy

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So far, research of geothermal resources in Italy has been mainly focused on the high enthalpy fields of the central-southern part of the country. Northern Italy, which exhibits interesting potential for medium enthalpy fluids, has instead drawn relatively less attention. In this paper, we review the geothermal data of this area and in particular focus on the thermal regime of the sector lying between the Alps and Apennines orogenic belts. We processed temperature data mainly derived from exploration oil wells and carefully evaluated the rock properties under any possible condition of burial depth, temperature and anisotropy. To this purpose, we used an approach that allows the inference of in situ thermal parameters on the basis of litostratigraphic data. We obtained geothermal gradients and heat-flow estimates that allow us to draw a new picture of the thermal pattern. With the exception of small areas, the western sector seems chiefly in a conductive thermal regime. Convection due to downward movement of groundwater is likely to occur at local heat-flow minima, whereas upflow of heated water of meteoric origin can account for the thermal anomalies occurring in artesian systems. In the eastern sector (east Po plain), thermal data show anomalies controlled by the morphology of the deep Mesozoic carbonate basement. There is direct evidence that the bedrock forms an aquifer hosting medium enthalpy waters. From well temperatures, we estimated the thermal gradient of the deep carbonate unit by means of an inversion technique. The thermal gradient is substantially lower than average value of the whole Po Basin. This pattern cannot be accounted for by vertical changes of thermal properties, thus suggesting that convection may occur in the deep carbonate aquifer, acting as a reservoir of hot fluids. Hydro-stratigraphic data and the Rayleigh number analysis indicate that underground water is likely to circulate by thermal, rather than forced convection.

SP2S1.02

SP2S1 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

Reconstruction of long-term ground surface heat flux histories in Russia from geothermal data

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Borehole temperature data have been successfully used for reconstruction of ground surface temperature histories (GSTH) for a long time, but more rarely – for estimation of the past climatic ground surface heat flux histories (SHFHs) (Wang and Brass, 1999; Beltrami et al., 2000, 2001, 2002, 2006). The determination of SHFH is important because this parameter is a fundamental one in general circulation models (GCMs). And there is a set of difficulties with the experimental and theoretical evaluation of heat flux anomaly associated with its small quantity. In the report we present the reconstructions of SHFHs calculated from GSTHs obtained using geothermal data. The investigations were conducted on several time intervals: 1) the recent 30 000 years for Onega Lake and Middle Ural regions; 2) the last millennium for the Urals and 3) the 150-years reconstruction of SHFH on the basis of the Ural long-term meteorological records. The obtained SHFHs were compared with external radiative forcing data and with the variation of carbon dioxide concentrations. Surface temperature change was preceded by heat flux change with infinitesimal amplitudes about several tens of mW per square meter. The comparison of radiative forcing data with the reconstructed SHFHs gives us the timing and general similarity of their variations. The ratio of surface heat flux change to radiative forcing only amounts to a few percent.

SP2S1.03

SP2S1 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

Renovation of the global database of borehole temperatures for the study of climate change

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It has been widely recognized among the scientific community that borehole temperature comprises an independent archive of information on climate change which is complementary to the meteorological and other climate proxy records. With the support from the international geothermal community, a global database of borehole temperatures was constructed for the specific purpose of climate change research. Although this database has become an important data source in climate research, there are certain limitations because the framework of the existing borehole temperature database was hand-coded 17 years ago. There have been great advances in database technology that can do a lot of things impossible a decade ago. The database renovation work is underway to take the advantages of the contemporary online database technology and related online resources to enrich this database and make it more user friendly. The major improvements will include but not limited to 1) dynamically linking a borehole site to Google Earth to allow for inspection of site specific geographical information; 2) dynamically linking an original key reference of a given borehole site to Google Scholar to allow for a complete list of related publications; and 3) enabling site selection and data download based on country, coordinate range, and contributor. We invite contribution from the geothermal and climate research community to the renovation and enrichment of the global database of borehole temperatures.

SP2S1.04

SP2S1 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

Thermal erosion of lithosphere by vigorous convection in the low-viscosity big mantle wedge and it implications for the destruction of the North China Craton

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In stable craton, surface heat flow is in equilibrium with heat flowing into the lithosphere at its base plus radiogenic heat production within the lithosphere. However, in the low-viscosity big mantle wedge formed by stagnant subducting slab at the transition zone, increasing vigor of mantle convection is likely to upset the thermal balance of the cratonic lithosphere, leading to unstable of the craton. A two-dimensional heat conduction/convection model is established to simulate the thermal erosion of lithosphere by vigorous mantle convection in the big mantle wedge. The bottom of solid lithosphere is adjusted at certain time intervals according to the average depth of 1200°C isotherm. Modeling results show that, the vigorous mantle convection compresses the rheological boundary layer greatly, resulting in a thin layer of high heat flow beneath the lithosphere. The convection supplies more heat than the solid lithosphere can transfer by conduction. The lithosphere is heating and thinning toward a new equilibrium. The thinning rate of the lithosphere is high relative to the mantle viscosity. The lower the viscosity, the higher is the thinning rate. Regardless of the viscosity, the thinning rate of lithosphere decreases with time, but the lithospheric equilibrium thickness depends on the viscosity in the big mantle wedge. If taking into account of the melting temperature lowering by peridotite–melt interaction, the thinning rate can be enhanced significantly in the early stage. These modeling results may shed light on the destruction of the North China Craton in the Mesozoic.

SP2S1.05

SP2S1 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

Obliteration of thermal springs by lateral flows of groundwater: implications for estimates of deep heat flow in sedimentary basins

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Analysis of geothermal and hydrogeologic characteristics of Paleozoic Interior basins of Brazil has allowed identification of a special association in the geographic distributions of thermal springs and areas of occurrence of lateral groundwater movements. Specifically, thermal springs are found to be absent in regions inferred to have distributed recharge systems and deep sub-horizontal flows. This trend is found to be remarkably evident in the sedimentary basins of the Amazon region, in the central parts of the Parnaiba basin and in the west-central parts of the Paran á basin. There are indications that similar trends also prevail in sedimentary basins of other continental areas, notably in northern Alberta (Canada), Missouri-Mississippi Valley (USA) and Gangetic Plains (India). We also report progress obtained in model studies of processes responsible for mutual exclusion of regions of thermal springs and lateral flows of groundwater. Results of numerical simulations indicate that lateral flows with velocities in excess of one cm/year are potentially capable of masking the occurrences of thermal anomalies. Also, lateral flows lead to development of large low temperature / low heat flow zones, capable of suppressing surface manifestations of deep geothermal resources. Analysis of Peclet - Rayleigh domains of flow systems indicate that lateral movements are capable of obliterating the effects of thermal buoyancy. There are indications that near-surface manifestations of deep geothermal resources are “smeared out” in areas of lateral flows, implications of which need to be considered in assessment of geothermal resources. We conclude that an understanding of the perturbing effects of subsurface flow systems is important in studies of deep crustal heat flow in sedimentary basins.

SP2S1.06

SP2S1 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

Thermal effusivity: a new old geothermal parameter. Utilization and measurement

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Thermal effusivity (TE) also known as thermal inertia (J m^{-2} K $sec^{-1/2}$) is a thermal parameter that is determined as square root of the product of thermal conductivity and volumetric heat capacity. It is a measure of a materials ability to exchange thermal energy in a system of contacting bodies. TE is responsible for the wave propagation disturbances, which are often interpreted as thermal diffusivity change. Under remote IR probing of the Earth and planets from space TE of planet's surface determines the day-night temperature difference.

Despite the importance of TE in geothermal processes, it is rarely measured directly and usually calculated from thermal conductivity, diffusivity and heat capacity. In our report we demonstrate some examples of TE utilization in geothermy and a new contact method of direct TE measurement. The method is based on periodic heating of a standard plate surface, back side of which is in contact with the investigated sample, and measuring the temperature oscillations in the plate at various distances from the heater. The results of TE measurements and influence of the moisture content in porous rocks on the TE are presented.

SP2S2.01

SP2S2 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

New challenges in applied geothermics related to 4D thermal reservoir modeling and heterogeneous rock analysis

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4D reservoir thermal property modeling and heterogeneous rock analysis became the important constituents for design of thermal EOR methods and solution of other problems in oil and gas industry. It was established that uncertainties in thermal conductivity and volumetric heat capacity of reservoirs and caprocks obtained from application of traditional theoretical and experimental approaches and previous databases in thermal reservoir simulators lead to significant errors in modeling results. One of the main reasons is neglecting the essential spatial variations in the thermal properties within the reservoir and significant temporal variations in rock thermal properties caused by reservoir heating and pore fluid changes during heavy oil production. From the sensitivity study of the hydrodynamic models it was estimated that the theoretical models incorporated in the widely used simulators give typically by more than 100% deviation to the real thermal rock properties that can lead to significant errors (up to 50%) in prediction of the important recovery parameters such as steam-oil ratio and cumulative oil production. New approaches were found to predict the rock thermal properties and control oil-saturation, and pore space geometry from combination of experimental studies and the effective medium theory. Vast experimental validation outlined areas of application and restrictions of the new and traditional theoretical thermal conductivity models for sedimentary rocks. Irreversible changes of properties of cores after their recovery, preparations, cleaning, drying and saturation were established to be accounted for. Continuous thermal core logging on full size cores with determination of thermal conductivity, volumetric heat capacity, rock anisotropy coefficient, and thermal heterogeneity factor is necessary for multiscale rock heterogeneity analysis and can be provided now.

SP2S2.02

SP2S2 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

Calibrated rock thermal properties and present day heat flow data as important factors in petroleum systems modeling

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Petroleum Systems Modeling is a widely used strategic tool to support the successful exploration for hydrocarbons. Complex numerical simulation methods utilize discretized reconstructions of a basin history to assess oil and gas generation, expulsion or retention, migration, accumulation and loss. Source rock maturition modeling is already possible with data from a single well (1D) and 2D and 3D simulations can additionally provide fluid flow and resulting locations of possible hydrocarbon entrapment zones, overpressure distributions, etc. Predictive capabilities improve with the addition of higher quality input datasuch as geochemical properties of source rock units and correlations with the eventually discovered fluids, kerogen reactions (kinetics of cracking), paleoclimatology, litho-stratigraphy, etc. One of the most important fundamental factors is accurate thermal history prediction, however such predictions are often based on the reconstruction and prediction of paleo-heat flow regimes which largely depend on present day heat flow measurements and calibrations. In addition to the heat flow regime, each basin has own thermal conductivity pattern that is a function of 3D lithology distributions and heat transfer within a basin. In order to improve the reconstruction of basin heat evolution, general thermal conductivity and thermal diffusivity pattern on anisotropic and heterogeneous rock samples is approximated in a form of databases provided by petroleum systems modeling software. By using the well SG-6 (West Siberian basin) for a 1D numerical simulation, we investigate (I) the effect of different thermal properties of the sedimentary sequence and subsequently (II) the influence of different heat flow histories on source rock maturity. The well SG-6 is drilled and cored up to the total depth of 7502 m whereby the rock thermal properties are measured down to the bottom.

SP2S2.03

SP2S2 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

Thermal petrophysics in its applications in oil and gas industry

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Thermal petrophysics has seen an increasing interest within the oil and gas industry over the last decade. That interest was to a great extent stimulated by the growing understanding of the role of rock's thermal properties in the solution of numerous problems in the domain of oil and gas exploration and production: for reservoir characterization and simulation, design and optimization of thermal methods of enhanced oil recovery, basin modeling, wellbore integrity, drilling, cementing and fracturing operations, and some others. Knowledge on rock's thermal properties obtained within geothermal research and commercial applications has provided a good basis for further developments, but in the recent years we have observed an essential enhancement in the theoretical and experimental basis of thermal petrophysics. We will give an overview of the most recent achievements in thermal petrophysics. Accurate measurements of thermal properties of rock together with their spatial and temporal variations became an essential component of characterization of heat and mass transfer in hydrocarbon reservoirs. In addition, typical levels of uncertainty of thermal properties of rocks obtained by traditional measurement techniques may result in substantial errors in hydrodynamical reservoir models and in predicted hydrocarbon recovery parameters. Such errors in the estimations of the recovery can be directly related to the economics of the process which further emphasizes the importance of accurate and reliable knowledge of thermal petrophysical parameters of reservoir rocks. We will discuss the significant improvements that were achieved in the accuracy and in the reliability of measurements of thermal properties of rock samples, and the impact of such improvements on the characterization of heterogeneity and of anisotropy of reservoir rock. The latter is particularly relevant with respect to shale oil and gas formations.

SP2S2.04

SP2S2 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

The VigorThermoGIS code: A new tool for geothermal resource assessment

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A review of subsurface temperature models of the four target regions in Southern Italy related to the VIGOR Project (Campania, Apulia, Calabria and Sicily) was performed. The available bottom hole temperature (BHT) observations coming from several hundred hydrocarbon exploratory wells represented a low-cost, directly accessible database for investigating the subsurface thermal structure down to 5 km depth. The regional thermal field was characterized using the geothermal gradients inferred by BHT data corrected for drilling disturbances. The results represented an improved temperature model on which the heat in place was evaluated at regional scale. Examining an extensive database of geophysical and geological data, the geothermal reservoirs in the four regions were characterized from the thermal and petrophysical point of view. The VigorThermoGIS code, based on the volumetric estimation method and Monte Carlo simulations, provided probabilistic estimates of the stored heat representing one of the main parameters for the geothermal potential assessment.

SP2S2.05

SP2S2 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

Monitoring of a multifunctional building's geothermal borehole heat exchanger field

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Heating and cooling account for large energy consumption in office buildings. Here, renewables can strongly reduce the CO_2 emission. We present the E.ON Energy Research Center, a multifunctional building in Aachen and its new energy concept. It includes a geothermal borehole heat exchanger (BHE) field besides a gas-fired combined heat and power (CHP) unit and photovoltaic. The field consists of 40 double U-tube BHEs each, 100 meters deep. The working fluid is a 35 % glycol-water solution. The project aim is to ensure a sustainable and long-term operation depending on the heating and cooling demands for different types of space such as offices, conference rooms or server-rooms. We present different tools like the Distributed Temperature Sensing (DTS) for monitoring the temperature distributions of the BHEs, Enhanced Geothermal Response Test for measuring the apparent thermal conductivity, and SHEMAT, a simulator for heat and mass transport for numerical simulation. Specific groundwater flow is also an important parameter that affects the long-term efficiency of a geothermal field. In order to estimate the specific discharge rate and direction of the groundwater flow, temperature sensor-rings will be installed in one of the BHEs providing temperature data around the BHE. Forward simulations are performed for different discharge rates and inlet and outlet temperatures. Assimilations of measured temperature data will allow the estimation of the groundwater velocity and direction.

SP2S2.06

SP2S2 - From surface heat flow mapping to geodynamic analysis and geothermal energy

Oral

Optimized layout of engineered geothermal systems (EGS) and associated potential in Germany

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The forward modeling code SHEMAT can simulate operated Engineered Geothermal System (EGS) reservoirs by solving coupled partial differentiall equations governing fluid flow and heat transport. Building on EGS's strengths of inherent modularity and storage capability, it is possible to implement multiple wells in the reservoir to extend the rock volume accessible for circulating water in order to increase the heat yield. By varying parameters like flow rates and well-separations in the subsurface, we analyze their long-term impacts on the reservoir's development in time. This allows us to experiment with different placements of the engineered fractures and different EGS layouts for achieving optimized heat extraction. Considering the available crystalline area and accounting for competing land uses, we evaluate the overall EGS potential in Germany and compare it with those of other popular renewables: The area available in Germany suffices to support 13,450 EGS plants consisting of six reversed-triplets (18 wells) each, providing an average electric power of 35.3 MW_e corresponding to a total capacity of 475 GW_e. When operated at full capacity, these systems can collectively supply about 4 TW h of electric energy in one year, more than six times the electric energy produced in Germany in 2011. We conclude that engineered geothermal systems make a compelling case for contributing towards national power production in a future powered by a sustainable, decentralized energy system, given the engineering capacity to deploy a suitably engineered fracture system at depth.

SP3PS.01

SP3PS - Interdisciplinary ocean bottom stations

Poster

The Hawaiian PLUME project: A broadband seismic dataset provides glimpses into Ocean and atmosphere processes

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The Hawaiian PLUME (Plume-Lithosphere Undersea Mantle Experiment) project operated a two-stage network of nearly 70 broadband ocean-bottom and 10 land seismometers from January 2005 through May 2007. With an aperture exceeding 1000 km, PLUME has been one of the first and largest, long deployments of broadband ocean bottom seismometers (OBSs). In addition, the ocean bottom sites also operated a Cox-Webb differential pressure gauge. The deployment of broadband instruments allowed us to apply a wide range of seismic analyses to determine crust and mantle properties around Hawaii thereby revealing structure with unprecedented detail.

Somewhat unexpectedly, we were also able to observe Earth's free oscillations of unprecedented quality for unburied seismometers. Our network also produced excellent pressure recordings of the enigmatic 15 November 2006 Kuril islands tsunami. The relatively few, near-coastal tide gauge stations in the western Pacific Ocean recorded peak-to-peak heights of no more than 50 cm, and there was no significant damage in Japan. Yet, after crossing the North Pacific Ocean, the tsunami reached a height of over 1.5 m in Crescent City, CA, causing damage to docks of nearly $2 million. The PLUME DPG network documents a marked amplitude disparity between northern and southern stations consistent with either source radiation effects or shadowing effects by the islands.

The PLUME instruments also recorded the development of 2006 Hurricane Ioke and its release of energy along its journey. This long-lived category 5 hurricane was the largest recorded hurricane to form in the Central Pacific Ocean. Unlike 2005 Hurricane Katrina, which generated the most seismic energy when it made landfall as a weakened hurricane, Hurricane Ioke did not encounter a significant coastline. Yet, we recorded strong seismic signals with very patchy characteristics throughout the network.

SP3PS.02

SP3PS - Interdisciplinary ocean bottom stations

Poster

Communications gateway for Ocean observatories

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We describe an autonomously deployable, communications gateway designed to provide long-term and near real-time data from ocean observatories. The key features of this new system are its abilities to telemeter sensor data from the seafloor to shore without cables or moorings, and to be deployed without a ship, thereby greatly reducing life-cycle costs.

The free-floating surface communications gateway utilizes a Liquid Robotics wave glider comprising a surfboard-sized float towed by a tethered, submerged glider, which converts wave motion into thrust. For navigation, the wave glider is equipped with a small computer, a GPS receiver, a rudder, solar panels and batteries, and an Iridium satellite modem. Acoustic communications connect the subsea instruments and the surface gateway while communications between the gateway and land are provided by the Iridium satellite constellation. Wave gliders have demonstrated trans-oceanic range and long-term station keeping capabilities.

The acoustics communications package is mounted in a shallow, towed «torpedo,» which utilizes a WHOI micro modem and a Benthos low frequency, directional transducer. A matching modem and transducer will be located on the ocean bottom package.

Tests of the surface gateway in 4350 m of water demonstrated an acoustic efficiency of approximately 396 bits/J. For example, it has the ability to send 4 channels of compressed, 1 sample per second data from the ocean bottom to the gateway with an average power draw of approximately 0.15 W and a latency of less than 3 minutes.

This gateway will be used first to send near real-time data from a broadband ocean bottom seismic observatory, designed for a two-year operational life. Such data from presently unobserved oceanic areas are critical for both national and international agencies in monitoring and characterizing earthquakes, tsunamis, and nuclear explosions.

SP3PS.03

SP3PS - Interdisciplinary ocean bottom stations

Poster

Crustal deformation along the Nankai subduction zone inferred from onshore GPS velocities and seafloor geodetic observations

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The Philippine Sea plate (PH) subducts beneath the Amurian plate (AM) along the Nankai Trough with a rate of about 4-6 cm/yr, where megathrust earthquakes have repeatedly occurred every 100-150 years. Considering the rupture area of the 1944 Tonankai earthquake did not reach to the Tokai area, we are concerned about the expansion of damage to this area by next megathrust earthquakes, because this earthquake has possibilities of interrelating with adjacent segments according to the historical record. It is important to know the spatio-temporal variation of crustal deformation accompanied with plate interaction. For this issue, we have conducted seafloor geodetic observation at the Nankai Trough using a GPS/Acoustic technique since 2004. In this system, we estimate the position of a surveying vessel by Kinematic GPS analysis and measure the distance between the vessel and the benchmark on the seafloor by Acoustic measurements. Next we determine the location of the benchmark. At the Nankai subduction zone, several seafloor benchmarks are located about 30-80 km away from the deformation front of the Nankai Trough. The locations and their velocities are determined within a precision of 2-3 cm and 1-5 cm/yr at horizontal component. In this study, we investigate interplate coupling at the Nankai Trough using onshore GPS velocities derived from Geophysical Survey Institute of Japan and offshore site velocities derived from seafloor geodetic observation. Then, we assume that observed crustal deformation are mainly responsible for the elastic deformation associated with subduction of the PH. The plate interface along the Nankai Trough is represented by multiple triangular fault segments. Moreover relative plate motion of the PH-AM is assigned to the plate interface as a priori constraint. We investigate interplate coupling at the Nankai Trough through the inversion analysis based on the above information.

SP3PS.04

SP3PS - Interdisciplinary ocean bottom stations

Poster

Interplate locking derived from the seafloor crustal deformation measurement at the northern part of the Suruga Bay, Japan

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In Japan, seafloor crustal deformation measurement has been carried out at the subduction margins, e.g., Japan trench, Suruga trough, and Nankai trough. It is essential to observe seafloor crustal deformation because most of the focal areas of great subduction earthquakes, such as Tokai and Tonankai earthquakes, are located under the seafloor.

We observed seafloor crustal deformations at two observation points across the Suruga trough from 2005 to 2011 to investigate interplate locking condition at the source area of the anticipated great subduction, Tokai, earthquake. We performed the observations 13 times at both an eastern point at the Suruga trough (SNE) and a western point at the Suruga trough (SNW). We reanalyzed all previous observation data to improve the data quality through the following three processes: 1) Omitting reflected waves from the sea surface or vessel body in the acoustic data. 2) Removing the acoustic data during the vessel's attitude data exceed a criteria. 3) Removing the acoustic data during unstable GPS satellite tracking condition. The RMS of travel-time residual in one epoch is improved by one order of magnitude through the improvement of data quality.

We estimated the displacement velocities with relative to the Amurian plate from the result of repeated observation. The estimated displacement velocity vectors at SNE and SNW are 42 ±8 mm/y to N94 ±3°W direction and 53 ±17 mm/y to N94 ±4°W direction, respectively. The directions are the same as those measured at the on-land GPS stations. The magnitudes of velocity vector indicate significant shortening by approximately 10 mm/y between SNW and on-land GPS stations at the western part of the Suruga Trough. We also calculated the theoretical surface deformation pattern to depict the interplate locking condition. These results show that the plate interface at the northernmost Suruga trough is strongly locked.

SP3PS.05

SP3PS - Interdisciplinary ocean bottom stations

Poster

Earthquake observations just above the Japan Trench by using ultra-deep ocean bottom seismometers

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Recent giant earthquakes such as the 2011 Tohoku earthquake demonstrate large slip zones that can generate giant tsunami are located adjacent to trench. Observations in the vicinity are essential to resolve details of phenomena where the noticeable regions are, however it is a challenging issue because most trenches, which include the Japan Trench, are below ultra deep sea. A number of ocean bottom seismometers (OBSs) have been used for marine seismic studies since last century, but most of them are available at less than 6,000 m water depth. Few seismometers equipped with special vessels have been to the deeper zones, although the specialties are problems in order to make seismic array easily. It is one of the solutions if compact OBSs are able to be set under ultra deep sea. We have been developing several compact free-fall/pop-up type OBSs, which includes a new type OBS, ultra-deep ocean bottom seismometer (UOBS). It has enabled to obtain seismic data from just above the Japan Trench since 2012. Each UOBS has a three-component seismometer, a data-logger with a precise clock and batteries inside a housing which is a single glass sphere (dia. 17 in.) with the transponder unit for acoustic communication to vessels, and radio beacon and flashing light for recovery. Each seismometer is on a passive gimbal system so that it could keep directions, one of which is vertical and the others are horizontals orthogonally. Seismic data are stored continuously after 24 bits analogue to digital conversion with 200 Hz sampling. Parameters such as recording period and sampling rate can be set by both wired communication via RS-232C and wireless communication through the acoustic transponder. A prototype UOBS was installed to the sea bottom below more than 6,500 m from sea surface on May 2012. It was recovered after using acoustic transmission. A modified UOBS was deployed below over 7,500 m on August, and recovered on October 2012. We obtained the seismic data from both UOBSs.

SP3PS.06

SP3PS - Interdisciplinary ocean bottom stations

Poster

Seafloor crustal deformation associated with the plate convergence at the Nankai Trough, Japan

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We have developed an instruments for observing ocean bottom crustal deformation that is composed of the kinematic GPS and acoustic ranging techniques, called the GPS/Acoustic system [Tadokoro et al., 2006]. We started to monitor ocean bottom crustal deformations associated with the plate convergence at the Nankai Trough, Japan. The Nankai Trough is one of the active plate boundaries where the large subduction earthquakes, Nankai and Tonankai earthquakes, have repeatedly occurred with intervals of about 90-150 years, resulting from the plate subduction of the Philippine Sea Plate beneath the Amurian Plate. The 1944 Tonankai and 1946 Nankai earthquakes are the most recent significant earthquakes along the trough. The source regions of the earthquakes are located beneath the ocean bottom. It is, therefore, necessary to monitor the crustal activities including crustal deformation. We installed three monitoring sites (KMN, KMS, and KME) at the source area of the Tonankai earthquakes with water depths of about 1920-2030 m. These sites are located 70–90 km landward from the trough. We performed the crustal deformation monitoring for 4-8 years until the end of 2012; and we obtained averaged horizontal site velocities w.r.t. the Amurian Plate at the three sites. We can observe crustal deformations in ocean areas with the errors of 5 mm/y through the more than 4 years monitoring using our observation system. The obtained site velocities are as follows: 41+/-5 mm/y in N76+/-6W at KMN, 38+/-5 mm/y in N71+/-4W at KMS, and 44+/-5 mm/y in N72+/-5W at KME. All the three site velocity vectors are the same length and direction taking the errors into account; and the directions of velocity are consistent with those, N74-80W, at the on-land GPS stations (GEONET by the Geospatial Information Authority of Japan). The observational result is the strong evidence for uniform interplate locking beneath the study region. The back-slip model predicts the coupling ratios of 60-80 %.

SP3PS.07

SP3PS - Interdisciplinary ocean bottom stations

Poster

Coordinating European OBS parks

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Within Europe, more than 380 Ocean Bottom Seismometers (OBS) are distributed across 10 instrument parks in 6 countries. At least 120 of these OBS are wideband or broadband, over 260 can be deployed for at least 6 months at a time and 140 for at least one year. New parks are planned in two other European countries, which should add over 70 OBSs to this “fleet”. However, these parks are under the control of individual countries or universities and hence to date this has made it difficult to organize large-scale experiments, especially for seismologists without marine experience.

We report on a recent initiative to coordinate the use of these distributed instruments and their data products, to encourage large-scale experiments, possibly with onshore and offshore components, by seismologists who have not necessarily used OBSs before. The ongoing or planned developments include: Helping scientists with marine-specific formalities such as ship requests; clearer explanations of the noise floors of OBS instrumenta- tion; improved clarity of instrument pricing and availability; standardized data output formats and data validation; and archiving in established seismological data centers. These efforts should allow improved experiment design in scientifically interesting regions with an offshore component and an easier, clearer way to organize large-scale, multi-country experiments.

We will present details of this initiative to help organize large-scale experiments, the particularities of OBS sensors and marine deployments, the available instrumentation and new developments.

SP3S1.01

SP3S1 - Interdisciplinary ocean bottom stations

Oral

The Japan trench ocean bottom seismic and tsunami network

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Huge tsunami, which was generated by the 2011 off the Pacific Coast of Tohoku Earthquake of M9 subduction zone earthquake, attacked the coastal areas in the north-eastern Japan and gave severe casualties (about 20,000 people) and property damages in the areas. The present tsunami warning system, based on land seismic observation data, did not work effectively in the case of the M9 earthquake. It is strongly acknowledged that marine observation data is necessary to make tsunami height estimation more accurately. Therefore, new ocean bottom observation project has started in 2011 that advances the countermeasures against earthquake and tsunami disaster related to subduction zone earthquake and outer rise earthquake around Japan Trench and Kuril Trench. A large scale ocean bottom cabled observation network is scheduled to be deployed around Japan Trench and Kuril Trench by 2015. The network is consisted of about 150 ocean bottom observation stations. Ocean bottom fiber optic cables, about 5700 km in total length, connect the stations to land. Observation stations with tsunami meters and seismometers will be placed on the seafloor off Hokkaido, off Tohoku and off Kanto, in a spacing of about 30 km almost in the direction of East-West (perpendicular to the trench axis) and in a spacing of about 50 - 60 km almost in the direction of North-South (parallel to the trench axis). Two sets of JAE three component servo accelerometers, a Geospace Technologies three component velocity seismometers, and two Paroscientific quartz type depth sensors and a three-component quartz type accelerometers (frequency outputs) will be installed. Tsunami data and seismometer data will be digitized at sampling frequency of 10 Hz and 100 Hz, respectively, and will be added clock information at land stations. These digitized data will be transmitted to the data centers, JMA (Japan Meteorological Agency), universities, and so on, using IP network.

SP3S1.02

SP3S1 - Interdisciplinary ocean bottom stations

Oral

How important and indispensable the offshore real time monitoring system is: Ocean floor networks around the Nankai trough SW Japan

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The offshore real time monitoring system is very important for the early warning of earthquakes and tsunamis. Lessons from 2004 Sumatra Earthquakes and 2011 East Japan Earthquake 2011 accelerate deployments of ocean floor networks such as DONET, DONET2 and East Japan cable.

Especially, DONET have deployed and DONET2 is under developing around the Nankai trough southwestern Japan. In the Nankai trough seismogenic zones, mega thrust earthquakes have occurred with the intervals of every 100-200 years. However, recurrence patters among these mega thrust earthquakes are quite different. Furthermore, these seismogenic zones are located near the coasts of southwestern Japan, so, evacuations from tsunamis are severe problems. Based on these conditions, Japanese government and research community recognized that real time monitoring systems of earthquakes and tsunamis are very important.

Furthermore, Ocean floor networks equipped with multi kinds of sensors such as seismometers and pressure gauges are very powerful and significant tools to monitor the broad band phenomena in seismogenic zones. In the Nankai trough, we constructed DONET which is Dense Ocean floor Network for Earthquakes and Tsunamis around the Tonankai seismogenic zone with 20 observatories. Multi kinds of sensors such as an accelerometer, a broad band seismometer, a precise pressure gauge, a differential pressure gauge and a precise thermometer are equipped in each observatory. Now, we are already developing DONET2 with 31 observatories around the Nankai seismogenic zone. DONET2 system is more powerful rather than DONET to monitor large seismogenic zones.

Finally, we will apply these real time data to early warning and prediction researches for the disaster reductions and understandings of seismic linkages among mega thrust earthquakes.

SP3S1.03

SP3S1 - Interdisciplinary ocean bottom stations

Oral

Monitoring of a Mid-Atlantic Ridge hydrothermal system and volcano at the EMSO-Azores subsea observatory

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Hydrothermal cells at mid-ocean ridges are powered by magmatic heat, and develop in the highly fractured and permeable upper few kms of the oceanic crust. Vent distribution, the partition between focused (smokers) and diffuse vents, and the fluxes that feed hydrothermal ecosystems, are also controlled by secondary near-surface fluid circulations and mixing between seawater and hydrothermal fluids. The Azores node of EMSO (European Multidisciplinary Subsea Observatory) at the Lucky Strike volcano (37°N, Mid-Atlantic Ridge) acquires time-series data designed to better constrain hydrothermal dynamics, from the scale of the permeable axial domain (> 1 km), to the scale of vent microhabitats (1 cm) in order to address two main research themes: 1- the contribution of ridge hydrothermalism to heat and chemical exchanges between solid Earth and Ocean; and 2- the hydrothermal forcing on mid-ocean ridge vent ecosystems. The observatory combines autonomous instruments (OBSs, pressure and temperature probes, oceanographic mooring and current meter) and a prototype buoyed observatory infrastructure (BOREL-SEAMON) that allows real time and near real time data transmission to a shore-based server, as well as back and forth communication with two sets of instruments: an ecological monitoring module at the «Tour Eiffel» hydrothermal venting edifice; and a geophysical module that transmits seismic detection alerts and seafloor pressure data. This prototype system has been operational since 2010. In this presentation we give an overview of our results so far, and outline plans for future upgrades of the Lucky Strike EMSO observatory.

SP3S1.04

SP3S1 - Interdisciplinary ocean bottom stations

Oral

Seafloor geodetic monitoring in the hypocentral area of the 2011 Great Tohoku Earthquake

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A massive earthquake of M 9.0 occurred along the Japan Trench subduction zone to cause devastating damage to the Pacific coast of northeastern Japan. The rupture of the earthquake started at the central part of the subduction zone, where interplate earthquakes of M ~ 7.5 have occurred along the subducting plate boundary repeatedly at about 40 years intervals, so-called the Miyagi-Oki earthquakes. In the area, we have maintained a geodetic observation network composed of seafloor high-precision acoustic transponders for GPS/Acoustic observation and seafloor pressure recorders for continuous monitoring of vertical deformation. Our seafloor geodetic observations provided not only the coseismic deformation associated with the M-9 mainshock but also postseismic deformation as well as slow slip events in the rupture area preceding the massive earthquake. The network witnessed huge coseismic displacement near the Japan Trench, the largest observed displacements were~ 31 m in horizontal and ~ 5 m in vertical, and these observations were strong evidence of the extraordinarily large amount of fault slip > 50 m. The mainshock was preceded by a series of slow-slip events: a slow-slip event started near the trench about 1.5 months before the mainshock. Two days before the mainshock, a M 7.3 interplate earthquake occurred in the down-dip side of this slip-slip event to cause evident afterslip propagating towards the hypocenter of the M-9 earthquake with much faster moment release rate than the prior slip event. After the occurrence of the mainshock, our network observes large postseismic deformation. Although it is difficult to discriminate between the effects of afterslip and visco-elastic relaxation, our GPS/A and seafloor pressure data strongly suggest occurrence of large afterslip near the trench axis.

SP3S1.05

SP3S1 - Interdisciplinary ocean bottom stations

Oral

BBOBS-NX: practical observation tool for broadband seismology at the seafloor

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Since 1999, we have already developed the mobile broadband ocean bottom seismometer (BBOBS), and many practical observations have been conducted. But, the noise level of BBOBS's horizontal components in long periods is rather high in average and its variation in time is also large. The reason of this high noise level is assumed as the small tilt variation of the large housing sphere that contains the broadband sensor, recorder and batteries, due to the bottom current. To clear this problem, one idea of observation without the tilt variation is the use of small and low profile broadband sensor that enables to penetrate into the sediment, that is apart from the large housing. This next generation type of BBOBS (BBOBS-NX) has been tested since 2008. The observation procedure of the BBOBS-NX is as following; (1) free-fall the BBOBS-NX to the seafloor aiming enough penetration of the sensor unit with the recording unit attached above it, (2) detach and move the recording unit from the sensor unit by the ROV to start the observation, (3) pull-up the recording unit and the sensor unit connected with the umbilical rope to recover the whole BBOBS-NX by the ROV. The averaged noise level of the BBOBS-NX is below the new high noise model for all three components in periods longer than 20 s, which is more than 20 dB of noise reduction in horizontal components compared to the BBOBS. So, the BBOBS-NX's data is suitable for analyses using horizontal component waveforms, such as the receiver function analysis. From a rough estimation, one year observation by the BBOBS-NX is long enough to get a reliable receiver function at a single station, although at least three years long observation was required for same quality by the BBOBS. Recently, we have started the normal oceanic mantle project since 2010 around the Shatsky Rise in the northwestern Pacific by using several BBOBS-NX and other instruments to research the nature of the LAB and the water content in the MTZ until 2014.

SP3S1.06

SP3S1 - Interdisciplinary ocean bottom stations

Oral

On the importance of OBS to ambient seismic noise interferometry

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In addition to the common methods of seismology, the ambient seismic noise interferometry is a reliable method to investigate the structure of the crust and the uppermost mantle that simply cannot be obtained from earthquake data. Due to the fact, that nearly 70 % of earth's surface is covered by the oceans as well as the huge amount of active tectonical processes at ocean floor, it is promising to modify approved methods of seismological survey to application for offshore devices. The seismic noise interferometry specifically uses the correlated synchronous records of two seismic stations to extract the surface wave Green's function of their corresponding interstation path. This procedure is independent of the occurrence of seismic events, whereby it is a promising tool at regions with less seismicity. In comparison to equivalent onshore studies the frequency range and characteristics correlated records are significantly dependent on bathymetric profiles between the two stations as well as their location. For example, interstation path profiles between two stations with no elevation have a strong acoustic phase with a weak surface wave signal. Furthermore, it has to be pointed out that the problems of exact orientation of seismometer components, as well as determination and adequate lag time correction of long time records, develop a broad field of systematic approaches.

SP3S1.07

SP3S1 - Interdisciplinary ocean bottom stations

Oral

Development of new ocean bottom cabled seismic and tsunami observation system off Sanriku using ICT

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The Pacific plate is subducting below the northeastern Japan islands arc. The 2011 Tohoku earthquake occurred at the plate boundary between the Pacific plate and the landward plate below landward slope of the Japan trench. In 1996, Earthquake Research Institute, University of Tokyo had installed seismic and tsunami observation system using seafloor optical fiber in the off-Sanriku area. The cabled system observed seismic waves and tsunamis generated by the 2011 Tohoku earthquake, and the data from the system are indispensable to estimate the source process of the 2011 event. However, the landing station of the system was damaged by huge tsunami 30 minutes after the mainshock. Therefore we decide to install newly developed Ocean Bottom Cabled Seismic and Tsunami (OBCST) observation system off Sanriku to continue the sea floor observation. Until 2010, we had already developed and installed the new compact Ocean Bottom Cabled Seismometer system near Awashima-island in the Japan Sea. After the installation, data are being collected continuously and we have continuous seismic data for approximately 2.5 years at the present. The new system for off-Sanriku area is based on this system. The new OBCST has three accelerometers as a seismic sensor. Signals from accelerometers are 24-bit digitized with a sampling rate of 1 kHz and sent to a landing station using standard TCP/IP data transmission. A precise pressure gauge is equipped as a tsunami sensor. The tsunami data are also transmitted by TCP/IP protocol. In addition, we have a plan that an observation node has an external port for additional observation sensor which will install on seafloor using Power over Ethernet technology. The data will be stored on the landing station and sent to Earthquake Research Institute in the real-time. At the present, we are producing a proto-type of the new OBCST. In this paper, we will present a system of the new OBCST in detail, and installation plan.

SP3S1.08

SP3S1 - Interdisciplinary ocean bottom stations

Oral

Positioning accuracy of seafloor benchmarker due to acoustic velocity heterogeneity via numerical simulation for development of seafloor geodesy

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Positioning of an underwater sensor using acoustic signals is one of the most important parts in oceanographic applications, and also in seafloor geodesy. In seafloor geodetic observation, acoustic ranging technique is combined with GPS geodesy. For accurate acoustic ranging, we have to know acoustic velocity along each observed acoustic ray path. Acoustic velocity heterogeneity is the most influence factor not only in acoustic ranging, but also in present seafloor geodetic observation. To reduce estimation error of seafloor benchmarker positions, we need to develop acoustic velocity modeling and its variation with more realistic conditions. We have performed travel-time calculation by precise travel-time function as possible and synthetic data test to evaluate locating error of seafloor benchmarkers due to velocity modeling and/or heterogeneity. We have given perturbation related with velocity variation to synthetic travel-time directly, not calculated travel-time with various velocity profiles. Because there are many acoustic velocity profiles with the same travel-time between given points. The results showed that random travel time perturbation less than 0.10 ms does not affect location analysis. That means a seafloor benchmarker can be located within an accuracy of 1 cm in horizontal from true position, even if we used different 1-dimensional velocity structure model. Small random travel time perturbation corresponds to small-scale velocity heterogeneity, like diurnal changes near sea surface due to air-sea interaction. However, non-random travel time perturbation with 0.05 ms or larger makes position shift larger than several centimeters. This travel time variation corresponds to large-scale velocity heterogeneity, such as block structures due to sea current. Through this study, we discuss future development on observation system and methodology for seafloor geodesy, including acoustic velocity modeling of spatio-temporal variation.