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IUGG-1377

Application of Helmert Variance Component Estimation in the joint inversion of rupture process

C. XU[1,2], *L. Yi*[3]
[1]*Wuhan University, School of Geodesy and Geomatics, Wuhan, China Peoples Republic*
[2]*Collaborative Innovation Center of Geospatial Technology, Wuhan, China Peoples Republic*
[3]*Wuhan University, School of Geodesy and Gematics, Wuhan, China Peoples Republic*

The weights determination of multiple datasets in the joint inversion of rupture process is an essential issue, which directly affects the contributions of different datasets and the reliability of the final results. Helmert variance component estimation (HVCE) is a popular and traditional weight determination method in joint inversion of geodesy. Here we extent the HVCE method to joint inversion of rupture process based on teleseismic body wave and GPS coseismic displacements. In this approach, spatial and temporal constraints are all considered as virtual observations and their weights will be simultaneously determined with the real observation datasets. We then applied this method to the rupture process inversion of Lushan earthquake, China.

The HVCE method is superior over the Akaike's Bayes Inversion Criterion (ABIC) method by the following aspects. Firstly, it depends less on the priori value of weights, which is needed to be carefully chosen in ABIC method to assure the accuracy and reduce computational burden. Secondly, instead of searching the optimal weights in a certain range, the weights in the HVCE method are determined iteratively and more objective. Finally, for joint inversions with three or more types of datasets, the HVCE method is much faster and needs much less computation cost than the ABIC method, which needs to searching the parameter-space in three or more dimensions to find the optimal weights.

We invert for the static slip distribution and rupture process based on GPS coseismic displacements and teleseismic waveforms separately. Then compare the results of the HVCE and ABIC methods and analyze the possible relationship between them.

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Joint Analysis of GOCE Gravity Gradients Data with Seismological and Geodynamic Observations to Infer Mantle Properties

M. Greff-Lefftz[1], *L. Métivier*[2], *I. Panet*[2], *G. Pajot-Métivier*[2], *L. Caron*[1]
[1]*Institut de Physique du Globe de Paris, Géomagnétisme, Paris, France*
[2]*Institut National de l'Information Géographique et Forestière- Université Paris Diderot, LAREG, Paris, France*

Joint inversion of the observed seismic velocities ad geoid has been commonly used to constrain the viscosity profile within the mantle as well as the lateral density variations. But recently, ESA's Gravity field and steady-state Ocean Circulation Explorer (GOCE) measurements of the second-order derivatives of the Earth’s gravity potential give new possibilities to understand these mantle properties. Using a simple mantle model and seismic tomography results, we investigate how the gravity and the gradients of gravity data can allow us to infer information on the radial profile of viscosity and on the mantle mass anomalies.We start with lateral density variations in the Earth's mantle based either on slab history or deduced from seismic tomography. The main uncertainties are: for the latter case, the relationship between seismic velocity and density -the so-called density/velocity scaling factor- and for the former case, the variation with depth of the density contrast between the cold slabs and the surrounding mantle.We first perform a Monte Carlo search for the viscosity and the density/velocity scaling factor profiles within the mantle which allow to fit the observed geoid, gravity and gradients of gravity. We compute the posterior probability distribution of the unknown parameters, and we discuss the respective contributions of the geoid, gravity and gravity gradients in the estimation. Finally, for the mantle model based on slabs history, using the same approach, we jointly estimate the viscosity and the density contrast between the cold slabs and the surrounding mantle.Our results open towards an integrated model of the Earth from the joint analysis of these gradient data with seismological and geodynamical observations.

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New anisotropic teleseismic body-wave tomography code AniTomo to illuminate heterogeneous anisotropic upper mantle

H. Munzarova[1], *J. Plomerova*[1], *E. Kissling*[2]
[1]*Institute of Geophysic- AS CR, Seismic department, Prague, Czech Republic*
[2]*Institute of Geophysics, Department of Earth Sciences- ETH Zürich, Zürich, Switzerland*

Considering only isotropic wave propagation and neglecting anisotropy in tomography studies is a simplification obviously incongruous with current understanding of mantle-lithosphere plate dynamics. Furthermore, significant distortions of imaged velocity heterogeneities may result from anisotropy neglecting. Therefore, we are developping a novel code for anisotropic teleseismic tomography (AniTomo) that allows to invert relative P-wave travel time residuals simultaneously for coupled isotropic-anisotropic P-wave velocity models of the upper mantle. We have modified frequently-used isotropic teleseismic tomography code Telinv by assuming weak hexagonal anisotropy with symmetry axis oriented generally in 3D to be, together with heterogeneities, the source of observed P-wave travel-time residuals. Results of independent methods and datasets, such as shear wave splitting, are useful constraints for construction of reasonable initial models. Careful testing of the new code with synthetics, concentrating on strengths and weaknesses of the code, is a necessary step before AniTomo is applied to real datasets. We examine various aspects coming along with anisotropic tomography, particularly, influence of ray coverage on resolvability of individual model parameters and of initial models on the result. Synthetic models are designed to schematically represent different heterogeneous and anisotropic structures in the upper mantle. As example, a model mimicking subduction in the Northern Apennines allows quantitative assessment of the well-known trade-off between effects of seismic anisotropy and heterogeneities (Munzarova et al., G-Cubed, 2013).

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IUGG-3605

Magnetotelluric data with phases >90° and peculiar induction vectors: Electrical anisotropy or 3D structures?

U. Weckmann[1]*, R. Barth*[1]
[1]*Helmholtz Centre Potsdam - GFZ, Section 2.2, Potsdam, Germany*

Fossil mobile belts or collision zones have experienced several episodes of contraction and deformation. Many seismic and magnetotelluric (MT) studies have suggested anisotropy in the lower crust and upper mantle as a possible result. Two MT data set, which show typical effects of anisotropy, such as phases out of quadrant and regions with long parallel induction vectors in line with the conductivity contrast, will be revisited. Generally, these effects might also be caused by current deflecting strong 3D conductivity contrasts. Therefore these data sets will be re-examined using 3D isotropic inversion.
Across the Waterberg Fault / Omaruru Lineament a broad zone with phases exceeding 90° was interpreted by 2D anisotropic modelling as a combination of shallow and deep anisotropic layers (Weckmann et al., 2003). Modern 2D anisotropic inversion also reveals one anomalous structure in the upper crust (personal communication, J. Pek). Our second example is located at the boundary of the Namaqua Natal Mobile Belt and the Kaapvaal Craton in South Africa. Here the anisotropy is believed to reflect deeper structures at crustal or mantle levels (Hamilton et al., 2006; Silver et al., 2001). The MT data shows long induction vectors parallel to the major conductivity contrast which look alike over a more than 100km broad region.
We will present different approaches to invert these data using 3D inversion. In case of shallow crustal anisotropy it seems to be difficult to find 3D models which incorporate sufficiently small anomalies to fit the observed effects in the data. In contrast, our studies suggest that instead of a deep seated anisotropic structure, large-scale strong conductivity contrasts also result in parallel induction vectors over such a wide area.

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IUGG-4628

Characterization of Sao Francisco Basin, Brazil - joint inversion of MT, gravity and magnetic data

F. Solon[1], *L.A. Gallardo*[2], *S.L. Fontes*[1]
[1]*Observatorio Nacional, Department of Gaophysics, Rio de Janeiro, Brazil*
[2]*CICESE, Earth Science Division, Ensenada, Mexico*

The multiple crossgradient joint inversion has proved to be an effective approach which employs structural resemblance constraints. This algorithm is based on the use of a structural constraint called cross-gradient, which measures the structural similarity between different geophysical models and provide estimates of multiple physical properties that are structurally matching. This method was recently applied successfully to geophysical data from Sao Francisco Basin, in Brazil, where the joint inversion of gravity, magnetic and MT data were performed. The study comprises a total of 43 stations along eight MT profiles. For this work we used data from 11 MT stations forming a profile coincident with a reflection seismic line that was part of a seismic survey executed in the 90s by Petrobras. We also used Bouguer anomaly and magnetic data acquired and processed by the Petroleum National Agency (ANP). The study highlights the advantages of using structurally integrated physical property distributions for geophysical interpretations in Precambrian basins. Beyond presenting similarity in structure, the physical property distributions jointly estimated are more geologically meaningful than the ones obtained from separate inversion. The three estimated physical property distributions have a common structure that we believe to the basement under our study area. It is expected better results in shallower regions of the models with the joint inversion including seismic data.

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IUGG-5105

Topographic uplift of the Southern African Plateau from the African Superswell deduced through petrologically-consistent thermo-chemical modelling

A. Jones[1], *J.C. Afonso*[2], *J. Fullea*[3]
[1]*Dublin Institute for Advanced Studies, School of Cosmic Physics, Dublin, Ireland*
[2]*Macquarie University, Department of Earth and Planetary Sciences, Sydney, Australia*
[3]*CSIC–UCM, Institute of Geosciences, Madrid, Spain*

The deep mantle African Superswell is thought to cause up to 500 m of the uplift of the Southern African Plateau. We investigate this phenomenon through stochastic thermo-chemical inversion modelling of the geoid, surface heat flow, Rayleigh and Love dispersion curves and MT data, in a manner that is fully petrologically-consistent. We invert for a three layer crustal velocity, density and thermal structure, but assume the resistivity layering (based on prior inversion of the MT data alone). Inversions are performed using an improved Delayed Rejection and Adaptive Metropolis (DRAM) type Markov chain Monte Carlo (MCMC) algorithm.

We demonstrate that a single layer lithosphere can fit most of the data, but not the MT responses. We further demonstrate that modelling the seismic data alone, without the constraint of requiring reasonable oxide chemistry or of fitting the geoid, permits wildly acceptable elevations and with very poorly defined lithosphere-asthenosphere boundary (LAB). We parameterise the lithosphere into three layers, and bound the permitted oxide chemistry of each layer consistent with known chemical layering.

We find acceptable models, from 5 million tested in each case, that fit all responses and yield a posteriori elevation distributions centred on 900-950 m, suggesting dynamic support from the lower mantle of some 400 m.

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IUGG-2699

Sparse geophysical inversion

M. Sambridge[1]*, R. Hawkins*[1]*, E. Saygin*[1]
[1]*Australian National University, Research School of Earth Sciences, Canberra, Australia*

Applications of inverse theory in the geosciences have become ubiquitous over the past 30 years. From the early days where theoretical advances led to an understanding of the uniqueness and resolution of continuous fields, through to massive parameter estimation procedures based on matrix inversion and nonlinear optimization. With the increase of computational power, widespread availability of inversion techniques, and ever increasing multi-faceted data sources, geophysics has become a fertile ground to explore and apply inference methods developed `in-house' or imported from other fields. Two regimes are popular. One based on optimization of a functional of the data and some regularization criteria, and another based on statistical sampling techniques that typically involve a Bayesian formulation of the inference problem.

A recent trend, which has emerged independently in both regimes, is to maximize the sparsity of a solution, measured through the number of parameters representing unknowns. In the optimization regime this is explicitly implemented via regularization techniques based on L0 or L1 norms, applied to appropriate transforms of the unknowns. A process closely related to developments in the field of Compressed Sensing. In contrast, within the probabilistic regime it is implicitly incorporated via the `natural parsimony' of transdimensional Markov chain Monte Carlo sampling over variable dimensional spaces. In both cases the number of unknowns is constrained by the data during the inversion process rather than imposed externally. Here we present new results showing that sparsity principles in either regime not only reduces complexity but also improves the accuracy and robustness of the solution.

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IUGG-3204

Joint 3D inversion of multiple electromagnetic data sets

N. Meqbel[1], *O. Ritter*[1]
[1]*Helmholtz-Centre Potsdam - GFZ German Research Centre for Geosciences, Geophysical Deep Sounding, Potsdam, Germany*

Electromagnetic (EM) methods are routinely applied to image the subsurface from shallow to regional structures. Individual EM methods differ in their sensitivities towards resistive and conductive structures as well as in their exploration depths. If a good balance between different EM data can be found, joint 3D inversion of multiple EM data sets can result in significantly better resolution of subsurface structures than the individual inversions. We present a weighting algorithm to combine magnetotelluric (MT), controlled source EM (CSEM), and geoelectric (DC) data. MT data are generally more sensitive to regional conductive structures, whereas CSEM and DC data are better suited to recover more shallow and resistive structures. Our new scheme is based on weighting individual components of the total data gradient after each model update. Norms of individual data residuals are used to assess how much of the total data gradient must be assigned to each method to achieve a balanced contribution of all data sets for the joint inverse model. Synthetic inversion tests demonstrate advantages of joint inversion in general and also the influence of the weighting. In our tests, the CSEM data gradients are several orders of magnitudes larger than those of the MT and DC data sets. Consequently, direct joint inversion of CSEM, MT and DC data results in models which are dominated by structures required by the CSEM data. Applying the new adaptive weighting scheme results in an inversion model which resembles better the original model and which has better data fit and faster convergence rate. We used the Modular System EM (ModEM) as a framework to implement the new joint inversion and briefly describe the new modules for forward modelling and their interfaces to the ModEM package.

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IUGG-3434

Creation the earth crust and upper mantle 3D models based on joint inversion

P. Martyshko[1]*, I. Ladovskiy*[2]*, D. Byzhov*[2]
[1]*Institute of Geophysics- UB RAS, Yekaterinburg, Russia*
[2]*Institute of Geophysics- UB RAS, Lab of Math Geophysics, Ekaterinburg, Russia*

Geological and geophysical 3D model creation for Earth crust and upper mantle structure is fundamental direction in Earth science. These models allow us to make conclusions about constitution, formation conditions and tectonic evolution of geological structures. Geophysical and (mostly) seismic studies showed that geological environment on deep horizons have a complex hierarchical structure with layers and blocks and is not homogeneous either along or across the upper lithosphere seismic floor. Such regularity is found on almost all profiles and deep seismic soundings (DSS) geotraverses, which total length on northern Eurasia area under study is more than 10000 km. As part of the project of the Russian Science Foundation «3D models of Urals region Nether-Polar zone deep structure construction based on new geophysical fields complex interpretation methods and modern computer grid modeling technologies» we have interpretated the geophysical data of northern Eurasia between 48°–72° E and 60°–68° N. We developed new 3D density model construction method and used it for lithosphere modelling using velocity and seismic density cuts as initial data. This method based on joint inversion of seismic, gravity and magnetic data. For territories in the borders of several 6-degree Gauss-Kruger zones it is permissible to use gravity model of flat layer. Density parallelepiped construction technique was tested on the northern Eurasia where 7 regional seismic profiles are located**.** We demonstrated that quite informative data can be got from regional profiles and DSS traverses which were made in significant amount on all Russia territory. We used such data to create 3D geological-geophysical model upper lithosphere.

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IUGG-5029

Effect of ray and speed perturbations on ionospheric tomography by over-the-horizon radar:A new method

C. Roy[1], G. Occhipinti[1], L. Boschi[2], J.P. Molinie[3], M. Wieczorek[1]
[1]Institut de Physique du Globe de Paris, Planetology and Space Science, Paris, France
[2]Université Pierre et Marie Curie, Institut des Sciences de la Terre de Paris, Paris, France
[3]ONERA, DEMR, Palaiseau, France

Most recent methods in ionospheric tomography are based on the inversion of the total electron content measured by ground-based GPS receivers. As a consequence of the high frequency of the GPS signal and the absence of horizontal raypaths, the electron density structure is mainly reconstructed in the F2 region (300 km), where the ionosphere reaches the maximum of ionization, and is not sensitive to the lower ionospheric structure. We propose here a new tomographic method of the lower ionosphere, based on the full inversion of over-the-horizon (OTH) radar data. Previous studies using OTH radar for ionospheric tomography inverted only the leading edge echo curve of backscatter ionograms. The major advantageof our methodology is taking into account, numerically and jointly, the effect that the electron density perturbations induce not only in the speed of electromagnetic waves but also on the raypath geometry. This last point is extremely critical for OTH radar inversions as the emitted signal propagates through the ionosphere between a fixed starting point (the radar) and an unknown end point on the Earth surface where the signal is backscattered. We detail our ionospheric tomography method with the aid of benchmark tests. Having proved the necessity to take into account both effects simultaneously, we apply our method to real data. This is the first time that the effect of the raypath deflection has been quantified and that the ionospheric plasma density has been estimated over the entirety of Europe with an OTH radar.

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IUGG-5266

Joining wavefield modeling, optimized data selection, and waveform tomography for multi-scale mantle structure

T. Nissen-Meyer[1], K. Hosseini[2], K. Sigloch[1]
[1]University of Oxford, Department of Earth Sciences, Oxford, United Kingdom
[2]Ludwig-Maximilians-University, Department of Earth Sciences, Munich, Germany

Multi-scale structure is expected to dominate the boundary layers of the convecting mantle. Seismology is the primary means of imaging such features, supported by significant recent advances in seismic data acquisition and realistic modeling of wave propagation. We propose an approach combining broadband waveform modeling, quantitative data selection and waveform inversion of multiple parameters. Our incentive is that multiscale structures cannot be correctly represented by any one technique focusing on a particular end of the spectrum (small- versus large-scale), nor on a particular nature (volumetric versus topographic), and connecting data selection, wavefield modeling with tomography will impose crucial constraints on the procedure and lead to more reliable images.

We present the strategy to streamline these disparate tools, focusing on lower-mantle structures of volumetric (LLSVP, ULVZ) and discontinuous type (CMB topography). Facilitated by AxiSEM (www.axisem.info) and the related database extension Instaseis, we model broadband seismograms instantaneously for spherical models, and 3D wavefields efficiently for in-plane 2D structures. Such (in particular differential) wavefield modeling delivers preliminary constraints on data that are most sensitive to the structures of interest. We join this with time-dependent sensitivity kernels to quantitatively optimize data selection to these structures. This represents the basis for accumulating massive data sets and measurements for waveform tomography, in particular using core-diffracted waves measured in multiple frequency bands for volumetric tomography, and complementary phases for CMB topography.

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JA01p-146

Joint inversion modeling of geological CO2 storage using time lapse microgravity and ground deformation

H. Kabirzadeh[1], *M. G. Sideris*[1], *J. W. Kim*[1]
[1]*University of Calgary, Geomatics Engineering, Calgary, Canada*

Storing CO_2 in geological reservoirs requires special care and continuous monitoring for securing the injected CO_2. Four-dimensional measurements of microgravity and surface deformation can give us valuable information about the behavior of the injected CO_2 in and around the reservoir. After injection, the excessive CO_2 causes a negative density change in the pore content and consequently a negative gravity anomaly at the surface. In addition, the positive volumetric change caused by excessive pressure inside the reservoir results in an uplift at the surface. At least two surveys should be conducted before and after the storage fluid content changes. After data acquisition and processing, an inversion algorithm can be used to map the residual gravity and associated ground deformation changes to density and volume changes in the reservoir.

In the joint inversion, we divide the subsurface geometry into predefined rectangular cells. A linear inversion is then used to estimate the density and volumetric changes in each cell jointly. We supplement Tikhonov regularization with a few other constraints in order to stabilize the inverse problem and reduce the ambiguity. Total mass can remain unchanged as a constraint during the inversion. In addition, large portion of the CO_2 tends to be stored around the injection well, and, hence, we constraint the changes to be around the well within a short distance. The method is tested on synthetic data after adding white noise, assuming a reservoir located at 1800 meters depth with a 20-meter thickness. We assume 2.5 million tons of CO_2 is injected into this reservoir. The ground deformation and microgravity data are obtained from the forward modelling of the reservoir. The inverted model shows a good agreement with the predefined model.

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JA01p-147

Land surface temperature forecasting using MODIS Imagesand Modular Neural Networks

F. Taghavi[1]*, Z. Zargaran*[2]*, A. Ahmadi*[3]
[1]*Institute of Geophysics-University of Tehran, Space Physics, Tehran, Iran*
[2]*University of Economic Sciences, economic sciences, Tehran, Iran*
[3]*Amirkabir University of Technology,*
Institute of Industrial Engineering and Management Systems, Tehran, Iran

In this study, a hybrid model of satellite images processing and modular networks with self-organizing map and particle swarm optimization algorithms for land surface temperature forecast presents in city of Tehran,Iran. Calculating LST based on brightness temperature features has been done in 31 and 32 MODIS channels. Thus, brightness temperature data related to these images is entered to the neural network and values of LST are recovered as the output of the network. In this way, networks are trained and their weights are extracted, after the optimal structure is obtained for networks. Then applying a neural network with a modular structure and clustering algorithms, training will be also modular. The results show that using PSO algorithm causes appropriate distribution of cluster of SOM method and using satellite images improved performance of the proposed model. Finally, results are compared with training neural network models and non-modular structure. The results of this comparison show that model-training time in predicting the LST is decreased and the accuracy of model is increased. So that in this hybrid model Mean Square Errors and Mean Absolute Percentage Error are 0.0081 and 10.59 respectively. The little difference between the predicted values and actual values of temperature in the region shows that this model could predict the temperature very carefully.

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3D inversion of magnetic anomaly data using a genetic algorithm

F. G. Montesiinos[1], *I. Blanco-Montenegro*[2], *J. Arnoso*[3]
[1]*Universidad Complutense de Madrid,*
Fac. de CC. Matemáticas Astronomía y Geodesia, Madrid, Spain
[2]*Escuela Politécnica Superior-Universidad de Burgos, Departamento de Física, Burgos, Spain*
[3]*Consejo Superior de Investigaciones Científicas, instituto de Geociencias CSIC-UCM, Madrid, Spain*

We present a new magnetic inversion method based on a genetic algorithm aimed at identifying the 3D geometry and location of magnetic anomaly sources with known magnetization. The main advantages of our method are: 1) a 3-D context is used; 2) different directions for the ambient magnetic field and the total magnetization vector can be considered (this is especially useful when remanent magnetization is not negligible); 3) non-gridded, non-planar and inaccurate anomaly data are accepted; 4) non-regular subsoil partitions can be used; 5) no constraint about the depth to the top of the sources is necessary; 6) an initial model is not needed; 7) previous models can be incorporated to the process; 8) the algorithm is fast, so the use of large data sets and models involving tens of thousands of elementary cells is possible.

Assuming that the parameters defining the magnetization vector (intensity, inclination and declination) are known, the genetic algorithm finds the geometry of the sources by seeking the optimum solution from an initial population of models in successive iterations through an evolutionary process. The evolution consists of three genetic operators (selection, crossover and mutation) acting on each generation, and a smoothing operator, looking for the best fit to the observed data and a solution made up with geologically reasonable compact sources.

We tested the efficiency of our inversion method with several complex synthetic anomalies that are shown, as well as the application to aeromagnetic data of the volcanic island of Gran Canaria (Canary Islands).

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Joint inversion of magnetotelluric, receiver function and gravity data using a combination of correlation and gradient approaches

M. Plasman[1]*, P. Tarits*[1]*, C. Tiberi*[2]*, S. Hautot*[3]
[1]*IUEM, LDO, Plouzané, France*
[2]*Université Montpellier 2, Géosciences Montpellier, Montpellier, France*
[3]*IMAGIR, IMAGIR, Brest, France*

We are developing a new joint 3D inversion method combining magnetotelluric (MT), seismology (receiver function RF) and gravity data. A preliminary series of tests was carried out in 1D between MT and RF. The parameter coupling is based on a correlation coefficient calculated between the two data set. The forward RF computation is based on Sambridge inversion. A non linear descent technique is used to minimize the objective function which combines both misfit functions, their regularization terms and the joint function. The algorithm is applied to data acquired in the framework of the French Colibrea and US Crafti projects to study the East African Rift at the North Tanzanian Divergence (NTD). When used separately these methods show different 1D models : while the MT results show an heterogeneous crust and significant discontinuities at 50-80 km in depth depending on the sites, probably the limit between the asthenosphere and lithosphere, the RF inversion show an heterogeneous crust obviously dominated by the Moho interface at different depths according to the seismic sites.

Following these tests, we created a new 3D joint inversion based on a combination of correlation functions and gradient dot products which are implemented to couple the resistivity, velocity and density during inversion. The procedure starts with separate 3D distribution of resistivity, density and a pseudo-3D velocity model. The later is obtained from the extrapolation between sites of the 1D velocity model from the RF inversion. At each iteration, resistivity, density and velocity values are updated and the total objective function minimized. The algorithm is tested on two ~100 km EW profiles, across the Ngorongoro volcanic belt to the North of the NTD and the Manyara fault system to the South.

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JA01p-150

A new gravity study to model crustal structures of the volcanic island of Gran Canaria (Spain)

F.G. Montesinos[1], J. Arnoso[2], M. Benavent[1], E.J. Vélez[2], T. Martín-Crespo[3], D. Gómez-Ortiz[3], A. Gorbatikov[4]
[1]Universidad Complutense de Madrid, Facultad de Matemáticas, Madrid, Spain
[2]Consejo Superior de Investigaciones Científicas, Instituto de Geociencias CSIC - UCM, Madrid, Spain
[3]Universidad Rey Juan Carlos, ESCET, Móstoles- Madrid, Spain
[4]Russian Academy of Sciences, Institute of Physics of the Earth, Moscow, Russia

We present a new gravity study to model the crustal structure of Gran Canaria Island. The Bouguer anomaly map is calculated from new gravity data measured in 266 stations distributed homogenously in the island and the marine gravity data from U.S. Geological Survey (Folguer, 1989). To obtain a more precise map, we used a new tidal model for Gran Canaria for solid Earth tides and ocean tide loading corrections and , taking into account the high terrain roughness on this island, we calculate a careful terrain correction with a DTM 1:5000 (Spanish National Geographic Institute). This map improves considerably the previous ones because it covers large regions where no data were available. Moreover, the higher spatial density of the survey network allows to study smaller and shallow-seated anomalies in the gravity field, related to the earlier volcanic process that had not been studied previously.

In order to model the crustal structures, we apply a nonlinear inversion using a genetic algorithm (Montesinos et al. 2005). From several fixed density contrasts, this algorithm determines the 3D-geometry of the anomaly gravity field sources, which are interpreted through the volcanic activity occurred along the evolution of the island. This gravity model is dominated by high density structures located at the NW, SW and SE zones of the island. These structures surround a low density body related to the formation of the large Tejeda caldera. The most important high density structure identified over the NW part of the island could be related to the main feeding system of the shield volcano. Moreover, other structures are also identified and their interpretation provides a new insight and more information in connection with the previous geological and geophysical studies.

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JA01p-151

Features of the deep structure of some volcanic islands of the Canary Archipelago from the passive seismo-prospecting method

A. Gorbatikov[1], J. Arnoso[2], M. Stepanova[1], F.G. Montesinos[3], T. Benavent[3], E.J. Vélez[2], I. Blanco-Montenegro[4], V. Soler[5]
[1]Russian Academy of Sciences, Institute of Physics of the Earth, Moscow, Russia
[2]Consejo Superior de Investigaciones Científicas,
Instituto de Geociencias CSIC - UCM, Madrid, Spain
[3]Universidad Complutense de Madrid, Facultad de Matemáticas, Madrid, Spain
[4]Universidad de Burgos, Escuela Politécnica Superior, Madrid, Spain
[5]Consejo Superior de Investigaciones Científicas,
IPNA. Estación Volcanológica de Canarias, La Laguna. Tenerife, Spain

The Microseismic Sounding Method (MSM) [Gorbatikov, etc., 2008,2011,2013] belongs to group of passive methods of seismic prospecting and can be applied at the solution of geologic-geophysical and structural problems to various classes of geological objects, and considering various geographical and climatic conditions. The model of formation of a microseismic field in MSM doesn't proceed from the obligatory horizontal lamination of the medium. In this regard, it is considered that the main contribution to a microseismic field is provided by fundamental Rayleigh modes, and the existence of the highest modes is minimum. Informative parameter (a useful signal) in MSM is extent of distortion of initial amplitude field of microseisms due to interaction with velocity inclusions. The phase information is not used. The form and depth of the heterogeneity is estimated through the distribution of the distortions of the initial field at the surface, and the frequency at which these distortions are manifested as well.

The MSM method was applied to estimate the models of the deep structure of several islands of the Canary Archipelago: El Hierro, Lanzarote and Gran Canaria. The respective velocity models obtained were then compared in independent studies: 1) with distribution of micro-seismicity and inversion of the gravity field at El Hierro Island, 2) with inversions of gravity and magnetic fields, and with morphological and structural maps at Lanzarote and Gran Canaria islands. A good correlation with the results of various methods has been found.

Joint Inter-Association Symposium

JA01p - JA01 Joint Inversion and Mutually Constrained Inversion of Geophysical Observations (IAGA, IAG, IASPEI) (IAGA, IAG, IASPEI)

JA01p-152

Features of the subsurface structure of the Timanfaya volcanic area (Lanzarote) from a joint analysis of magnetic and gravimetric maps

I. Blanco-Montenegro[1], F. G. Montesinos[2], J. Arnoso[3], E. Vélez[3], T. Benavent[2]
[1]Escuela Politécnica Superior-Universidad de Burgos, Departamento de Física, Burgos, Spain
[2]Universidad Complutense de Madrid,
Facultad de CC. Matemáticas Astronomía y Geodesia, Madrid, Spain
[3]Consejo Superior de Investigaciones Científicas, Instituto de Geociencias CSIC-UCM, Madrid, Spain

Timanfaya is a National Park which occupies a surface of 51,07 km² in the SW of Lanzarote Island (Canarian Archipelago). The eruption that took place in this area between 1730 and 1736 was one of the most important historic volcanic events occurred in the Canary Islands.
In this work, we analyse gravity and magnetic anomaly data with the aim of studying the subsurface structure beneath Lanzarote and the Timanfaya National Park. On the one hand, processing of aeromagnetic data acquired in 1993 by the National Geographic Institute of Spain at a constant height of 500 m asl allows the characterization of the subsurface structure of the Timanfaya area at a large scale in the context of the whole island of Lanzarote. Compared with previous studies based on a magnetic anomaly map continued up to 3800 m asl, the 500 m dataset provides us with a more detailed characterization of the magnetic sources, reavealing a linear magnetic structure following approximately the WNW-ESE direction in the southern part of Timanfaya. On the other hand, new gravity data have been measured in areas not studied until now. These data allows us to identify shallow anomaly sources related with the volcanic activity in Timanfaya. The Bouguer gravity anomaly map clearly shows several areas associated with gravity lows and highs which confirm the presence of crustal anomalies and structural alignments. The joint analysis of the magnetic and gravity maps shows a good correlation between them and provides us with complementary images of the subsurface structure at different scales. These common signatures can be related to features of the volcanic activity in Timanfaya, such as the fractures controlling the feeding system of the Timanfaya eruption.

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JA01p-153

Simultaneous measurements of elastic wave velocity and electrical conductivity in a brine-saturated granitic rock under confining pressures

T. Watanabe[1]*, M. Makimura*[1]*, A. Higuchi*[1]
[1]*University of Toyama, Department of Earth Sciences, Toyama, Japan*

Geophysical mapping of fluids is critical for understanding crustal processes. Seismic velocity and electrical resistivity structures have been revealed to study the fluid distribution. However, the fluid distribution has been still poorly constrained. Observed velocity and resistivity should be combined to make a quantitative inference on fluid distribution. The combined interpretation requires a thorough understanding of velocity and resistivity in fluid-saturated rocks.

Elastic wave velocities and electrical conductivity in a brine-saturated granitic rock have been studied under the confining pressures of up to 150 MPa. The pore-fluid pressure was kept at 0.1 MPa. Cylindrical samples (D=26 mm, L=30 mm) of a fine grained biotite granite were heated to 100-600 C to increase the amount of crack (open grain boundary), and filled with 0.1 M KCl aqueous solution. The pore-fluid was electrically insulated from the metal work by using plastic devices.

Velocity and conductivity showed reproducibly contrasting changes with increasing confining pressure. Elastic wave velocities increased by less than 10% as the confining pressure increased from 0.1 MPa to 50 MPa, while electrical conductivity decreased by an order of magnitude. The changes were caused by the closure of cracks under pressure. The steep decrease in conductivity suggests a power low distribution of the aperture of crack. Both velocity and conductivity showed no remarkable changes at higher pressures. An empirical relationship between the normalized conductivity and crack density parameter was obtained. This relationship can be applied to a combined interpretation of seismic velocities and electrical resistivity.

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JA01p-154

Short-scale crustal density variations in Australia revealed by global gravity model GGMplus and terrestrial gravity observations

S. Claessens[1], *J. Delamotte*[1], *C. Hirt*[1]
[1]*Curtin University, Department of Spatial Sciences, Perth, Australia*

Global Gravity Model Plus (GGMplus) is a recently developed ultra-high (7.2 arcsec) resolution model of the Earth's gravitational field, covering all land masses and near-coastal areas within +/- 60° latitude. The model is a composite of GRACE and GOCE satellite observations, the EGM2008 global gravity model, and short-scale topographic gravity effects. The small-scale gravity effects from topographic features are based on a constant terrain density assumption, and they form the key component to obtain ultra-high resolution.

This contribution shows how GGMplus can be used in conjunction with terrestrial gravity observations to reveal near-surface mass density variations in the Earth's crust. It is shown that variations in the Earth's gravity field due to topography are successfully modelled by GGMplus, so that remaining differences with gravity observations are primarily due to mass density variations. In effect, GGMplus data is used as a terrain correction. However, as GGMplus contains the effect of large-scale (> ~10 km) density variations through the inclusion of EGM2008, this method filters out large-scale features and highlights short-scale (< ~10 km) density variations. Results over various parts of Australia using recent gravity surveys are presented, which show strong correlation with known lines of geological significance.

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JA01p-155

Geophysical insights on the deep structure of Ciomadul volcano through interpretation of potential field data

L. Zlagnean[1]*, L. Besutiu*[1]*, I. Seghedi*[2]*, L. Atanasiu*[1]*, M. Pomeran*[1]
[1]*Institute of Geodynamics, SOLID EARTH DYNAMICS, Bucharest, Romania*
[2]*Institute of Geodynamics,*
ENDOGENE PROCESSES- NATURAL HAZARDS AND RISK, Bucharest, Romania

Pliocene–Quaternary magmatism characterizes the South Harghita Mountains which form the southern part of the Calimani-Gurghiu-Harghita volcanic chain. South-easternmost located of this chain, not far from the Vrancea active seismic area, Ciomadul volcano seems to mark one of the latest episodes of the post-collisional volcanism within East Carpathians.

Several challenging aspects, such as (i) the major heat flow anomaly, (ii) abrupt attenuation of seismic waves, (iii) the deeply located low velocity zone, (iv) associated earthquake hypocentres and (v) petrologic and magnetotelluric constrains on the magma storage, seem to favour the idea of the presence of a magma chamber beneath Ciomadul volcano.

Recently conducted geomagnetic and gravity surveys in the area have allowed for some new insights on the in-depth structure of the volcanic edifice. Joint inversion and forward modelling of the potential data was mainly used for deciphering the lateral and in-depth development of the volcanic structure.

The paper proposes some 2D and 3D tentative interpretative models of the potential field data. Lab rock physics determinations on samples collected from the study area and additional geophysical information are used to constrain the revealed structures.

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JA01p-156

Refinement of Tibetan crust density distribution and determination of Tibetan geoid and Moho depth

W.B. Shen[1,2], *J. Han*[1,3], *C. Hwang*[3], *X. Deng*[1], *R. Tenzer*[1], *C.K. Shum*[4], *H. Wang*[1]
[1]*Wuhan University, School of Geodesy and Geomatics, Wuhan, China Peoples Republic*
[2]*Wuhan University, State Key Laboratory of Information Engineering in Surveying- Mapping and Remote Sensing, Wuhan, China Peoples Republic*
[3]*National Chiao Tung University, Dept of Civil Engineering, Hsinchu, Taiwan Republic of China*
[4]*The Ohio State University, School of Earth Sciences, Columbus, USA*

The Tibetan Plateau is a unique geophysical feature due to its extreme size and elevation, and one of the most active regions in the world with competing climatic and geodynamic processes. During the period of the continental collision of India and Eurasia continental plates over the last 40–50 My, the Tibetan Plateau has experienced more than 2000 km shortening, gained more than 4 km elevation. More accurate determination of crust density, geoid and Moho depth in Tibet region may provide further constraints for understanding the geodynamics of Tibetan Plateau. This study focuses on providing a refined 5′×5′ Tibetan crust density distribution with seven layers based on global CRUST1.0, glacier model and digital elevation model (DEM), determining a regional 5′×5′ Tibetan geoid based on the shallow layer method (Shen 2006), the refined 5′×5′ Tibetan crust density distribution and EGM2008, and estimating the Moho depth of the Tibetan Plateau based on the 5′×5′ Tibetan geoid, EGM2008 and Airy-Heiskanen isostatic compensation hypothesis. This study is supported by NSFC (grant Nos. 41429401, 41174011, 41210006).

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Improving velocity models using surface waves for moment tensor of M~5.0 earthquakes at large distances (>300 km), examples from Brazil

F. Dias[1], *M. Assumpção*[1]
[1]*University of Sao Paulo, IAG, Sao Paulo, Brazil*

In some regions where there are few and moderate-size earthquakes, the moment tensor solution determination usually is difficult. It may happen because the events were not well recorded by stations or the azimuth gap is so large that event the first motion mechanism can be evaluated. We show an example of a 5.2 mb offshore event in 2007 recorded by four stations (between 300 km and 400 km) and a 4.8 mb event in Pantanal Basin in 2009 and the closest broadband station (BEB4B) was ~800 km from the earthquake. We measure the Rayleigh and Love surface waves dispersion in each station for both earthquakes to built a velocity model to perform the moment tensor inversion. The Moho depth and Vp/Vs was fixed from receiver function crust models.We perform the waveform inversion with ISOLA code using velocity model obtained from surface waves dispersion. The epicenter was fixed and we chose Deviatoric MT inversion for the three components of at frequency range 0.04,0.06 - 0.1,0.12 Hz for the Pantanal basin and 0.04,0.05-0.08,0.09 for the offshore event. We obtained a good fitting between real and synthetic seismograms and the P and S-waves arrival was marked in the seismograms showing that the adjusted waves were the surface waves for all stations in both earthquakes. The mechanism from waveform fitting with the mechanism from first-motion polarities are very similar with Kagan angle < 35. The inversion of a moderate earthquake at large distance using a few stations is very challenging. We showed a way to obtain a reasonable velocity model that helps to perform the inversion that may be useful in low seismicity regions.

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JA01p-158

Evaluation methods of geophysical data for deciphering the deep geological structure in Curvature Carpathians zone

L. ASIMOPOLOS[1], N.S. ASIMOPOLOS[2]
[1]GEOLOGICAL INSTITUTE OF ROMANIA, BUCHAREST, Romania
[2]GEOLOGICAL INSTITUTE OF ROMANIA, GEOPHYSICS, BUCHAREST, Romania

The data used in this work were obtained by extracting geophysical data, data files with more parameters, along of four geological sections, from the Curvature Carpathians zone.

Were also used additional data on the territory of Romania, with regional character, anomalies of the Geoid, Bouguer and Free Air from the website of Gravimetric Bureau International, in the modeling of deep geological structure.

Also, we have developed algorithms and related software programs for calculating of trend surfaces of higher order. These methods of analysis of trends we used for filtration of geophysical data in surface.

Analysis with polynomial trend surfaces, using the regression analysis that satisfy the criterion of least squares, for the gravity data, contributes to the recognition, isolation and measurement of trends that can be represented by surfaces, thus achieving a separation in regional variations and local variations. This separation is achieved by adjusting the trend function at different values.

The difference between the surface of trend and the observed value in a certain point is the residual value. The trend surface was considered as regional or large-scale and the residual value was regarded as local or small-scale component. Removing the regional trend had the effect of highlighting local components represented by residual values.

For integrated study the gravity data and geomagnetic data in relations with knowledge about geological structures, we examined several bibliographic sources about physical properties (magnetic susceptibility, density) for different types of formations. Based on these physical properties, we made 2D models about deep structures. These 2D models obtained, we compared them with sections obtained

by magnetotelluric and geomagnetic soundings.

Joint Inter-Association Symposium

JA02a - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

IUGG-1050

Space weather modelling for end users

D. Boteler[1], L. Trichtchenko[1], R. Pirjola[2], . Blais[1], P. Fernberg[1]
[1]Natural Resources Canada, Earth Sciences Sector, Ottawa, Canada
[2]Finnish Meteorological Institute, Finnish Meteorological Institute, Helsinki, Finland

Power system and pipeline operators need to know how geomagnetic disturbance will affect their system. This requires information presented in ways that are convenient to be used to assess the hazard to particular system and to be suitable for use as input to other models to examine impact on specific pieces of equipment (eg transformers) or the stability of the overall system.

Here we describe work that has been done to model geomagnetic induction in power systems and pipelines. On the geophysical side the modelling allows for spatial variability in the magnetic source fields and in the earth conductivity structure. Modelling details include the ability to show geomagnetically induced currents or voltages in specific parts of the system such as individual transformer or pipeline locations. The user has flexibility in choice of many features such as sampling rates, benchmark conditions for testing and the ability to change the system details to test mitigation strategies. The modelling also includes features to make it user friendly for power system and pipeline engineers, such as automatic retrieval of geomagnetic data and models, and input and output data formats consistent with industry practices.

The modelling can be used with archived data for analysis of past events, such as the March 1989 storm. Future work is intended to make these tools work in real time so they can be used to as part of space weather situational awareness systems. The modelling tools described could also be used as part of a modular system, being designed to work with predicted magnetic field information provided by a space weather forecast module, or providing data to an engineering module to examine the operational impact on a system.

Joint Inter-Association Symposium

JA02a - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

IUGG-1947

Reproducing Electric Field Observations during Magnetic Storms by means of Rigorous 3-D Modelling and Distortion Matrix Co-estimation

C. Püthe[1], *C. Manoj*[2], *A. Kuvshinov*[1]
[1]*ETH Zürich, Institute of Geophysics, Zürich, Switzerland*
[2]*University of Colorado, CIRES and NOAA's NGDC, Boulder, USA*

Electric fields induced in the conducting Earth during magnetic storms drive currents in power transmission grids, telecommunication lines or buried pipelines. These geomagnetically induced currents (GIC) can cause severe service disruptions. The prediction of GIC is thus of great importance for public and industry.

A key step in the prediction of the hazard to technological systems during magnetic storms is the calculation of the geoelectric field. To address this issue for mid-latitude regions, we developed a method that involves 3-D modelling of induction processes in a heterogeneous Earth and the construction of a model of the magnetospheric source from observatory magnetic data. Time series of the electric field can be computed for every location on Earth's surface.

The actual electric field however is known to be often distorted by galvanic effects, arising from very local near-surface heterogeneities or topography. Galvanic effects are commonly accounted for with a real-valued time-independent distortion matrix, which linearly relates measured and computed electric fields. Using data of various magnetic storms, we estimated distortion matrices for observatory sites onshore and on the ocean bottom. Strong correlations between modellings and measurements validate our method. We further show that 3-D modelling is crucial for a correct separation of galvanic and inductive effects and a precise prediction of electric field time series during magnetic storms.

Since the required computational resources are negligible, our approach is suitable for a real-time prediction of GIC. For this purpose, a reliable forecast of the source field, e.g. based on data from satellites analysing the solar wind, is necessary.

Joint Inter-Association Symposium

JA02a - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

IUGG-2246

Sensitivity of geomagnetically induced currents to varying auroral electrojet and conductivity models

C. Beggan[1]
[1]*British Geological Survey, Edinburgh, United Kingdom*

Geomagnetically induced currents (GIC) are created by the interaction of rapid changes in the magnitude of the magnetic field with the conductive subsurface of the Earth. The changing magnetic field induces electric currents, which are particularly strong along boundaries between regions of contrasting conductivity structure such as the land and sea. A technique known as the 'thin-sheet approximation' can be used to determine the electric field at the Earth's surface, which in turn allows the calculation of GIC in the earthing connections of high-voltage nodes within a power grid. The thinsheet approximation uses a spatially varying conductance over the region of interest on a 2D surface, combined with a 1D layered model of upper lithosphere conductance. We produce synthetic models of the auroral electrojet in different locations over the United Kingdom (UK) and investigate the effects of varying the 2D thin-sheet model. We assess different two-dimensional surface conductance models and vary the underlying 1D conductivity models to simulate the effects of resistant through to conductive lithosphere. With an advanced network model of high-voltage electrical distribution grid, we compute the expected GIC at each node in the system given the input surface electric fields from the various synthetic electrojets and conductivity models. We find that the electrojet location is the primary control on the size of GIC, with conductivity being a second-order effect in general, though it can be locally important.

Joint Inter-Association Symposium

JA02a - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

IUGG-3612

Observatory locations for ground based monitoring of space weather

E. Clarke[1], *L. Billingham*[1], *C. Beggan*[1]
[1]*British Geological Survey, Earth Hazards and Observatories, Edinburgh, United Kingdom*

Magnetic observatories and variometer stations are located, within certain constraints, to optimise the requirements of scientific research. However, a question that often arises is: what is the most favourable spatial distribution of observatories used operationally for ground based monitoring of space weather?

This is investigated from the perspective of two separate real time space weather applications: geomagnetic referencing for directional drilling - where the Earth's magnetic field is applied in well bore navigation and placement; and monitoring geomagnetically induced current (GIC) - where the observatory data may be used as a proxy for GIC in a power transmission network. For both, the ideal place for a magnetometer is at the location where the data are to be applied, especially at high geomagnetic latitudes. In reality that is rarely possible and the question becomes: what is the maximum distance beyond which the data are no longer useful for the application?

Data are selected from high geomagnetic latitude locations (60-75°) and a statistical analysis carried out to investigate the effect of distance on extrapolating the disturbance field in any direction. Pairs of observatories within 1000km of each other, with data overlapping by more than one year were chosen, providing ~3000 years of station pairs. The method to isolate the disturbance field and examine the errors is shown. The results are presented as a function of distance and geomagnetic latitude and, by including data over periods of more than 11 years, seasonal and solar cycle variations are also determined. The results are discussed in relation to how they can be applied in practice to aid directional drillers and power network operators.

Joint Inter-Association Symposium

JA02a - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

IUGG-4671

Near real-time geomagnetic maps of the continental United States

E.J. Rigler[1]*, A. Pulkkinen*[2]*, M. Wiltberger*[3]*, C. Balch*[4]
[1]*U.S. Geological Survey, Geomagnetism Program, Denver, USA*
[2]*NASA-GSFC, Space Weather Laboratory, Greenbelt, USA*
[3]*NCAR, High Altitude Observatory, Boulder, USA*
[4]*NOAA, Space Weather Prediction Center, Boulder, USA*

The use of geomagnetic data in space weather operations has historically been limited to near real-time measurements made at specific magnetic observatories, or to global magnetic indices (e.g., Kp, Dst, etc.). However, modern technological systems (e.g., electrical power grids, directional drilling platforms) increasingly require information about ground magnetic disturbance as a geographic distribution. Geospatial interpolation becomes a necessity, and given the sparseness of real-time operational magnetic observatories over the continental United States (CONUS), a physics-based magnetic data inversion approach was deemed most appropriate for a real-time operational map of geomagnetic activity. Combining resources, the U.S. Geological Survey, NASA, and NOAA have developed a new, geographically gridded magnetic activity map of CONUS for use in space weather operations. We present initial validation results, paying particular attention to the geospatial distributions of map uncertainty, and implications for space weather operations.

Joint Inter-Association Symposium

JA02a - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

IUGG-5578

Level crossings and complex bursts: a classic approach to a modern problem

N. Watkins[1], *S. Chapman*[2]
[1]*London School of Economics and Political Science, Centre for the Analysis of Time Series, London, United Kingdom*
[2]*University of Warwick, Centre for Fusion- Space and Astrophysics- Physics, Coventry, United Kingdom*

'Bursts' have been widely studied in models of intermittent dynamical systems such as self organised criticalityand turbulence, and in natural datasets such as the auroral electrojet (AE) ionospheric index. Much can be done by simulation, but is also desirable to have analytical approaches to bursts which permit handling time dependence and heavy tailed amplitudes, and make contact with mature mathematics such as the theory of random fields, and of level crossings in noise. We discuss some classic results in this area and demonstrate that they apply not only in the context in which they were originally applied but also in models of contemporary interest including the highly skewed (lognormal), heavy tailed (alpha-stable), and long range dependent (fractional Gaussian) cases, each of which captures a property important to natural hazards, including space weather.

In particular we study the surplus run length ratio [SRLR] formula, which states that the ensemble expectation value of the time between successive up and down-crossings of a threshold by values of stationary time series from a stochastic process is the empirical survival function of the process divided by the time rate of upcrossings at that level. It thus naturally separates time domain and amplitude domain effects, even for the ergodic long range correlated fractional Gaussian noise model. We also show a similar formula relating the integrated burst area to the SRLR and the mean excess function, which holds not just for the high thresholds to which the mean excess is usually applied, but at arbitrary ones. As well the space weather problem of the non-Gaussian, correlated, AE dataset we briefly discuss economic applications such as the debate between value at risk and other competing measures.

Joint Inter-Association Symposium

JA02b - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

IUGG-0654

The analysis of long-term trends of drag effect on model LEO satellites due to upper atmospheric influence by solar/geomagnetic activity

V.U.J. Nwankwo[1], *S. Chakrabarti*[2]
[1]*S. N. Bose National Centre for Basic Sciences, Kolkata, India*
[2]*S. N. Bose National Centre for Basic Sciences, Astrophysics and Cosmology, Kolkata, India*

Solar and geomagnetic energetic events and their effects on the interplanetary space environment are characterized by various parameters, such as, solar radio flux (F10.7), geomagnetic Ap and disturbance storm time (Dst) indices. These events heat the upper atmosphere and modify its density distribution. Thus, the known atmospheric drag effect on LEO Satellites increases. In this paper, we computed and/or estimated atmospheric drag effect on the trajectory of a hypothetical LEO satellite as a function of day to day variation of solar parameters due to solar and geomagnetic activity at different phases of the solar cycle. Using present forecast on the strength of current solar maximum, we also estimate orbital decay of the satellite in the coming months. Considering up to five-year analysis, we estimated the decay rate of a typical LEO satellite initially at h=450-480 km during solar maximum and solar minimum conditions, and around the peak of current/ongoing solar maximum in 2012-2014. We also presented (in brief) observations from analysed data relating to the influence of solar and geomagnetic energetic events on the upper atmosphere.

Joint Inter-Association Symposium

JA02b - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

IUGG-1252

An extreme coronal mass ejection and consequences for the Magnetosphere and Earth

B. Tsurutani[1], *G. Lakhina*[2]
[1] *Jet Propulsion Laboratory, Astrophysics and Space Physics, Pasadena, USA*
[2] *Indian Institute for Geomagnetism, Space Physics, Navi Mumbai, India*

A "perfect" ICME could create a magnetic storm with intensity up to the saturation limit (Dst ~ -2500 nT), a value greater than the Carrington storm. Many of the other space weather effects will not be limited by saturation effects, however. The interplanetary shock would arrive at Earth within ~12 hrs with a magnetosonic Mach number ~45. The shock impingement onto the magnetosphere will create a SI^+ of ~234 nT, the magnetic pulse duration in the magnetosphere will be ~22 s with a dB/dt of ~30 nT s^{-1}, and the magnetospheric electric field associated with the dB/dt ~1.9 V m^{-1}, creating a new relativistic electron radiation belt. The magnetopause location of 4 R_e from the Earth's surface will allow expose of orbiting satellites to extreme levels of flare and ICME shock-accelerated particle radiation. The results of our calculations are compared with current observational records. Comments are made concerning further data analysis and numerical modeling needed for the field of space weather.

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JA02b - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

IUGG-1730

Progress in the development of operational space weather forecasts at the Met Office

D. Jackson[1]
[1]*Met Office, Exeter, United Kingdom*

The Met Office (the national meteorological service for the United Kingdom) has a growing role in space weather forecasting, underlined by the official launch of the Met Office Space Weather Operations Centre (MOSWOC) in October 2014. MOSWOC operates 24/7, producing space weather alerts and advice to a range of customers. In this presentation, typical daily operations and services will be described, together with the models used to produce the forecasts and nowcasts on which these services are based.

The long-term goal of Met Office research and development is to develop data-driven forecast models covering the whole Sun to Earth domain, for enhanced forecast capability. This work is outlined, with specific focus on improved representations of the coupling between the coronal magnetic field and the heliosphere and between the Earth's lower and middle atmosphere and its thermosphere and ionosphere. Near-real time validation of these models is vital to ensure the ongoing development of operational forecast models, and progress in this area will also be summarised.

Joint Inter-Association Symposium

JA02b - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

IUGG-3929

Analysis of parameters of coronal mass ejections available in near real-time for operational space weather forecasting

G. Kelly[1]
[1]*British Geological Survey, Geomagnetism Team, Edinburgh, United Kingdom*

Forecasts of geomagnetic activity are vital for helping to protect vulnerable technological infrastructure. However, we have relatively little data with which to make a decision about the level of expected activity. Whilst advances in modelling techniques (for example, the WSA-ENLIL model) and increases in data availability are helping, there is still a knowledge gap and forecasts still depend heavily on the judgement of the forecaster. The aim of this work is to help forecasters put coronal mass ejections (CMEs) into context, based on past events, in a straightforward manner.

We have analysed CMEs during 12 years from Jan 1998 to Dec 2009, focusing on the data available at the time for forecasting. CMEs which were identified as having a potential to impact the Earth are then assessed and correlated with any resulting geomagnetic activity. Here we present statistics of Earth-directed CMEs and their likelihood to cause geomagnetic storms based on near-real time data. We review parameters including CME velocity, source location and associated flares and filament eruptions, and compare our results with other related studies.

Joint Inter-Association Symposium

JA02p - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

JA02p-159

Testing the global magnetohydrodynamic models against the empirical statistical relationships

E. Gordeev[1], V. Sergeev[1], M. Kuznetsova[2], L. Rasatetter[2], A. Pembroke[2], I. Honkonen[2,3], A. Chulaki[2], A.M. Mendoza[2], M. Palmroth[3]
[1]Saint Petersburg State University, Physics of Earth, Saint-Petersburg, Russia
[2]NASA Goddard Space Flight Center, CCMC, Greenbelt- Maryland, USA
[3]Finnish Meteorological Institute, Space Physics, Helsinki, Finland

Global MHD modeling is the powerful tool in space physics research and the only approach that enables to simulate dynamics of the entire magnetospheric system under the varying solar wind conditions. There exist several advanced and still developing global MHD codes that are used widely to simulate magnetospheric dynamics and investigate different aspects of solar wind-magnetosphere-ionosphere interaction. Despite the previous efforts, the problem of validation and objective benchmarking of existing global MHD models still remain important but difficult problem. Using four models that are now supported at NASA Community Coordinated Modeling Center - BATSRUS, GUMICS, LFM and Open GGCM - we demonstrate an approach for systematic and quantitative testing of code performance. This approach is based on statistical comparison of simulation results with known empirical dependences of the key magnetospheric parameters obtained from real observations. As the key parameters we use the principal large-scale characteristics of the magnetospheric state including magnetopause size and shape, geometry of the tail neutral sheet, magnetotail plasma pressure, tail lobe magnetic field, cross-polar cap electric potential. Testing results of MHD models against predictions of empirical models, we can identify quantitatively the merits and shortcomings of the global MHD codes for slow large-scale magnetospheric processes in statistical sense. In order to obtain a good statistics we performed a set of simulations with the wide range of solar wind input conditions.

Joint Inter-Association Symposium

JA02p - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

JA02p-160

Regional estimation of geomagnetically induced currents based on the local magnetic or electric field

A. Viljanen[1]*, P. Wintoft*[2]*, M. Wik*[2]
[1]*Finnish Meteorological Institute, Helsinki, Finland*
[2]*Swedish Institute of Space Physics, IRF Lund, Lund, Sweden*

Time-varying ionospheric and magnetospheric currents produce geomagnetically induced currents (GIC) in power grids, pipelines and other technological conductor systems, and can thus affect the normal operation of these systems. Previous studies have demonstrated a close relationship between the time derivative of the horizontal geomagnetic field vector (d**H**/dt) and GIC at a nearby location in a power grid. Similarly, a high correlation exists between GIC and the local geoelectric field (E), typically modelled from a measured magnetic field and assuming locally 1-dimensional ground conductivity models.

When trying to forecast GIC, it is not feasible to assume a precise prediction of a time-series. Instead, other measures summarising the activity level over a given period are obviously preferable. In this presentation, we consider the 30-min maximum of dH/dt or E as a local activity indicator (dH/dt_30 or E_30). Concerning GIC, we use the sum of currents through the neutral leads at substations in a given power grid, and apply its 30-min maximum as a regional activity measure (GIC_30).

We show that dH/dt_30 at a single point yields a proxy for GIC activity in a larger region. A practical consequence is that if dH/dt_30 can be predicted at some point then it is also possible to assess the expected GIC level in the surrounding area. As is also demonstrated, E_30 and GIC_30 depend linearly on dH/dt_30, so there is no saturation with increasing geomagnetic activity contrary to often used activity indices.

Joint Inter-Association Symposium

JA02p - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

JA02p-161

Importance of Earth resistivity and power network status in modelling geomagnetically induced currents

J.M. Torta[1], S. Marsal[1], A. Marcuello[2], P. Queralt[2], J. Ledo[2]
[1]Observatori de l'Ebre- OE CSIC, Univ. Ramon Llull, Roquettes, Spain
[2]Universitat de Barcelona, Institut Geomodels. Dept. Geodinàmica i Geofísica, Barcelona, Spain

Through an assessment of the hazard from GIC to the power network in Spain, we analyze the importance of the Earth resistivity model used to provide estimates of the expected GIC. In the absence of the 2D or 3D specific information, we have employed 1D model calculations, i.e. a series of horizontal layers of different resistivity based on the sparse published magnetotellurics survey results; on the grounds that assessing the vulnerability of a system usually does not require knowledge of the precise values of predicted GIC. None of the proposed 1D structures performs substantially better than modelling the Earth as a uniform half-space, suggesting that the actual structure must be laterally heterogeneous, especially because the contrast is large at ocean-land interfaces. Though at mid-latitude regions the source field is rather uniform and the effect of its spatial changes might be of less importance, this has also been investigated by interpolating the field from the records of several geomagnetic observatories with the technique of spherical elementary current systems. A critical fact is the difficulty of obtaining detailed network parameters in the precise instant of a geomagnetic storm and determining the topology of the network for a given amplitude of the incident field. The switching off of a key transmission line or transformer can be essential to boost significant currents through the remaining elements. In addition, we have performed measurements of the surface impedance in the vicinity of one of the transformers where we have GIC measurements. This allows assessing the reliability of both the information about the network topology and resistances, and the assumptions made when all the details or the network status are not available

Joint Inter-Association Symposium

JA02p - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

JA02p-162

A COSPAR/ILWS roadmap towards advanced space weather science to protect society's technological infrastructure

H. Opgenoorth[1], *C. Schrijver*[2], *K. Kauristie*[3],
. COSPAR and ILWS Roadmap Team[4]
[1]*Swedish Institute of Space Physics, Uppsala Division, Uppsala, Sweden*
[2]*Lockheed Martin, Solar and Astrophysics Laboratory, Palo Alto, USA*
[3]*Finnish Meteorological Institute, Arctic Research, Helsinki, Finland*
[4]*Several Institutes, Several Departments, Several Cities, Finland*

As mankind's technological capabilities grow, society constructs a rapidly deepening insight into the workings of the universe at large, being guided by exploring space near to our home. But at the same time our societal dependence on technology increases and with that comes a growing appreciation of the challenges presented by the phenomena that occur in that space around our home planet. The complexity of the coupled Sun-Earth system, the sparseness by which it can be covered by remote-sensing and in-situ instrumentation, and the costs of the required observational and computational infrastructure warrant a well-planned and well-coordinated approach with cost-efficient solutions. COSPAR and the International Living With a Star program tasked an international team with the development of a roadmap with the goal of demonstrably improving our observational capabilities, scientific understanding, and the ability to forecast. With the team near to its final report, the presentation summarizes its prioritized recommendations to achieve these goals and the underlying rationale. The team's website (with its membership) is at http://www.lmsal.com/~schryver/COSPARrm.

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JA02p-163

Application of space radiation environment information to operations of spacecraft and manned space mission in Japan Aerospace Exploration Agency

H. Koshiishi[1]
[1]*Japan Aerospace Exploration Agency, Tsukuba, Japan*

Information on space radiation environment for safety of spacecraft and manned space mission has been gathered and analyzed by the space environment group in the Japan Aerospace Exploration Agency (JAXA) since 1987. Several instruments for in-situ measurements of space radiation environment have been developed and installed to Japanese satellites, Space Shuttle flights, and International Space Station, which are particle detector for electrons, protons, heavy ions, and neutrons, magnetometer, dosimeter, single event monitor, and potential monitor for electrostatic charge and discharge. Information obtained from these instruments has been gathered into the Space Environment and Effects System (SEES) in the JAXA as well as other information obtained from other spacecrafts and ground-based equipments. The SEES has several functions by using these data as follows; (1) to inform real-time information on space radiation environment for operators of spacecraft and manned space mission, (2) to alert space radiation hazard for those operators in case of solar flares, coronal mass ejections, and geomagnetic storms and sub-storms, (3) to provide usual space radiation environment models such as solar, interplanetary, geo-magnetospheric, and cosmic-ray activities for engineers, (4) to analyze the gathered data with international scientific researchers for understanding of solar-terrestrial physics as well as for development of more precise space radiation environment models for future space missions.

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JA02p - JA02 Modelling of Space Weather Effects: Solar, Magnetospheric and Earth Resistivity Constraints (IAGA, IAMAS)

JA02p-164

Compilation of 3-D global conductivity model of the Earth for space weather applications

D. Alekseev[1], *A. Kuvshinov*[2], *N. Palshin*[3]
[1]*Nord-West Ltd, Nord-West Ltd, Moscow, Russia*
[2]*Institute of Geophysics, ETH Zurich, Zurich, Switzerland*
[3]*Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia*

We have compiled a global 3-D conductivity model of the Earth with a primary goal to be used for realistic simulation of geomagnetically induced currents (GIC). GICs are generated by magnetospheric substorms (occurred in high latitudes) and geomagnetic storms (occurred in mid-to-low latitudes), and pose a potential threat for man-made electric and electronic systems, such as power electric grids and communication lines. Though precise simulation and prediction of GICs within any particular area or power grid requires high-detailed regional conductivity grids, the initial problem of recovering of ionospheric source distribution is of global scale and therefore at this step there is a need for a global 3-D conductivity model. Bearing in mind the frequency range of the most intense high-latitude geomagnetic disturbances (a few minutes to a few hours), the 3-D model represents the structure in depth range of 0-100 km and thus covers seawater, sediments, earth crust, and partly lithosphere/asthenosphere. More explicitly the model consists of a series of quasi-spherical layers, whose vertical and lateral boundaries have been specified based on available data, including global maps of bathymetry, sediment thickness, upper and lower crust thicknesses as well as lithosphere thickness. This a priori model constructed from non-EM data, was then refined by incorporating the surface conductance model of Russia, as well as conductivity models of Fennoscandia, Australia and South-West of the United States. Moreover, a numerical formalism which was developed for compilation of the model allows for its further refining by assimilation of regional 3-D conductivity distributions inferred from the actual EM data.

Joint Inter-Association Symposium

JA04a - JA4 Results from SWARM, Ground Based Data and Earlier Satellite Missions - Recognition of Eigil Friis-Christensen (IAGA, IAG, IAMAS)

IUGG-0289

Swarm, one year of operations: data quality and instrument status update

G. Ottavianelli[1], I. Coco[1], I. Di Lodovico[1], R. Floberghagen[1], P. Vogel[2], R. Mecozzi[2], C. Siemes[2]
[1]European Space Agency, ESRIN, Frascati, Italy
[2]European Space Agency, ESTEC, Noordwijk, Netherlands

Swarm is a three-satellite ESA Earth Explorer mission with the key objectives of studying the geomagnetic field with unprecedented accuracy and the electrodynamics of the Earth's ionosphere. The three spacecraft have been launched in November 2013 and following the commissioning phase, they reach one year of operations in April 2015. This presentation provides an update on the L1b data processors, the products quality and the instruments status. It also presents an outlook of the upcoming activities with regards to mission operations.

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JA04a - JA4 Results from SWARM, Ground Based Data and Earlier Satellite Missions - Recognition of Eigil Friis-Christensen (IAGA, IAG, IAMAS)

IUGG-1299

A preliminary model of the electrical conductivity of the Earth's mantle from the Swarm mission

J. Velimsky[1]
[1]*Charles University in Prague- Faculty of Mathematics and Physics, Department of Geophysics, Prague 8, Czech Republic*

A time-domain approach to the global inversion of observatory and satellite data in terms of 3-D electrical conductivity structure of the mantle has been developed in the preparation of the L2 products for the Swarm mission (Velímský 2013). This approach relies on the separation of individual contributions to the total geomagnetic field by means of comprehensive modeling (Sabaka et al. 2013), and inversion of the series of spherical harmonic coefficients of magnetospheric fields and their induced counterparts by regularized quasi-Newton minimization of data misfit. The initial results based on the inversion of first 1.5 years of data will be presented.

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IUGG-1429

Precise orbit determination and neutral density retrieval for the Swarm satellites

J. van den IJssel[1], J. Teixeira da Encarnacao[1], E. Doornbos[1], P. Visser[1]
[1]Delft University of Technology, Faculty of Aerospace Engineering, Delft, Netherlands

The Swarm satellites have as their primary mission the observation of Earth's magnetic field. They are equipped with GPS receivers and accelerometers for precise orbit determination and the study of thermospheric neutral densities. Within the Swarm ESL consortium, TU Delft is in charge of providing the L2 products associated with these instruments.To precisely geolocate the Swarm observations, each Swarm satellite is equipped with an 8-channel, dual-frequency GPS receiver. For more than one year of Swarm GPS data, both reduced-dynamic and kinematic Precise Science Orbits have been computed for all three Swarm satellites. Validation of the reduced-dynamic orbits with independent satellite laser ranging data confirms that the location of each of the three satellites is known to within a few cm. Orbit comparisons indicate that the quality of the kinematic orbits is at the 10 cm level.

Regarding the accelerometer data, the efforts at TU Delft have focused so far mainly on the analysis of strategies to remove unwanted signals from the data. These signals include a large dependency on temperature variations and artifacts like steps and spikes. These unwanted signals are much less prevalent in the data from Swarm C, compared to the other two satellites. For Swarm C, it is much easier to identify acceleration variations associated with density changes with orbital height and density fluctuations during geomagnetic storms, as well as radiation pressure jumps at eclipse transitions. In order to retrieve the valuable high-frequency information from these data, the measurements have successfully been combined with the acceleration information derived from GPS tracking data, to produce a preliminary data set of calibrated non-gravitational accelerations.

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IUGG-3215

A lithospheric magnetic field model derived from the Swarm satellite measurements

E. Thebault[1]*, P. Vigneron*[2]*, S. Maus*[3]*, A. Chulliat*[4]*, O. Sirol*[2]*, G. Hulot*[2]
[1]*Université de Nantes, Laboratoire de Planétologie et de Géodynamique, Nantes, France*
[2]*Institut de Physique du Globe de Paris- Sorbonne Paris Cité- Univ Paris Diderot, Equipe de Géomagnétisme, Paris, France*
[3]*University of Colorado, Geomagnetism, Boulder, USA*
[4]*University of Colorado, NOAA/NGDC and the Cooperative Institute for Research in Environmental Science s, Boulder, USA*

The Swarm constellation of satellites was launched in November 2013 and has since then delivered high quality scalar and vector magnetic field measurements. A consortium of several research institutions was selected by the European Space Agency (ESA) to provide a number of scientific products which will be made available to the scientific community. Within this framework, specific tools were tailor-made to better extract the magnetic signal emanating from Earth's the lithospheric. These tools rely on the scalar gradient measured by the lower pair of Swarm satellites and rely on a regional modeling scheme that is more sensitive to small spatial scales and weak signals than the standard spherical harmonic modeling. In this presentation, we report on various activities related to data analysis and processing. We assess the efficiency of this dedicated chain for modeling the lithospheric magnetic field using more than one year of measurements, and finally discuss refinements that are continuously implemented in order to further improve the robustness and the spatial resolution of the lithospheric field model.

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IUGG-4097

First results from the Swarm SCARF Dedicated Ionospheric Field Inversion chain

A. Chulliat[1], *P. Vigneron*[2], *E. Thebault*[3], *O. Sirol*[2], *G. Hulot*[2]
[1]*University of Colorado and NOAA/NGDC,*
Cooperative Institute for Research in Environmental Sciences, Boulder CO, USA
[2]*Institut de Physique du Globe de Paris, Geomagnetism, Paris, France*
[3]*University of Nantes, Laboratoire de Planétologie et Géodynamique, Nantes, France*

ESA's Swarm satellite mission was successfully launched on November 23, 2014. It is comprised of three satellites: a lower-orbit pair at around 460 km altitude and a third satellite at around 510 km altitude in a different orbital plane. More than one year of high-quality geomagnetic data from Swarm are now available, making it possible to use the Dedicated Ionospheric Field Inversion (DIFI) chain developed as part of the Swarm Satellite Constellation Application and Research Facility (SCARF) before the launch. This algorithm calculates global, spherical harmonic models of the geomagnetic Sq field generated by electrical currents flowing in the ionospheric E-layer at mid- to low-latitudes. It separates the primary and induced parts of the Sq field using 3-D models of the mantle electrical conductivity and takes into account seasonal variations as well as variations with solar activity. First results of the DIFI algorithm will be presented, including a preliminary Sq field model based upon one year of Swarm data. Results will be validated against independent observatory data and compared to Sq field models derived from previous magnetic satellite missions.

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JA04a - JA4 Results from SWARM, Ground Based Data and Earlier Satellite Missions - Recognition of Eigil Friis-Christensen (IAGA, IAG, IAMAS)

IUGG-4186

Swarm satellite constellation mission: From data to first scientific results

N. Olsen[1], *G. Hulot*[2], *A. Kuvshinov*[3], *C. Stolle*[4], *A. Thomson*[5], *P. Visser*[6], *S. Buchert*[7], *T. Jager*[8], *D. Knudsen*[9], *R. Peresty*[10]
[1]*Technical University of Denmark, DTU Space - National Space Institute, Kngs Lyngby, Denmark*
[2]*Institut de Physique du Globe de Paris, Geomagnetisme Group, Paris, France*
[3]*ETH, Earth and Planetary Magnetism Group, Zurich, Switzerland*
[4]*GeoForschungsZentrum Potsdam, Earth's Magnetic Field, Potsdam, Germany*
[5]*British Geological Survey, Geomagnetism Team, Edinburgh, United Kingdom*
[6]*Delft University of Technology, Astrodynamics and Space Missions, Delft, Netherlands*
[7]*Swedish Institute of Space Physics, Space Plasma Physics Group, Uppsala, Sweden*
[8]*CEA- LETI, MINATEC Campus, Grenoble, France*
[9]*University of Calgary, Physics and Astronomy, Calgary, Canada*
[10]*Aeronautical Research and Test Institute VZLU, Space Technology, Prague, Czech Republic*

Swarm is a three-satellite ESA Earth Explorer mission with the key objectives of studying the Earth’s magnetic field and its interaction with the environment. Launched in November 2013, the three spacecraft have provided more than one year of high quality data.

This presentation discusses some of the scientific highlights that have been obtained using Swarm data. These advances include the update of high precision models of the recent Earth magnetic field as well as new investigations of the near-Earth environment. It also presents new developments in Swarm scientific data processing.

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JA04b - JA4 Results from SWARM, Ground Based Data and Earlier Satellite Missions - Recognition of Eigil Friis-Christensen (IAGA, IAG, IAMAS)

IUGG-1110

Field-aligned current distribution deduced from Swarm dual-satellite observations

H. Lühr[1]*, G. Kervalishvili*[2]*, J. Rauberg*[2]*, I. Michaelis*[2]*, J. Merayo*[3]*, P. Brauer*[3]
[1]*GFZ- German Research Centre for Geosciences, Potsdam, Germany*
[2]*GFZ- German Research Centre for Geosciences, Earth's Magnetic Field, Potsdam, Germany*
[3]*Technical University of Denmark, National Space Institute, Lyngby, Denmark*

ESA's Earth Observation Mission Swarm was launched on 22 November 2013. Two of the three satellites are flying at about 460 km altitude side-by-side separated only by 1.4° in longitude. The third spacecraft is cruising at about 520 km. The satellite pair at lower altitude allows for the first time the unique determination of field-aligned currents (FAC) in the ionosphere. Here we present the processing technique and then show initial results of the first 7 months. In a statistical sense all the known features of FACs, Regions 0, 1, 2, can be recognised clearly. Also seasonal differences between the hemispheres are well reflected. We performed comparisons between traditional, single-satellite FAC determinations with the advanced dual-satellite FAC results. In general the fit between the two profiles is very good at auroral latitudes. Only if the FAC sheet is moving or is strongly tilted with respect to the satellite track, significant differences occur. The situation is different within the polar cap. Here we find markedly stronger FAC densities with the dual-spacecraft technique, in particular in the evening to midnight sector. We suggest that these newly observed FAC sheets are related to theta auroras. Comparisons with auroral observations are required for confirming that.

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JA04b - JA4 Results from SWARM, Ground Based Data and Earlier Satellite Missions - Recognition of Eigil Friis-Christensen (IAGA, IAG, IAMAS)

IUGG-1541

On the Importance of SWARM measurements for space weather

M. Codrescu[1], *M. Fedrizzi*[2], *T. Fuller-Rowell*[2]
[1]*Space Weather Prediction Center, Boulder, USA*
[2]*University of Colorado, CIRES and SWPC, Boulder, USA*

The reliance of modern society on technologies that are sensitive to space weather disturbances continues to increase. New systems being designed today require more and more accurate specification of the space environment in order to fulfill their missions. In particular, knowledge of neutral mass density has become critical for collision avoidance, vehicle reentry, and space debris tracking. The size and complexity of the thermosphere-ionosphere system though, make it impossible to measure all relevant parameters that are necessary for accurate specification and forecast of space weather. However, any available measurements can be used in data assimilation schemes to constrain the results of numerical models and improve space weather nowcasting and forecasting. Simulations using the Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics (CTIPe) model will be used to demonstrate the usefulness of SWARM accelerometer measurements for correcting seasonal biases in thermosphere total mass density. At this time, a couple of weeks of total mass density measurements in near real time is the only known solution to correct the models' seasonal bias. The possible use of the SWARM Electrical Field Instrument, magnetic field, and GPS measurements for space weather will also be discussed.

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IUGG-2661

Comparing Swarm electron density data using COSMIC GPS radio occultation observations

N. Pedatella[1], *C. Stolle*[2], *J. Chau*[3]
[1]*University Corporation for Atmospheric Research, COSMIC, Boulder, USA*
[2]*Helmholtz Centre Potsdam German Research Centre for Geosciences GFZ, Earth Magnetic Field, Potsdam, Germany*
[3]*Leibniz Institute of Atmospheric Physics at the Rostock University, Radar Soundings and Sounding Rockets, Kuhlungsborn, Germany*

In an effort to validate the Swarm Langmuir probe electron density measurements, we have compared the Swarm observations with the Global Positioning System (GPS) radio occultation (RO) electron density observations from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC). The primary advantage of this approach is that it permits a more global validation of the Swarm observations then comparisons against ground-based facilities. The validity of our approach is first established by comparing the COSMIC GPS RO observations with in-situ observations from the CHallenging Minisatellite Payload (CHAMP) and Communications/Navigation Outage Forecasting System (C/NOFS) satellites. This comparison demonstrates that the COSMIC GPS RO observations are unbiased and are well-suited for validating in-situ satellite observations in the F-region and topside ionosphere. The Swarm in-situ electron density observations are compared directly with COSMIC GPS RO electron density observations that occur within 2 degrees latitude and longitude and 15 minutes universal time of the Swarm measurements. This restriction ensures that the Swarm and COSMIC observations are sampling the same region of the ionosphere at the same time, reducing the influence of any spatial or temporal ionospheric variability on the results. Based on this comparison, along with comparison of the Swarm electron densities with ground-based observations, we are able to establish the overall quality and accuracy of the Swarm electron density observations at all latitudes and local times.

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IUGG-3517

Swarm satellite and EISCAT radar observations of evening sector aurora

A. Aikio[1], *H. Vanhamäki*[1], *S. Buchert*[2], *K. Kauristie*[3], *C. Stolle*[4], *D. Knudsen*[5]
[1]*University of Oulu, Astronomy and Space Physics, Oulu, Finland*
[2]*Swedish Institute of Space Physics, IRF-U, Uppsala, Sweden*
[3]*Finnish Meteorological Institute, Arctic Research, Helsinki, Finland*
[4]*GFZ, -Potsdam, Potsdam, Germany*
[5]*University of Calgary, Physics and Astronomy, Calgary, Canada*

During 20 November 2014 Swarm A and C satellites passed over the evening side auroral oval during 16:23-16:28 UT and made a very close conjunction with the Tromso EISCAT UHF and VHF radars (67° cgmLat) that were making measurements in the field-aligned and vertical directions, respectively. In addition, the EISCAT Svalbard radar provided measurements from the polar cap. Swarm B passed over the same region 80 min later. The mainland radars show indication of electron precipitation in the E and lower F regions as well as and increases in electron and ion temperatures. The Langmuir probes at Swarm s/c show strong variations in electron temperature and electron density as they cross the auroral oval. Since the EISCAT radar measurements reach locally the Swarm satellite altitudes, this event provides an excellent possibility for detailed comparison. In addition, we will study the field-aligned current distribution associated with the auroral structures by using measurements from the vector magnetic field instrument onboard Swarm, ground-based optical data provided by all-sky cameras, and the radar data. Finally, the IMAGE magnetometers show a clear region of eastward electrojet and we will compare the boundaries of the electrojet current region to characteristic signatures in the Swarm data, including electric field information from Swarm A.

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IUGG-3792

Monitoring the plasmapause by SWARM

B. Heilig[1], *H. Lühr*[2], *M. Vellante*[3], *J. Reda*[4], *J. Lichtenberger*[5], *W. Kurth*[6], *F. Darrouzet*[7]
[1]*Geological and Geophysical Institute of Hungary, Earth Physics Dept., Tihany, Hungary*
[2]*GFZ German Research Centre for Geosciences, Earth's Magnetic Field, Potsdam, Germany*
[3]*University of L'Aquila, Physical and Chemical Sciences, L'Aquila, Italy*
[4]*Institute of Geophysics- PAS, Belsk Geophysical Observatory, Belsk, Poland*
[5]*Eötvös University, Geophysics and Space Science, Budapest, Hungary*
[6]*University of Iowa, Physics and Astronomy, Iowa City, USA*
[7]*Belgian Institute for Space Aeronomy, Space Science, Brussels, Belgium*

Recently a new method for monitoring the plasmapause location in the equatorial plane was introduced based on magnetic field observations made by the CHAMP satellite in the topside ionosphere (Heilig and Lühr, 2013). Related signals are small-scale field-aligned currents (some 10km scale size). The method is planned to be applied to the SWARM constellation. The signals related to the plasmapause on the dayside often appear mixed with other phenomena (e.g. ULF waves). Now making use of the special constellation of SWARM we will be able to discriminate temporal and spatial variations and detect the dayside plasmapause more clearly.

We plan to build an empirical plasmapause model, similar to the CHAMP-based model (Heilig and Lühr, 2013). The model will be validated by means of ground (EMMA magnetometer network) plasmapause observations, as well as by the in-situ plasma observations of the Van Allen Probes.

Heilig, B., and H. Lühr (2013) New plasmapause model derived from CHAMP field-aligned current signatures, Ann. Geophys., 31, 529-539, doi:10.5194/angeo-31-529-2013

Joint Inter-Association Symposium

JA04b - JA4 Results from SWARM, Ground Based Data and Earlier Satellite Missions - Recognition of Eigil Friis-Christensen (IAGA, IAG, IAMAS)

IUGG-4835

The swarm electric field instruments: Status and science

D. Knudsen[1], *J. Burchill*[1], *W. Archer*[1], *M. Patrick*[1], *S. Buchert*[2], *E. Donovan*[1]
[1]*University of Calgary, Physics and Astronomy, Calgary, Canada*
[2]*Swedish Institute of Space Physics, Uppsala, Uppsala, Sweden*

The Swarm Electric Field Instruments derive electric fields from plasma observations that include ion drift velocity and temperature measured by a pair of thermal ion imager (TII) sensors; and plasma density, electron temperature and spacecraft potential measured by a pair of Langmuir probes (LPs). LP data products are available nearly continuously since commissioning; the TII data are also available but with gaps while the operation of this new type of sensor is adapted to the ionospheric environment. This talk will provide an overview of the EFI operation and initial scientific results in areas that include fast flow channels, ion heating, ion upflow, and auroral and high-latitude electrodynamics.

Joint Inter-Association Symposium

JA04c - JA4 Results from SWARM, Ground Based Data and Earlier Satellite Missions - Recognition of Eigil Friis-Christensen (IAGA, IAG, IAMAS)

IUGG-1889

On the relevance of levelling magnetic data for studying ionospheric currents

C. Stolle[1,2], *I. Michaelis*[1], *J. Rauberg*[1], *J. Matzka*[1,3]
[1]*Helmholtz Centre Potsdam German Research Centre for Geosciences GFZ, 2.3 "Earth Magnetic Field", Potsdam, Germany*
[2]*University of Potsdam, Faculty of Science, Potsdam, Germany*
[3]*Adolf Schmidt Observatory, Geomagnetic Observatory, Niemegk, Germany*

Observations of the Earth’s magnetic field are an excellent tool for remote sensing ionospheric currents. Especially with the advent of the high precision magnetic Swarm satellite constellation mission new opportunities arise for investigating the upper atmosphere.

However, for a reliable analysis of the magnetic field sources in the ionosphere, field contributions from other sources have to be estimated and removed from the data. These sources are the Earth’s core and lithosphere as well as large-scale currents in the magnetosphere. These non-ionospheric contributions can be predicted from geomagnetic field models. One such standard model is the International Geomagnetic Reference Field (IGRF) that covers contributions from the Earth’s core field. Some more advanced, high-precision magnetic field models provide also a description of the lithospheric and magnetospheric contributions.

In this work, we compare and evaluate different strategies for isolating the residuals, i.e. the ionospheric magnetic field signal, for different ionospheric current systems, for different latitudes and local times, during both geomagnetically disturbed and quiet magnetic conditions. The strategies we investigated are: (1) removal of IGRF predictions, (2) removal of high-precision magnetic field models vs. (3) simple detrending. We will present examples and statistical analyses of magnetic residuals of high-precision magnetic field observations onboard LEO-satellites and ground observatory data.

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IUGG-2003

Small scale field-aligned currents generated by acoustic gravity waves commonly observed by SWARM

T. Iyemori[1], K. Nakanishi[2], T. Aoyama[2], H. Luehr[3]
[1]Graduate School of Science- Kyoto University,
World Data Center for Geomagnetism- Kyoto, Kyoto, Japan
[2]Graduate School of Science- Kyoto University, Department of Geophysics, Kyoto, Japan
[3]German Research Centre for Geosciences, Helmholtz Centre Potsdam, Potsdam, Germany

By using the data obtained during the initial one month when the SWARM satellites were flying on almost the same orbit with gradually increasing separation among the satellites, we could confirm that the small magnetic fluctuations with apparent period about 10-30 seconds along the orbit observed in middle and low latitudes are the manifestation of small spatial scale (50-250km) field-aligned currents. We estimated the temporal scale of variation of the field-aligned currents to be roughly 200 – 350 seconds or less. That is, the source of the current is suggested to be the acoustic mode atmospheric waves. In this paper, we show the evidence of the above results and compare the magnetic data with meteorological satellite data and with ground magnetic and micro-barometric observations.

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IUGG-2317

A perspective on geomagnetic research and discovery

R. Clauer[1]
[1]*Virginia Tech, Electrical and Computer Engineering, Newport News, USA*

Now is an interesting time to be investigating the geomagnetic field. The Earth's magnetic dipole is taking flight. The northern magnetic pole is moving at a rate not previously seen and the field strength is decreasing. In addition, our understanding of the interaction of the solar wind with the Earth's magnetic field is now described in mathematical frameworks that can enable complex numerical simulations using powerful computers. However, the basis of this progress and knowledge resides upon careful measurements of the geomagnetic field and the variations of that field. The Danish magnetic variometer chains in Greenland, the first Danish satellite Oersted, devoted entirely to geomagnetism, and now the SWARM satellites have, and are, making substantial contributions to the measurement and understanding of the dynamic geomagnetic field. This scientific session devoted to the science being accomplished by the Swarm satellite constellation is being dedicated to Dr. Eigil Friis-Christensen who has played a major role in the study of geomagnetism. He has both personally accomplished fundamental scientific discovery and understanding, and through his leadership, he has enabled others to accomplish together more than they could accomplish individually alone. In the Danish Satellite missions, for example, he has brought together the communities that study the internal magnetic field and the external magnetic field variations. Such collaborations are leading to new ways to express and investigate asymmetries in the geomagnetic field. Here we will reflect upon aspects of geomagnetic research and understanding upon which we can trace the influence made by Dr. Friis-Christensen and his colleagues.

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IUGG-3489

Estimating statistical maps of Birkeland currents from Swarm magnetometer measurements represented in apex coordinates

K.M. Laundal[1], *N. Olsen*[2], *C.C. Finlay*[2], *N. Ostgaard*[1], *P. Tenfjord*[1], *J.P. Reistad*[1], *K. Snekvik*[1]
[1]*The University of Bergen, Department of physics and technology, Bergen, Norway*
[2]*Technical University of Denmark, National Space Institute, Copenhagen, Denmark*

Birkeland currents are magnetic field aligned currents, manifesting the coupling between ionospheric and magnetospheric dynamics. We estimate statistical maps of Birkeland currents from Swarm and CHAMP magnetometer measurements, sorted according to seasonal conditions and the orientation of the interplanetary magnetic field. The estimates are based on a description of the magnetic field disturbance vector by toroidal and poloidal scalar potentials, expanded in terms of spherical harmonic functions. With these potentials known, the field aligned (poloidal) currents can be calculated from the magnetic toroidal potential, and the horizontal ionospheric (toroidal) currents can be calculated from the poloidal potential. The magnetic field components are expressed in apex quasi-dipole coordinates, which organize the data with respect to a model of the Earth's main magnetic field (IGRF). We show that the R1 and R2 current systems appear more confined when the vector components are properly represented in the apex coordinate system, compared to commonly used approximations (which often arrange the data using apex coordinates without transforming the vector components properly). By sorting the data according to seasons and the orientation of the interplanetary magnetic field, we analyze interhemispheric differences in Birkeland currents. Such differences may partly explain observed differences in the auroral intensity in the two hemispheres.

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IUGG-3980

Investigating the benefit of a low-inclination Delta satellite for ESA's Swarm mission

G. Hulot[1], N. Olsen[2], C. Stolle[3], A. Chulliat[4], A. Kuvshinov[5], P. Vigneron[1], V. Lesur[3], H. Shimizu[6], B. Sreenivasan[7]
[1]IPGP, Geomagnetism, Paris, France
[2]National Space Institute- Technical University of Denmark, DTU Space, Lyngby, Denmark
[3]GFZ German Research Centre for Geosciences, Helmholtz Centre Potsdam, Potsdam, Germany
[4]University of Colorado and National Geophysical Data Center, Cooperative Institute for Research in Environmental Sciences, Boulder- Colorado, USA
[5]ETH Zürich, Earth and Planetary Magnetism, Zürich, Switzerland
[6]University of Tokyo, Earthquake Research Institute, Tokyo, Japan
[7]Indian Institute of Science, Centre for Earth Sciences, Bangalore, India

ESA's Swarm mission aims at studying all sources of Earth's magnetic field. Launched in November 2013, it consists of three identical satellites. Two (Alpha and Charlie) fly side-by-side on near polar orbits at an altitude of slightly less than 500 km. The third satellite (Bravo) is on a similar but slightly more polar, and higher, orbit. These different parameters allow for a progressive local time separation of the orbit of Bravo with respect to those of Alpha and Charlie. This configuration is far more optimal than just relying on a single satellite for magnetic field signal identification and characterization. Indeed, results obtained from the first 18 months of the mission provide ample evidence of the benefit of such a constellation. Local time separation between the Bravo and Alpha/Charlie orbits, however, is slow (6hrs local time separation is to be reached in April 2018). In addition, local times sampled by each of these polar orbits hardly change on time scales of a month. This limits our ability to characterize changes in the local time dependent ionospheric and magnetospheric field contributions, and model the electrical conductivity of the Earth's mantle. It also indirectly limits our ability to model the core and lithospheric field. To address these drawbacks, we build on the strength of the existing Swarm constellation and consider the benefit of launching a fourth, Delta, satellite at a similar altitude but on a much lower inclination orbit (60°). Such a satellite would provide less geographical coverage but a much faster mapping of all local times over these latitudes. This presentation will discuss the

benefit such an additional Delta satellite, with a possibly simplified payload, could bring to enhance the already high return of the Swarm mission.

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IUGG-4023

Relationship between PC index and magnetospheric field-aligned currents measured by swarm satellities

O. Troshichev[1]*, D. Sormakov*[1]*, C. Stolle*[2]
[1]*Arctic and Antarctic Research Institute, Geophysics, St.Petersburg, Russia*
[2]*GFZ German Research Centre for Geosciences, Helmholtz Centre Potsdam, Potsdam, Germany*

The Swarm satellites provided the data-set on the magnetospheric field-aligned currents flowing along the poleward auroral oval boundary (Region 1 FAC). The PC index has been introduced [Troshichev et al.,1988] as an indicator of the polar cap magnetic activity, generated by the geoeffective interplanetary electric field. The paper presents the results of analysis of the relationship between the PC index and the R1 field-aligned currents fixed by Swarm satellites in 2014. Taking into account that the magnetic substorm onsets are always preceded by the PC growth, we examined the isolated substorms (developed on the background of the quiet magnetic field) and chose those events (N=24), when the PC index gradually and steadily increased whereas magnetic activity in the auroral zone remains low till the substorm sudden onset. It is shown that in these cases the PC index grew in evident relation to increase of the Region 1 field-aligned currents, the accidental drops of the currents against the background of total trend being accompanied by the short-term decays in course of the appropriate PC index. The R1 currents, which close through the polar cap ionosphere, demonstrate the evident seasonal dependency, since the ionospheric conductivity in the sunlight summer polar cap is much higher than that in the dark winter polar cap. As a result, the linear relationship between the PC values and the R1 FAC intensity turns out to be different for summer and winter seasons. Conclusion is made that the electric field and ionospheric currents in polar cap (and the corresponding magnetic disturbances) are derived by the field-aligned currents, which are generated within the magnetosphere under influence of the geoeffective solar wind giving rise to plasma gradients in the magnetosphere.

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IUGG-0395

A regional geomagnetic reference field model over the North Atlantic

A. Talarn Zaragoza[1], *F.J. Pavón*[2], *M. Torta*[3]
[1]*Observatory de l'Ebre, Roquetes, Spain*
[2]*Istituto Nazionale di Geofisica e Vulcanologia,*
Geomagnetismo- Aeronomia e Geofisica Ambientale, Roma, Italy
[3]*Observatory de l'Ebre, Geomagnetismo y Aeronomia, Roquetes, Spain*

Including cross-over marine data covering areas lacking of observatory and repeat station data in epochs when precise three-component satellite magnetic field measurements were rare, but it has turned out to be an efficient approach to the modeling of the geomagnetic field and its secular variation. In this work the secular variation and the main field covering the North Atlantic Ocean from 1960 onwards has been modelled simultaneously using the method of main field differences. The model was obtained using different data sets, including cross-over marine data, observatory data, repeat station data, and satellite data from SWARM, OERSTED, CHAMP and MAGSAT and the OGO series. The use of surface and satellite data provided the opportunity to fit the anomaly bias at each observatory. The different altitudes of the data sets required the use of Revised Spherical Cap Harmonic Analysis (R-SCHA) in space, while for the time variation we chose the penalized B-splines. Taking advantage of the properties of the basis functions we introduced temporal and spatial regularization matrices with appropriate damping parameters, which were adjusted to assess the best compromise between the data fit and the model roughness. The obtained results are contrasted with the IGRF, CM4, and CHAOS-4 global models in order to emphasise the achieved improvements thanks to both the different data characteristics and the chosen technique.

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IUGG-2695

Estimating susceptibility and magnetization within the Earth's continental crust: Petrophysical and Satellite approaches

M. Purucker[1], *S. McEnroe*[2]
[1]*Goddard Space Flight Center, Codes 695 and 698, Greenbelt, USA*
[2]*Norwegian Institute of Science and Technology,*
Department of Geosciences and Mineral Engineering, Trondheim, Norway

Magnetic models made from satellite data are used to place constraints on the average magnetic susceptibility and its variability in the continental crust. Estimates of magnetic crustal thickness are made in a two-step process. The first step uses a recent seismic model (Crust1.0) to estimate the thickness of crystalline crust above the Moho, modified in the Andes and the Himalayas to account for the non-magnetic lower crust there. The second step calculates the magnetic field expected from such a layer of crystalline rock assuming the magnetization is solely induced in the earth's main field by rock of constant magnetic susceptibility, and modifies the starting crustal thickness to bring it into agreement with the CM5 model. This global model removes spherical harmonic degrees less than 15 to account for the core field mask. Our simulations use a range of crustal magnetic susceptibilities, and we test the resulting predictions and variability for agreement with seismic models. We also compare our results to petrophysical and petrological observations from rocks that have been deep in the crust.

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IUGG-2874

Swarm accelerometer data: Temperature dependence & GPS orbits: First gravity field solutions

A. Bezdek[1], *J. Sebera*[2], *J. Klokocnik*[2]
[1]*Astronomical Institute- ASCR, Ondrejov, Czech Republic*
[2]*Astronomical Institute- ASCR, GPS, Ondrejov, Czech Republic*

Each of the three Swarm satellites carries a space accelerometer whose objective is to measure the nongravitational forces, unfortunately the accelerometer data display unexpected and rather large temperature dependence. We show that using the onboard measured temperatures with a suitable phase shift this dependence can be subtracted and thus a validated accelerometer signal obtained. Precise GPS orbits may serve as a standard for Swarm accelerometer calibration as well as a data set from which independent gravity field solutions can be obtained. In 2014 there were several changes in the processing of Swarm GPS data that improved the quality of obtained gravity field solutions. We show the current status of our activities towards the GPS-based calibration of Swarm accelerometers, which should provide calibrated accelerometer measurements accompanied by an estimate of their uncertainty.

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IUGG-3296

Performance of Swarm satellites as gravity probes

N. Zehentner[1], *T. Mayer-Gürr*[1]
[1]*Graz University of Technology, Institute of Geodesy, Graz, Austria*

Although the main purpose of the SWARM satellites is to study the Earth's magnetic field, they are also well suited to study a second component of the system Earth, the gravity field. The Earth's gravity field can be investigated by analyzing satellite orbits. Fortunately the satellites are equipped with geodetic grade GPS receivers for the purpose of precise orbit determination. Under the assumption that the satellite orbit is solely estimated from the geometric GNSS observations, the computed positions can be utilized to investigate the Earth's gravity field.

The basic method, known as satellite to satellite tracking in high-low mode, is well known and has been used in the context of former satellite missions (e.g. CHAMP or GOCE). In recent years non-dedicated gravity field satellites, like SWARM, have been proposed as a possibility to fill gaps in the observational time series of gravity field satellites. Apart from filling gaps, the method is definitely an independent method to estimate the Earth's gravity field, which can be used to validate or supplement results from dedicated gravity field satellites.

In our contribution we will show results from the first full year of SWARM data in terms of gravity field solutions as well as kinematic orbits. We will classify the performance of the SWARM satellites in contrast to gravity field satellites, as well as different non-dedicated satellites. The validation will not only show the performance in terms of gravity field results, we will also assess the performance of the on-board GPS receiver in terms of positioning accuracy and observation quality.

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IUGG-3790

Sensing the conductivity of the upper mantle and lithosphere using ocean tidal magnetic field satellite measurements: Model studies and observations

N. Schnepf[1], *A. Kuvshinov*[2], *T. Sabaka*[3], *N. Olsen*[4]
[1]*Massachusetts Institute of Technology, Earth- Atmospheric and Planetary Science, Cambridge, USA*
[2]*ETHZ, Institute of Geophysics, Zurich, Switzerland*
[3]*NASA Goddard Space Flight Center, Planetary Geodynamics Laboratory, Greenbelt, USA*
[4]*Technical University of Denmark, National Space Institute, Lyngby, Denmark*

A few scientific groups convincingly demonstrated that the magnetic fields induced by the lunar semidiurnal (M2) ocean flow can be identified in magnetic satellite observations. These results support the idea to recover M2 magnetic signals from Swarm data, and to use these data for constraining lithosphere and upper mantle electrical conductivity in oceanic regions. Induction studies using ionospheric and magnetospheric primary sources are mostly sensitive to conducting structures in the mantle because of the inductive coupling between primary and induced sources. In contrast, using oceanic tides as a signal allows for studying shallower (and less conductive) regions since the coupling is galvanic. In this study, we perform global 3-D electromagnetic numerical simulations in order to investigate the sensitivity of M2 signals to conductivity distributions at different depths. The results of our sensitivity analysis are discussed, as is comparison of the modeled M2 signals with those recovered by the Comprehensive Inversion from satellite and observatory data. Simulations of seafloor M2 electric and magnetic fields suggest that these signals allow for better constraining of lithospheric conductivity.

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IUGG-3805

Investigation of vector gradient combinations from Swarm constellation for the determination of Earth's lithospheric field

S. Kotsiaros[1], *C.C. Finlay*[1], *N. Olsen*[1]
[1]*Technical University of Denmark, DTU Space, Kgs. Lyngby, Denmark*

The Swarm constellation mission aims at determining the lithospheric field on a global scale with the best possible resolution. We derive lithospheric field models taking advantage of the constellation aspect of Swarm by including magnetic vector gradient information. Specifically, we use more than one year of East-West and North-South magnetic gradient data, approximated by first differences of field vector data between the two lower Swarm satellites and along each satellite orbit, respectively. We find that gradient data are less sensitive to large-scale external field fluctuations. Moreover, gradient data appear to be a very efficient way of increasing the resolution of lithospheric field models and thus providing an initial validation of the gradient concept underlying the Swarm mission.

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JA04p-165

Possibility of electromagnetic sounding of planetary interior from a low-orbiting probe: Task for SWARM

V. Pilipenko[1]*, E. Fedorov*[1]
[1]*Institute of Physics of the Earth, Space Environment Lab., Moscow, Russia*

We show theoretically that it is possible to perform the magnetotelluric sounding of a planet's interior conductivity based on the registration of variable electric and magnetic fields on a low orbiting space probe. In this case, fast magnetosonic (FMS) waves in a planetary magnetosphere can play the role of sounding waves. The registration of FMS wave impedance (ratio of the electric and magnetic components) onboard a probe indeed makes it possible to estimate the planetary conductivity for a planet with a magnetosphere and ionosphere. The proposed approach can be tested using electromagnetic observations on low orbiting satellite SWARM with electric and magnetic sensors onboard in the Earth's topside ionosphere.

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JA04p-166

ULF wave power features in the topside ionosphere revealed by Swarm observations

C. Papadimitriou[1], *G. Balasis*[2], *I.A. Daglis*[3]
[1]*National Observatory of Athens, IAASARS, Athens, Greece*
[2]*National Observatory of Athens, IASSARS, Athens, Greece*
[3]*University of Athens, Faculty of Physics, Athens, Greece*

Recently developed automated methods for deriving the characteristics of ultra low frequency (ULF) waves are applied to the Swarm datasets in order to retrieve, on an operational basis, new information about the near-Earth electromagnetic environment. Processing Swarm measurements with these methods helps to elucidate the processes influencing the generation and propagation of ULF waves, which in turn play a crucial role in magnetospheric dynamics. Here we present the first ULF wave observations by Swarm, obtained by applying our analysis tools to the latest 12 months of the mission (i.e., after the constellation attained its final configuration) using scalar magnetic field data. We present the statistics of various parameters of the detected wave activity and focus on the differences between observations performed by the upper satellite and the lower pair of satellites, such as the differences in local time of the maxima of the wave power. If these initial results were to be confirmed, it could imply significant spatial variability of ULF wave turbulence in the upper ionosphere.

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JA04p-167

South Atlantic anomaly as seen by swarm data

J. Domingos[1,2,3]*, A. Pais*[1,4]*, D. Jault*[5]*, M. Mandea*[2]
[1]*University of Coimbra, CITEUC- Geophysical and Astronomical Observatory, Coimbra, Portugal*
[2]*CNES, Centre National d'Etudes Spatiales, Paris, France*
[3]*University of Grenoble-Alpes, ISTerre, Grenoble, France*
[4]*University of Coimbra, Department of Physics, Coimbra, Portugal*
[5]*University Grenoble-Alpes CNRS, ISTerre, Grenoble, France*

The aim of this work is to study the South Atlantic Anomaly, using data acquired since the end of 2013 by the Swarm satellite constellation, which provides the most recent and detailed information of the Earth's magnetic field. Despite the fact that the Swarm satellites have so far only produced a relatively short time series, the high passage frequency of the satellites provides important information for this period, on small timescales. A comparison with the 10.7 cm radio flux series can be done, since this has become a widely used index of solar activity. The study of Swarm data is also ideal for a detailed analysis of the spatial evolution of the South Atlantic Anomaly, which is known to drift westward. The intensity of the anomaly can be easily estimated and the evolution of the strength of the field in this area computed. Furthermore, by making an inversion of the Swarm data, a model based on Spherical Harmonics can be created to represent the field. This work follows general guidelines of some previous studies, however it is based on more recent, high-accuracy and high-resolution data from the Swarm mission. Combining Swarm data with available ground data, mainly on the area of interest, allows us to get a better understanding of the Earth's magnetic field variability, and more specifically, the South Atlantic Anomaly.

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JA04p-168

Preliminary evaluation of the spatial variation in the Swarm ion drifts

R. Fiori[1], S. Koustov[2], D. Boteler[1], D. Knudsen[3], J. Burchill[3], L. Trichtchenko[1]
[1]Natural Resources Canada, Canadian Space Weather Forecast Center, Ottawa, Canada
[2]University of Saskatchewan, Institute for Space and Atmospheric Studies, Saskatoon, Canada
[3]University of Calgary, Department of Physics and Astronomy, Calgary, Canada

The Canadian Electric Field Instrument (EFI) onboard the Swarm satellites make continuous high-resolution in situ measurements of the F-region ion drift. Making 2-D maps of the plasma convection in the high-latitude ionosphere is one way of achieving higher level data products thereby obtaining the maximum benefit from these measurements. The authors of this report have already established that a spherical cap harmonic mapping algorithm can be applied to generate maps of the high-latitude convection pattern based on a Swarm data set that was artificially generated using statistical models to emulate ion drift measurements along hypothetical Swarm satellite tracks. It was shown that Swarm-based measurements can be successfully mapped both over a localized region surrounding the satellite track (to examine small scale features) and across the entire high-latitude region. Due to the preliminary nature of the currently available Swarm data we assess spatial variations of the ion drift along the satellite track and compare them with expected variations. This is accomplished through comparison of Swarm ion drift measurements with (1) a statistical convection model for periods of quasi-stability in the solar wind and interplanetary magnetic field (IMF), and (2) SuperDARN measurements. Quality of the Swarm-based pattern prediction is evaluated in terms of solar wind and IMF conditions and separation of the point of mapping from the region of actual measurements.

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JA04p-169

Ionospheric gravity and diamagnetic current systems inferred from CHAMP and Swarm measurements

P. Alken[1]
[1]*University of Colorado at Boulder, Boulder, USA*

Large scale currents in the ionosphere are driven by a variety of sources, including neutral winds, gravity, and plasma pressure gradients. While the stronger day-time wind-driven currents have been extensively studied, gravity and diamagnetic currents in the ionosphere have received little attention, but can have substantial effects even during the night. With the availability of a new generation of magnetic field models based on high-accuracy satellite magnetic measurements, it becomes increasingly important to account for these smaller current systems. In this study, we use over a decade of high-quality geomagnetic field measurements from the CHAMP and Swarm missions to study the seasonal and longitudinal structure of these currents. These results allow us to visualize the global structure of these currents and quantify their magnetic perturbations both on the ground and at satellite altitude.

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JA04p-170

Magnetic signals generated by ocean flow in the Swarm satellite data: prediction and observation

J. Velimsky[1], *Z. Martinec*[1,2], *D. Einspigel*[1,2], *L. Sachl*[1,2]
[1]*Charles University in Prague- Faculty of Mathematics and Physics, Department of Geophysics, Prague 8, Czech Republic*
[2]*DIAS, School of Cosmic Physics- Geophysics Section, Dublin, Ireland*

Motion of sea water in the Earth’s main magnetic field generates the secondary induced field which can be decomposed into its poloidal and toroidal components. While the toroidal component is not directly observable outside the oceans, the poloidal magnetic field have been already validated by CHAMP satellite magnetic observations, land-based magnetic measurements and sea surface magnetic field measurements, despite the poloidal field being rather weak, reaching an intensity of up to a few nT. New possibilities of observations of the ocean-induced magnetic field came with the launching of ESA’s Swarm mission satellites which have provided a valuable amount of high-precision and high-resolution measurements of the Earth’s magnetic field. For a detection of weak ocean-induced signals and their interpretation, numerical modelling is crucial. We present results of modelling of the secondary magnetic field generated by ocean flow. Two ocean flow models are incorporated: 1) DEBOT, a barotropic model of ocean tide flow and 2) LSOMG, a baroclinic model of global ocean currents. The secondary magnetic field is modelled by two different approaches: 1) a single-layer approximation model and 2) a three-dimensional time-domain electromagnetic induction model. A preliminary comparison of predicted signals and observed signals extracted from Swarm satellite data will be shown. The future aim is to assimilate magnetic data provided by Swarm mission into the models.

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JA04p-171

Status of the Swarm accelerometers and GPS receivers

C. Siemes[1], *H. Bock*[2], *S. Bruinsma*[3], *E. Doornbos*[4], *J. Teixeira da Encarnacao*[4], *R. Floberghagen*[5], *L. Grunwaldt*[6], *J. van den IJssel*[4], *J. Kraus*[7], *G. Ottavianelli*[5], *R. Peresty*[7]
[1]*RHEA for ESA, EOP, Noordwijk, Netherlands*
[2]*PosiTim, GNSS Solutions and Services, Seeheim-Jugenheim, Germany*
[3]*CNES, Terrestrial and Planetary Geodesy, Toulouse, France*
[4]*Delft University of Technology, Faculty of Aerospace Engineering, Delft, Netherlands*
[5]*ESA, EOP, Frascati, Italy*
[6]*GFZ, Geodesy and Remote Sensing, Potsdam, Germany*
[7]*VZLU, SERENUM, Prag, Czech Republic*

The presentation addresses the status of the accelerometers and GPS receivers on board the Swarm satellites.

The GPS receivers meet the requirements for geolocation and datation in support of the magnetic observations. They can also be regarded as scientific instruments that are used for gravity field determination and the calibration of the accelerometers. Investigations on optimizing the receiver settings for the benefit of scientific applications are currently on-going and expected to be completed at the time of the IUGG general assembly. Furthermore, precise orbits (i.e. Swarm Level 2 products) become available to all Swarm users in January/February 2015.

Validation of accelerometer data revealed a number of shortcomings, of which the strong sensitivity to temperature variations is the most problematic. It generates slow temperature-driven changes of the bias as well as abrupt changes of the bias that are presumably caused by sudden release of thermal-induced mechanical stress in the accelerometer sensor structure.

We provide an impression of the quality of accelerometer and GPS receiver data and present the outcome of the GPS receiver setting optimization as well as the status of the ongoing investigations on correcting the accelerometer data for temperature effects.

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JA04p-172

On the validity of the automated detection of low latitude plasma depletions onboard Swarm

G.N. Kervalishvili[1], C. Stolle[1,2], J. Rauberg[1]
[1]Helmholtz Centre Potsdam German Research Centre for Geosciences GFZ, 2.3 "Earth Magnetic Field", Potsdam, Germany
[2]University of Potsdam, Faculty of Science, Potsdam, Germany

Low-latitude post sunset plasma depletions are an intrinsic regular phenomenon in the F region ionosphere that leave severe plasma density gradients, magnetic field variations and cause GPS signal detection degradations. The Swarm mission provides a regular data product on short-delay basis, which is called the Ionospheric Bubble Index (IBI). This index is based on an appropriate analysis of magnetic fluctuations. When a substantial agreement with corresponding plasma density variations is identified, the index flags the 1 Hz observations as located inside such an irregularity. The first aim of this product has been to identify geophysically related magnetic field fluctuations for data users working on internal field sources.

On the other hand, this product provides an easy access to screening plasma irregularity occurrence for scientists investigating the F region ionosphere, or GPS signal processing, e.g., for satellite orbit solutions. However, the two latter should mainly be interested in plasma density rather than in magnetic field fluctuations, which in turn is only a sufficient selection criteria in this product. The strength of the related magnetic signature (the necessary criteria for the implemented algorithm) depends on background plasma density, magnetic field strengths, or sensitivity of the magnetic sensors.

After a substantial amount of observations has been achieved, this paper is now ready to discuss the application of the IBI index for ionospheric plasma-related studies. We will also provide the climatological distribution of the depletion index as given by the Swarm observations.

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A preliminary model of the 1-D mantle conductivity structure from Swarm data

C. Püthe[1], *A. Kuvshinov*[1]
[1]*ETH Zürich, Institute of Geophysics, Zürich, Switzerland*

One of the primary goals of the Swarm multi-satellite geomagnetic mission is an improved understanding of the conductivity structure of Earth's mantle. After one year in space, the three satellites have collected enough data for a first, preliminary analysis. We invert the first year of Swarm data for a new model of the radial (1-D) conductivity structure. The study relies on a preprocessing of the raw data by the comprehensive inversion, which separates the measured magnetic field into contributions from core, lithosphere, ionosphere and magnetosphere (and corresponding induced parts) in the form of spherical harmonic expansion coefficients.

From time series of the external and induced coefficients of the magnetic potential due to the magnetospheric ring current, we estimate scalar response functions. An iterative approach is used to correct the estimated responses for 3-D effects arising from lateral heterogeneities in a surface shell. The corrected responses are subsequently inverted for the layered 1-D mantle conductivity structure with the Newton method. To check the quality of the data and to confirm that all tools in the processing chain work properly, the results are compared to 1-D conductivity models of Earth’s mantle recovered in previous studies.

As an alternative to the established iterative correction scheme, we recently developed a new method to directly invert the uncorrected responses for the 1-D conductivity structure in a 3-D environment. We compare the results obtained with both approaches and discuss their pros and cons.

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Investigating the polar electrojet using Swarm satellite magnetic data

C.D. Aakjær[1], *C.C. Finlay*[1], *N. Olsen*[1]
[1]*Technical University of Denmark, DTU Space, Kgs. Lyngby, Denmark*

The aim of this study is to investigate the magnetic perturbations caused by the polar electrojets, which are described by means of a model consisting of a series of line currents perpendicular to the orbit plane of the satellite.

The method is applied to Swarm magnetic scalar perturbations (which means observations after removal of contributions from the core, crust and the large-scale magnetosphere) in the Polar Regions (+/- 50 degrees from the poles) for individual satellite passes.

The obtained estimates of ionospheric currents provide information on the position and strength of the polar electrojets as well as their temporal evolution. In addition, applying the method to data taken by the side-by-side flying Swarm satellites Alpha and Charlie allows investigating longitudinal differences of the electrojets.

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Electrical conductivity of the Earth's mantle after one year of SWARM magnetic field measurements

F. Civet[1], E. Thebault[1], O. Verhoeven[2], B. Langlais[1], D. Saturnino[2]
[1]CNRS, Unversity of Nantes - LPGNantes - UMR6112, Nantes, France
[2]University of Nantes, LPGNantes - UM6112, Nantes, France

We present a global EM induction study using L1b Swarm satellite magnetic field measurements data down to a depth of 2000 km. Starting from raw measurements, we first derive a model for the main magnetic field, correct the data for a lithospheric field model, and additionally select the data to reduce the contributions of the ionospheric field. These computations allowed us to keep a full control on the data processes. We correct residual field from outliers and estimate the spherical harmonic coefficients of the transient field for periods between 2 and 256 days. We used full latitude range and all local times to keep a maximum amount of data. We perform a Bayesian inversion and construct a Markov chain during which model parameters are randomly updated at each iteration. We first consider regular layers of equal thickness and extra layers are added where conductivity contrast between successive layers exceed a threshold value. The mean and maximum likelihood of the electrical conductivity profile is then estimated from the probability density function. The obtained profile particularly shows a conductivity jump in the 600-700km depth range, consistent with the olivine phase transition at 660 km depth. Our study is the first one to show such a conductivity increase in this depth range without any a priori informations on the internal strucutres. Assuming a pyrolitic mantle composition, this profile is interpreted in terms of temperature variations in the depth range where the probability density function is the narrowest. We finally obtained a temperature gradient in the lower mantle close to adiabatic.

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JA04p-176

"Evolution of the South Atlantic Anomaly and recent contribution by Swarm data"

F.J. Pavón-Carrasco[1,2]*, A. De Santis*[1,3]*, E. Qamili*[1]
[1]*INGV, Geomagnetismo- Aeronomia e Geofisica Ambientale, Rome, Italy*
[2]*European Space Agency, The Living Planet Programme, Rome, Italy*
[3]*Università G. D'Annunzio, Earth Sciences, Chieti, Italy*

The South Atlantic Anomaly (SAA) is a current magnetic feature characterized by values of geomagnetic field intensity around 30% lower than expected for those latitudes and covers a large area in the South Atlantic Ocean between South America and South Africa. The study of the SAA is an important challenge nowadays not only for the geomagnetic and paleomagnetic community, but also for other areas focused on the Earth Observation due to the protective role of this potential field against the charged particles forming the solar wind. A further increase of the SAA could have dramatic consequences for human health and technologies because a large part of the solar wind could reach the Earth's surface. During the last fifty years, a constant monitoring of the SAA by satellites is showing a clear decay of the geomagnetic field intensity at the centre of the anomaly from 24.5 to 22.5 μT with an increase around 70% of the area of the SAA under 32 μT. In this context, the Swarm mission (constituted by a constellation of three satellites in near-polar low orbits at two different altitudes) is providing detailed measurements of the intensity and directional elements of the geomagnetic field with high-precision and resolution never reached in the former space missions. This work aims to analyse in detail in space and time the SAA from the Earth's surface up to the satellite altitude. In order to carry out this study, comprehensive geomagnetic models at regional and global scale will be performed using the dataset provided by the Swarm satellites and all the available ground data. This kind of study is crucial to understand the evolution of the Earth's magnetic field in this area, and to possibly predict its future behaviour.

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A Swarm near-real-time ring-current magnetic model

B. Hamilton[1], *A. Thomson*[1]
[1]*British Geological Survey, Geomagnetism, Edinburgh, United Kingdom*

For over a year, data from the ESA Swarm three-satellite constellation have been used to produce models of the Earth's large-scale magnetospheric field once every 1.5 hours and released rapidly on a daily basis as part of Swarm's Level-2 product range. As well as addressing scientific interests in the external field of the Earth, these magnetospheric field models could be of use in space weather applications where measures of geomagnetic activity are required, and as inputs to other magnetic field modelling studies. The algorithm takes as input the residuals after removing a priori models of the non-magnetospheric fields. It is reliable, operates automatically and has the potential to be run in near real-time if required. We compare the models with the observatory-based Dst and Vector Magnetic Disturbance (VMD) indices, and also compare models produced from different Swarm satellites, commenting on their consistency. We find our models to be most robust for the dominant spherical harmonic order 0 external and induced internal coefficients, with a more consistent baseline than the real-time Dst indices. The order 1 coefficients are less robust although this may improve with time as the Swarm constellation's orbit configuration becomes more favourable.

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Visual analysis of swarm and geomagnetic model data

D. Santillan Pedrosa[1], *G. Triebnig*[1]
[1]*EOX IT Services GmbH, Research Lab, Vienna, Austria*

The European Space Agency contributes to information technology developments for satellite data access and analysis. In the technology research project “Virtual Workspaces for Earth Observation Scientists” the Agency focused on the particular characteristics of the Swarm mission. A collaboration of scientists and industry delivered the presented Prototype system.

Traditionally scientists operate their own computing facilities into which they download the satellite data for performing their specialized tasks. The Prototype demonstrates augmentations and simplifications for this process by providing:

* Interactive tools with particularly convenient properties supporting the data selection, visualisation, scientific analysis and documentation

* Services in the cloud which make satellite data access easier and support on-demand generation of derived value-added information

The included features for Swarm mission data access, visualisation, and analysis are:

* Graphical Web Interface supporting interactive virtual globe and rich analytical toolset

* Plotting Swarm Level 1b data (such as Magnetic field vector , Magnetic field intensity) as a function of (co-)latitude/time

* Visualisation of magnetic field residuals with the possibility of selecting different provided field models and the option of uploading the users own model as spherical harmonics coefficients

* Visualisation of the magnetic field intensity maps (calculated on-the-fly based on selected model, time and altitude)

* Magnetic field intensity difference between two satellites

* Horizontal magnetic field residuals

* Magnetic field gradient maps

* Magnetic field intensity along field lines (Three-dimensional)

* Vector and scalar plots along multiple orbits

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Swarm electric field instrument activities after one year in operations

I. Coco[1], G. Ottavianelli[1], R. Floberghagen[1], P. Vogel[2], M. Kornberg[2], D. Knudsen[3], J. Burchill[3], S. Buchert[4], P.E. Holmdahl Olsen[5], L. Toffner-Clausen[5]
[1]European Space Agency, ESRIN, Frascati, Italy
[2]European Space Agency, ESTEC, Noordwijk, Netherlands
[3]University of Calgary, Physics and Astronomy Dept., Calgary, Canada
[4]Swedish Institute of Space Physics, Space Plasma Physics, Uppsala, Sweden
[5]Danish Technical University, National Space Institute, Copenhagen, Denmark

The EFIs include Thermal Ion Imagers (TII) for measuring the ionospheric O+ velocity and temperature, and Langmuir Probes for measuring ionospheric plasma density and electron temperature. Moreover, combining the velocity with the magnetic field measured by Swarm as well, the ionospheric electric field is calculated. After complex calibration activities, both at the instrument and data processing level, ESA and the EFI principal investigators have made available to the science community the first preliminary plasma dataset in February 2015. This poster shows an overview of the Swarm Electric Field Instruments (EFI) on all three spacecraft after one year in operations: instruments health status, evolutions of data processing and distribution, status of data quality and validation activities.

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GPS aided Accelerometer data for SWARM

S. Burla[1], *G. Apelbaum*[1], *J. Flury*[1]
[1]*Institute für Erdmessung, IfE- Uni Hannover, Hannover, Germany*

The accelerometers on board geodetic satellites measure the non-gravitational forces and thus play a significant role in such satellite missions. The SWARM mission which is a dedicated mission for the determination of the Earth's magnetic field also carries on board accelerometers on each satellite. We analyze the SWARM accelerometer data over several months. The preliminary screening of SWARM accelerometer data reveals very high jumps corresponding to some unknown effects. We focus on the reduction of these jumps with the help of GPS-derived accelerations and possibly try to understand the underlying process. An approach to model such jumps is also introduced in this contribution. Details and the preliminary results are given and discussed.

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Swarm dedicated core field model and it's relationship to other recent models

M. Rother[1], *V. Lesur*[1], *R. Schachtschneider*[1]
[1]*Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences, 2, Potsdam, Germany*

A new, fully re-calibrated, Swarm satellite magnetic data set has been announced for March 2015. In the framework of the Swarm Satellite Constellation Application and Research Facility activities, a first version of the dedicated core magnetic field model DCO will be estimated from about one and a half years of these data. In the context of general calibration and validation activities of the Swarm community and using or own calibration approach, versions of magnetic field models were already built from Swarm data. These models, in contrast to the DCO approach, used observatory data for stabilizing the inversion process. The DCO model will be presented and compared with these models and other similar models such as the GFZ IGRF-12 parent model and the most recent versions of the GRIMM and CHAOS series of models. Time series of corrections to the Euler angles between the sensor reference frame and the satellite coordinate system, as part of the DCO results, will also be presented. In particular we will discuss their stability and significance depending on various parameterisations.

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"Electromagnetic anomalies detected by Swarm satellites likely related to the first April 2014 M8.1 Chile Earthquake"

A. De Santis[1], M. Mandea[2], G. Balasis[3], F.J. Pavón-Carrasco[1,4], E. Qamili[1], G. Cianchini[1]
[1]Istituto Nazionale di Geofisica e Vulcanologia, Geomagnetismo- Aeronomia e Geofisica Ambientale, Rome, Italy
[2]CNES - Centre National d'Etudes Spatiales, Earth Observation, Paris, France
[3]National Observatory of Athens, Institute for Astronomy- Astrophysics- Space Applications and Remote Sensing, Athens, Greece
[4]European Space Agency, The Living Planet Programme, Rome, Italy

Recent scientific literature has suggested that intense seismic activity might generate upward electromagnetic (EM) perturbations that can be detected by ground-based and low altitude spaceborne measurements. For example, very low frequency (VLF) wave observations detected by DEMETER satellite (2004-2010) pointed out a statistically significant decrease of the measured ionospheric wave intensity a few hours before large shallow earthquakes (EQs). This result would confirm the existence of a lithosphere-atmosphere-ionosphere coupling before the occurrence of an impending large EQ. Swarm ESA constellation offers a great opportunity to study EM perturbations possibly related to seismic activity because it is a multi-satellite low Earth orbit (LEO) mission with a unique space-time configuration able to measure both electric and magnetic fields at various altitudes in the topside ionosphere. Swarm measurements taken shortly before and after large EQs happened since the constellation is in orbit have been analysed. A special interest is given to the shallow M8.1 Chile EQ (1 April 2014), as our study indicates some unexplained anomalies in Swarm data which might be related to this large EQ. We report the first results of the analysis.

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Estimating error associated with a magnetic field model

S. Macmillan[1], *A. Chulliat*[2]
[1]*British Geological Survey, Geomagnetism Team, Edinburgh, United Kingdom*
[2]*National Oceanic and Atmospheric Administration, Geomagnetism, Boulder, USA*

A common requirement for users of magnetic field models is to have information about the accuracy of the model. Any signal not captured by the model is part of the error, for example the unmodelled crustal and external fields. Some models are used long after they have been produced and errors associated with prediction of the core field inevitably arise. Estimates of ground-based errors were derived as part of the recent World Magnetic Model production. These estimates were derived from vector data from observatories and repeat stations around the world combined with scalar data from marine and airborne surveys. The errors arising from the crustal and external fields have distinct spatial patterns, with local maxima in the auroral and polar regions for the external field. Declination, the element of the magnetic field of greatest interest to many users, is not linear in spherical harmonic model coefficients but can be propagated from the orthogonal components which are linear. This results in further spatial variations (inclination and horizontal and total intensities are also affected). Some of these propagation-related spatial variations are difficult to validate in ground-based measurements because of the poor spatial coverage. We investigate whether satellite data such as those from the Swarm mission can provide such validation. To derive all-inclusive error estimates for a particular magnetic field model, the errors from the crustal and external fields and core field prediction can be combined with the propagated error estimates.

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ULF waves in the topside ionosphere observed by SWARM

B. Heilig[1], M. Vellante[2], P. Sutcliffe[3], P. Kovács[4], G. Vadász[4], M. Regi[2]
[1]Geological and Geophysical Institute of Hungary,
Tihany Geophysical Observatory, Tihany, Hungary
[2]University of L'Aquila, Physical and Chemical Sciences, L'Aquila, Italy
[3]South African National Space Agency, Space Science, Hermanus,
South Africa- Republic of
[4]Geological and Geophysical Institute of Hungary, Earth Physics, Budapest, Hungary

Different types of ULF waves (dayside compressional Pc4-5s, compressional Pc3s, transverse Pc2s and Pc1s, FLRs, night side Pi2s, etc.) have been successfully identified in the topside ionosphere. ULF observations in this region can help us to understand the wave structure in the magnetosphere, wave propagation, and also the effects of the ionosphere (transmission, reflection, mode conversion).

Because of the fast orbital speed of the LEO satellites, Fourier techniques are applicable only for limited types of analyses, otherwise techniques such as autoregressive methods or wavelet analysis are needed, for example, to resolve ULF wave spatial structure. ULF waves are interpreted in a mean field aligned coordinate system. LEO observations are compared to ground observations along the EMMA/MM100 magnetometer chain.

The first results clearly show that the quality of SWARM magnetic observations is high enough for successful detection of ULF waves. We present the first results of studies on ULF waves (compressional Pc3s and FLRs) detected by the SWARM trio. Our preliminary results confirm that the coherence length of compressional Pc3s is several thousands of kms on the dayside. Detection of Doppler shifted field line resonances is rather challenging, we analyse a unique event.

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On the advantages of flying absolute vector magnetometers on board satellites, lessons learned from the Swarm mission

G. Hulot[1]*, J.M. Léger*[2]*, P. Vigneron*[1]*, L. Brocco*[1]*, N. Olsen*[3]*, V. Lesur*[4]*, T. Jager*[2]*, F. Bertrand*[2]*, I. Fratter*[5]*, O. Sirol*[1]*, X. Lalanne*[1]
[1]*IPGP, Geomagnetism, Paris, France*
[2]*CEA, Léti, Grenoble, France*
[3]*National Space Institute- Technical University of Denmark, DTU Space, Lyngby, Denmark*
[4]*GFZ German Research Centre for Geosciences, Helmholtz Centre Potsdam, Potsdam, Germany*
[5]*Centre National d'Etudes Spatiales, CNES, Toulouse, France*

ESA's Swarm satellites carry a new generation of ^{4}He absolute magnetometers (ASM), designed by CEA-Léti and developed in partnership with CNES. These instruments are the first-ever space-born magnetometers to use a common sensor to simultaneously deliver 1Hz independent absolute scalar and vector readings of the magnetic field. They have provided the very high accuracy scalar field data nominally required by the mission (for both science and calibration purposes, since each satellite also carries a low noise high frequency fluxgate magnetometer designed by DTU), but also very useful experimental absolute vector data. In this presentation, we will report on the various tests and investigations carried out using these experimental data since launch in November 2013. In particular, we will illustrate the advantages of flying ASM instruments on space-born magnetic missions for nominal data quality checks, geomagnetic field modeling and science objectives.

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Swarm data and unmodelled magnetic contributions in geomagnetic field models

R. Tozzi[1], *M. Mandea*[2], *P. De Michelis*[1]
[1]*Istituto Nazionale di Geofisica e Vulcanologia, Struttura Ambiente, Roma, Italy*
[2]*CNES - Centre National d'Etudes Spatiales,*
Earth Observation / Directorate for Strategy and Programmes, Paris, France

A complex system of electric currents flowing in the ionosphere and magnetosphere origins from the interaction between the interplanetary magnetic field and the solar wind with the Earth's magnetic field. Magnetic fields, either primary or induced, produced by these currents contribute to the magnetic field measured by both ground observatories and satellites.
Here, low resolution scalar and vector data from the recently launched Swarm satellites are considered over one year (April 2014 to March 2015). The main, crustal and magnetospheric (mainly ring current contribution) magnetic fields are removed from the Swarm measurements by using the CHAOS-5 model. Residuals, representing mostly ionospheric and magnetospheric contributions other than that of the ring current, are then investigated according to geomagnetic season, as well as to the geomagnetic activity as estimated by proper indices. Correlations between these residuals and Bx, By and Bz components of the interplanetary magnetic field are then calculated for each geomagnetic season and geomagnetic activity level. This makes it possible to investigate the features of unmodelled contributions due to the external as well as induced crustal magnetic fields in the analysed residuals. Furthermore, this provides an opportunity to study the interaction between the interplanetary magnetic field and the Earth's magnetosphere and ionosphere by means of Swarm data.

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Seasonal trends of nighttime plasma densityenhancements in the topside ionosphere

E. Slominska[1], *J. Blecki*[2], *J. Slominski*[2], *M. Parrot*[3]
[1]*OBSEE, OBSEE, Warsaw-, Poland*
[2]*Space Research Centre PAS, SRC, Warsaw, Poland*
[3]*LPC2E/CNRS, LPC2E, Orleans, France*

Recently it has become apparent that the Weddell Sea Anomaly and the mid-latitude nighttime summer anomaly are phenomena, which are governed by similar mechanisms. Key questions relate to the fact how do those anomalies set up or how does spatial and altitudinal structure evolve. In-situ registrations of electron density from the Langmuir probe onboard CHAMP and DEMETER are used to study spatial and temporal evolution of nighttime plasma density enhancements. The inclination of orbits for both satellites was almost the same (i=87 and 98), but the altitudes were different 420-300km for CHAMP and 650km for DEMETER, providing a possibility for comparative studies. In addition taking advantage of CHAMP orbit, we can assess more thorough diurnal representation of the anomaly. With proposed studies, we aim to present cross-comparison of results from two ionospheric missions and prepare a test-bed for the further cross-validation with registrations from the Swarm constellation. The study introduces the normalized density difference index INDD in order to provide global estimates of the phenomenon. In the validation test, in-situ data are compared with dataset generated with the IRI model. With proposed index, we find signatures of two most common examples of NPDEs, the Weddell Sea Anomaly and mid-latitude nighttime summer anomaly in the ionosphere. The study provides evidences that occurrence of the WSA and MSNA is not limited to the local summer conditions, but tends to occur in remaining seasons. Analyzed annual trends and spatial pattern of INDD suggest that observed anomalies evince similarity with the behaviour of the equatorial ionosphere. Thus also responsible mechanisms (fountain effect and dynamo drift) cannot be neglected in the explanation of NPDEs.

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Swarm: imaging of magnetic field fluctuation scaling features

P. De Michelis[1], *G. Consolini*[2], *R. Tozzi*[1]
[1]*Istituto Nazionale di Geofisica e Vulcanologia, Struttura Ambiente, Rome, Italy*
[2]*INAF, Istituto di Astrofisica e Planetologia Spaziali, Rome, Italy*

We analyze the scaling features of magnetic field fluctuations at the Swarm's altitude capturing their essential characteristics and at the same time establishing a correlation with the dynamics of the systems responsible for them. In particular, we study the changes of the scaling properties of the geomagnetic field's spatial fluctuations by evaluating the local Hurst exponent and we reconstruct maps of this index at high latitudes in the northern and southern hemisphere. The spatio-temporal character of the magnetic field fluctuations are investigated taking into account different geomagnetic activity levels and interplanetary conditions.

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Geophysical signals detected during Swarm's Absolute Scalar Magnetometers burst mode sessions

P. Coïsson[1], L. Brocco[1], G. Hulot[1], P. Vigneron[1], V. Lesur[2], X. Lalanne[1], O. Sirol[1], J.M. Léger[3], T. Jager[3], F. Bertrand[3], A. Boness[3], I. Fratter[4]
[1]Institut de Physique du Globe de Paris, Geomagnetism, Paris, France
[2]GFZ German Research Centre for Geosciences, Helmholtz Centre Potsdam, Paris, Germany
[3]CEA LETI, MINATEC Campus, Grenoble, France
[4]Centre National d'Etudes Spatiales, CNES, Toulouse, France

Swarm satellites carry an Absolute Scalar Magnetometer (ASM) to measure the magnetic field intensity with high accuracy and stability. Nominal ASM data acquisition is at 1 Hz, but there is the possibility to acquire data in a so-called 'burst mode' at 250 Hz. During the commissioning phase of the mission, seven burst mode acquisition campaigns have been run simultaneously for all satellites, obtaining a total of ten days of burst-mode data.
We analyzed the burst mode data to identify high frequency geomagnetic signals, developing a detection algorithm to identify the occurrence of events and characterize them, discriminating between geophysical signals and possible instrumental perturbations.
We found that during quiet time the detected events concentrate near the geomagnetic equator, showing a link with ionospheric irregularities and plasma bubbles. During geomagnetic active periods, these events are mostly observed in the auroral regions, related to polar region currents.Since these campaigns have been conducted during the initial months of the mission, the three satellites were still close to each other, allowing for an analysis of the spatial coherence of the observed signals.

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Intermittent magnetic dynamics in the topside ionosphere as revealed by the SWARM mission

P. Kovacs[1], *G. Vadasz*[1], *B. Heilig*[1], *M. Echim*[2,3]
[1]*Geological and Geophysical Institute of Hungary, Earth Physics, Budapest, Hungary*
[2]*Belgian Institute for Space Aeronomy, Space Physics, Brussels, Belgium*
[3]*Institute of Space Science, Space Plasma and Magnetometry Group, Bucharest, Romania*

The space and terrestrial magnetic field observations exhibit signatures for the occurrence of deterministic nonlinear physical events in the solar-terrestrial system. Within the framework of a project devoted to the scientific exploitation of SWARM data, our goal is to find the nonlinear signatures in the ionosphere and investigate them in connection with local physical processes. The project is entitled ‘The study of MHD waves, turbulence and the plasmasphere based on SWARM observations’.

In our study, a statistical analysis is carried out on the VFM time records of SWARM mission in order to discriminate between Gaussian and non-Gaussian magnetic fluctuation in the ionosphere. We apply probability density function analysis of incremental magnetic field time-series of the individual SWARM records, and of spatial field differences measured between the simultaneous records of two SWARM spacecraft flying side by side. Non-Gaussian behavior of the spatial and temporal difference time-series can reveal multiscale intermittent magnetic fluctuation in the studied plasma region. The level of intermittent dynamics is measured by the fourth statistical moments of the increment time-series, i.e. by their flatness. Our aim is to investigate the variation of the flatness parameter as a function of the position of the SWARM spacecraft. Special intermittent events are further studied by power-spectral density function and high-order multifractal analyses. It is conjectured that the strongest intermittency appears in the auroral region as a consequence of the strong dynamical variation of the electric current system. On the other hand, the dayside magnetic records of the equatorial region also exhibit intermittency that can relate to the nonlinear dynamics of the equatorial electrojet.

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Swarm thermal ion imager preliminary level 1b product quality

J. Burchill[1], *D. Knudsen*[1]
[1]*University of Calgary, Physics and Astronomy, Calgary, Canada*

We present an overview of the Swarm Thermal Ion Imager (TII) preliminary Level 1b data quality. Each Swarm Electric Field Instrument includes two TII electrostatic analyzers which form images in ion energy (0 to 20 eV) and angle-of-arrival in orthogonal planes. The European Space Agency has made preliminary TII data products available for scientific use. Products for Swarm satellites A and B were generated with a prototype Level 1b processor at the University of Calgary. In this paper we review the processing algorithms and calibration techniques used to estimate ion velocity, ion temperature, and electric field from the TII data. By examining specific cases and statistical trends we assess the quality of the TII preliminary data products for scientific research.

Joint Inter-Association Symposium

JA04p - JA4 Results from SWARM, Ground Based Data and Earlier Satellite Missions - Recognition of Eigil Friis-Christensen (IAGA, IAG, IAMAS)

JA04p-193

Investigations on the variations of space weather and correlation analysis with the GOCE gradiometer and swarm magnetometer measurements

S. Ince[1], S. Pagiatakis[1]
[1]York University,
Earth and Space Science and Engineering- Lassonde School of Engineering,
Toronto, Canada

It is known that extreme variations in space weather and corresponding geomagnetic storms can affect satellite communication systems, disrupt electrical systems, damage hardware onboard the satellites and most importantly disturb the satellite measurements in an unusual way. In this study, we investigate the unexpected disturbances present in GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) mission derived gravity gradients along the satellite track over the magnetic poles and its possible correlation with the magnetic storms occurred within the same time period. The interplanetary magnetic field and plasma flow velocity along with electric field data observed by the solar satellites ACE-(Advanced Composition Explorer) and WIND are obtained from OMNI Website. Moreover, magnetic activity observations collected at CARISMA (Canadian Array for Real-time Investigations of Magnetic Activity) stations are included in our investigations for the comparison purposes. Lastly, Swarm magnetometer measurements along the Churchill line of CARISMA stations are included for correlation analysis. It is found that the CARISMA data are capable of monitoring the magnetic activity variations and agree well with the ACE and WIND observed datasets and can be useful for correcting GOCE mission gradiometer measurements due to their high resolution. By using these external and independent data we aim to understand the correlation between the disturbances observed in the GOCE gravity gradients and solar activity and eventually eliminate these effects from the gradiometer measurements.

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JA04p - JA4 Results from SWARM, Ground Based Data and Earlier Satellite Missions - Recognition of Eigil Friis-Christensen (IAGA, IAG, IAMAS)

JA04p-194

Comparison of plasma density and temperature by in-situ Langmuir probes and by incoherent scatter radars

L. Palin[1], H. Opgenoorth[1], S. Buchert[1], D. Knudsen[2], W. Archer[2], P. Erickson[3], M. Nicolls[4], A. Strømme[4], I. Coco[5]
[1]Swedish Institute of Space Physics, Space Plasma Physics, Uppsala, Sweden
[2]University of Calgary, Physics and Astronomy-, Calgary, Canada
[3]MIT Haystack Observatory, Atmospheric Sciences Group, Westford- MA, USA
[4]SRI International, Center for Geospace Studies, Menlo Park- CA, USA
[5]European Space Agency, ESRIN, Frascati, Italy

The Swarm Langmuir Probe measures plasma density and temperature in the tenuous topside ionosphere at a so far unprecedented temporal resolution. Thereby we can also resolve very fine spatial structures perpendicular to the orbit. With three satellites we are able to disentangle such spatio-temporal ambiguities, and look in a new way at topside ionospheric structures, in particular during events of magnetosphere ionosphere coupling or other dynamic ionospheric processes.

In this presentation we will show results from the calibration of such SWARM data with independent local measurements made with ground-based incoherent scatter radars, which also monitor the temporal dynamics of the plasma passed by SWARM for a much longer time. We will discuss the impact of temporal dynamics and spatial structures on the Swarm Langmuir Probe measurements.

Joint Inter-Association Symposium

JA05a - JA5 Physical Processes Prior to and During Earthquakes, Reliability of Precursors (IAGA, IASPEI)

IUGG-1001

Understanding fault failure.

M. Johnston[1]
[1]*U.S. Geological Survey, Earthquake Science Center, Menlo Park, USA*

Physical understanding of fault failure and prediction has remained elusive after more than a century of searching. Integration of geophysical data obtained during the last 50 years shows the likely reason for this failure. Fault zone geology, seismology, geodesy, heat flow, continuous deformation and laboratory data indicate geometrical irregularities in the fault surface exert major controls on the starting and stopping of ruptures, earthquake ruptures are multiple events produced by heterogeneous mechanical properties along the fault, faults are weak with a maximum shear stress on the order of 10 MPa, the average fault friction coefficient is on the order of 0.2, the stress release (stress drop) during earthquakes is ~1 MPa over thirteen decades of earthquake magnitude and fault failure nucleation size for damaging earthquakes is minuscule (<10 cm) and does not scale with final moment release. With this background, observed stress accumulation rates are uniform over hundreds of kilometers around active faults with no measurable deviations from these rates prior to earthquakes that might indicate the initiation of fault failure. These diverse data imply that earthquakes are runaway events where any small earthquake can cascade into any size event and the size of an earthquake is determined, not by how it starts, but by how it is stopped. Such scale-invariant behavior (Self Organized Criticality) where the size of an eventual earthquake is controlled by poorly known external boundary conditions (fault branching, different material properties, heterogeneous slip behavior, variable fault strength, non-linear friction, etc) appears to make short-term prediction intrinsically impossible.

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JA05a - JA5 Physical Processes Prior to and During Earthquakes, Reliability of Precursors (IAGA, IASPEI)

IUGG-1162

"New evidences confirming the relationships between electromagnetic precursors and intermediate depth earthquakes, Vrancea zone"

D. Stanica[1], *D.A. Stanica*[2]
[1]*Institute of Geodynamics of the Romanian Academy, Electromagnetism and Lithosphere Dynamics, Bucharest, Romania*
[2]*Institute of Geodynamics of the Romanian Academy, Electromagnetism and Lithosphere Dynamics, Bucharest, Romania*

Identification of the electromagnetic signals related to earthquakes is still under scientific debate and requires new reliable information about their possible inter-relationship. Consequently, in this paper, to obtain new insights into the Vrancea lithosphere, we used a 3-D magnetotelluric image to strengthen the connection between the geodynamic model and earthquake generation mechanisms. It is also considered that before earthquake initiation, due to the torsion process, the high stress reached in the seismogenic volume generates rocks dehydration and fluid migration along the faulting systems what lead to the lithosphere conductivity changes. We investigate these changes by using ULF electromagnetic data recorded in real time at the Geodynamic Observatory Provita de Sus, located at about 100km distance of the seismic active Vrancea zone. The daily mean distribution of the parameter Bzn = Bz/Bperp (where: Bz is vertical component of the geomagnetic field; Bperp is geomagnetic component perpendicular to strike) and its standard deviation are performed by using a FFT band-pass filter analysis in the frequency range 0.001Hz to 0.016Hz for which a 2-D geoelectrical structure exist. After analyzing the anomalous intervals on the Bzn* time series, obtained by using a standardized random variable equation, in correlation with earthquakes of $Mw \geq 4$, triggered in Vrancea zone in 2014, we may conclude that: (i) a pre-seismic value of maximum Bzn* reflects an impending earthquake; (ii) a superimposed effect of some earthquakes occurred at short time-intervals is also reflected by a maximum value; (iii) pre-seismic lead time is between 1 day to 32 days before the impending earthquake.

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IUGG-1302

Natural time analysis of seismicity as critical phenomena

S. Uyeda[1]
[1]*retired, Tokyo, Japan*

Natural Time Analysis of Seismicity as Critical Phenomena

S. Uyeda, M. Kamogawa and Y. Tomizawa

The postulate that analysis in Natural Time of time series of a dynamic system can specify when the system enters a critical stage is examined and its anzatz is reconstructed first and then the Natural Time analysis is applied to major earthquakes in Japan, assuming they are critical phenomena. In Natural Time, which may be alternatively called Event Time, one is interested in the order and energy of events but not in the time intervals between events. A dynamic system is judged as entering a critical stage when a specific index (variance of Natural Time weighted by the energy of the k-th event) approaches 0.07. This synergistic effect of the lateness and energy of events is the anzatz. The frequency distribution of this index calculated from actual seismic catalogues depends on the choice of the studied region, earthquake threshold and so on. Actual data as well as numerical simulations demonstrate that the frequency distribution of this index is not universal but mainly governed by the b-value of the concerned Gutenberg-Richter relation, higher b-value favoring peak at 0.07 . When one follows the time evolution this index in a seismic catalogue and finds it approaches with time to 0.07 from above, with spatial and magnitude scale invariance, we call such a case “true coincidence”. It was shown that true coincidence was clear before the 1995 Kobe earthquake, but not so clear for other earthquakess.

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IUGG-3229

Geoelectrical signals in seismotectonic areas: Knowns and unknowns

V. Lapenna[1]
[1]*CNR-IMAA, Tito, Italy*

This review conveys why 40 years of research on electrical phenomena observed in seismic areas leads to unfruitful debates and controversial conclusions. Since the “claimed” prediction of 1975 Haicheng (M =7.3) earthquake the scientific community paid great attention to discuss about the possible application of the electrical signals as earthquake precursors. The contribute of this work is to start with a critical reflection on the electrical-earthquake related signals separating knowns and unknowns. We select problems in which the scientific knowledge on geoelectrical phenomena has in recent decades rapidly developed: i) the 3D/4D resistivity modelling of complex seismotectonic structures; ii) the laboratory experiments with dry and saturated rock samples under mechanical stress; iii) the dynamical and multifractal analysis of time-dependent changes of electrical signals. On the other side, to-date the quality of ground-based observations of the electrical phenomena in world-wide seismic active areas is completely insufficient. The poor spatial resolution of monitoring network, the absence of operative standard protocols for field data acquisition and open-access data-bases of geoelectrical signals are the main drawbacks. Furthermore, while the seismoelectric effect in which the propagation of a seismic wave in a porous media can produce electrical signals has been clearly demonstrated, no robust models are available to describe the generation of the electrical signals potentially produced by mechanical stress and fluid-migration in focal areas. It appears extremely urgent to promote international collaborations for creating a modern network of seismoelectrical observatories and new models for jointly analyse seismic and electrical data generated in focal zones.

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IUGG-5486

The predictive value of short-term foreshocks

G.A. Papadopoulos[1], *M. Avlonitis*[2], *B. Di Fiore*[3], *G. Minadakis*[4]
[1]*National Observatory of Athens, Insitute of Geodynamics, Athens, Greece*
[2]*Ionian University, Department of Informatics, Corfu, Greece*
[3]*National Observatory of Athens, Institute of Geodynamics, Athens-, Greece*
[4]*National Observatory of Athens, Institute of Geodynamics, Athens, Greece*

Foreshocks preceding mainshocks in the short-term, ranging from minutes to a few months prior the mainshock, have been known from several decades ago. Understanding the generation mechanisms of foreshocks was supported by seismicity observations and statistics, laboratory experiments, theoretical considerations and simulation results. However, important issues remain open. For example, (1) Why only some mainshocks are preceded by foreshocks and not others? (2) Is the mainshock size dependent on some attributes of the foreshock sequence? (3) Is that possible to discriminate foreshocks from other seismicity styles (e.g. swarms)? To approach possible replies to these issues we reviewed about 400 papers, reports, books and other documents referring to foreshocks as well as to relevant laboratory experiments. We found that the ratio of mainshocks preceded by foreshocks increases with the increase of monitoring capabilities and that foreshock activity is dependent on source mechanical properties and favoured by material heterogeneity. Also, the mainshock size does not depend on the largest foreshock size but rather by the foreshock area. Seismicity statistics may account for an effective discrimination of foreshocks from other seismicity styles. Our literature survey showed that only the last years the seismicity catalogs organized in some well monitored areas are adequately complete to search foreshock activities. Therefore, we investigated for a set of “positive foreshock examples” covering a wide range of mainshock magnitudes from 4.5 to 9 in Japan, S. California, Italy and Greece. The positive examples used indicate that foreshocks bear important value for the mainshock prediction.

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IUGG-0284

Using of geomechanical models with geodetic and seismological data for the stress state monitoring in order to earthquake prediction

M. Gokhberg[1], *M. Garagash*[2], *V. Bondur*[3]
[1]*Shmidt Institut of the Physik of the Earth, Earth electromagnetic field, Moscow, Russia*
[2]*Shmidt Institut of the Physik of the Earth, geomechanical lab., Moscow, Russia*
[3]*AEROCOSMOS Institut for Scientific Research of Aerospace Monitoring, institut itself, Moscow, Russia*

Using of GPS observations and geomechanical models of the Earth's crust can detect short-term earthquake precursors. This result was obtained for the strong earthquake with a magnitude of M7.1, named Hector Mine, which occurred on October 16, 1999. in Southern California. To analyze the changes in the Earth's crust displacement field before the earthquake have been used the network from 21 stations GPS. Analysis of stress and strain showed that since July 1999 the stress-strain state of the earth's crust changed. Gradually, in the area bordering the Hector Mine earthquake epicenter, decreased the mean stress and shear strain risen.

Using of geomechanical model with seismological data in Southern California allow to analyse the stress-strain dynamic for the strongest earthquakes with M = 5.6 – 7.2 in the time interval 2009-2010.

Long-term observations of the Earth's crust displacement allow to allocate the places of possible earthquakes. So for the territory of Dagestan by GPS observations during 2002-2010 identified two local areas with high levels of strain and stress. In one of these places (near the settlement of Izberbash) 16.04.2013 was the earthquake with magnitude M4.8

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IUGG-1384

Electromagnetic pulses detected during and prior to earthquakes

M. Tsutsui[1]
[1]*Kyoto Sangyo University, Computer Sciences, Kyoto, Japan*

We have been observing electromagnetic (EM) waves in the earth and above the ground. For detecting EM waves, two sensor systems composed of tri-axial magnetic search coils and a vertical electric field antenna were respectively inserted into a bore hole of 100 m in depth and installed on the ground. When a big earthquake (M 6.3) occurred at 115 km distance from the EM observation site on April 13, 2013, the sensor system on the ground first detected tri-axial magnetic components of a pulse, and 13 sec later, another magnetic pulse was detected in the borehole, together with a seismic wave on the ground surface. This result suggests that these EM pulses were excited due to piezo-electric effect in the earth crust caused by vibrations of seismic S-wave, and they were radiated from the ground surface [1]. In the analysis of waveforms of EM pulses simultaneously detected above and under the ground surface, the EM pulse above the ground showed an elliptic polarization whereas that in the earth showed a linear polarization. This result suggests that the EM pulse was radiated from the deep earth passing through a boundary (the ground surface) of two media with different refractive index . Another earthquake-related EM pulse containing electric field component was detected above the ground at about 7 hour prior to an earthquake (M3.9) occurred at a distance of 24 km from the EM observation site. Based on my speculated excitation mechanism, this kind of EM pulses could be regarded as a precursory signal of the earthquake.

[1] Minoru Tsutsui, Behaviors of Electromagnetic Waves Directly Excited by Earthquakes, IEEE Geoscience and Remote Sensing Letters, Vol. 11, No. 11, pp-1961-1965, 2014.

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JA05b - JA5 Physical Processes Prior to and During Earthquakes, Reliability of Precursors (IAGA, IASPEI)

IUGG-2112

Earthquakes: can be analysed within similar mathematical framework withother extreme events?

S.M. Potirakis[1], G. Balasis[2], C. Nomicos[3], K. Eftaxias[4]
[1]Technological Education Institute TEI of Piraeus, Department of Electronics Engineering, Athens, Greece
[2]National Observatory of Athens, Institute for Astronomy- Astrophysics- Space Applications and Remote Sensing, Athens, Greece
[3]Technological Education Institute TEI of Athens, Department of Electronics Engineering, Athens, Greece
[4]University of Athens, Department of Physics, Athens, Greece

The field of study of complex systems considers that the dynamics of complex systems are founded on universal principles that may be used to describe a great variety of scientific and technological approaches of different types of natural, artificial, and social systems. We apply concepts of the nonextensive statistical physics, on time-series data of observable manifestations of the underlying complex processes ending up to different extreme events, in order to support the suggestion that a dynamical analogy characterizes the generation of a single earthquake (in terms of pre-seismic electromagnetic signals), epileptic seizure, magnetic storm, solar flare, and economic crisis. The analysis reveals that all the above mentioned different extreme events can be analyzed within similar mathematical framework. More precisely, we show that the populations of magnitudes of fluctuations included in all the above mentioned pulse-like-type time series follow the traditional Gutenberg–Richter law as well as a nonextensive model for earthquake dynamics, with similar nonextensive q-parameter values. Moreover, based on a multidisciplinary statistical analysis we show that the extreme events are characterized by crucial common symptoms, namely: (i) high organization, high compressibility, low complexity, high information content; (ii) strong persistency; and (iii) existence of clear preferred direction of emerged activities. These symptoms clearly discriminate the appearance of the extreme events under study from the corresponding background noise.

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IUGG-2360

Evidences of electro-magnetic changes associated to earthquakes: the case of the seismic swarm of the Pollino area (Southern Italy)

M. Balasco[1], *G. Romano*[2], *M. Santoro*[2], *A. Siniscalchi*[2], *T.A. Stabile*[1], *L. Telesca*[1], *V. Lapenna*[1]
[1]*Institute of Methodologies for Environmental Analysis, National Research Council of Italy, Tito Scalo- PZ, Italy*
[2]*University of Bari, Department of Earth and Geo-Environmental Science, Bari, Italy*

During 2011-2012 the seismic activity, in a sector of the Calabro-Lucanian Apennines in Southern Italy, has been gradually intensified, culminating in M_w=5.2 earthquake occurred on 25 October 2012 at 23:05:24 UCT. At the time of the mainshock, two magnetotelluric monitoring stations were operating: Tramutola station (Agri valley, Basilicata region, Southern Italy) active since 2006 and 50 km away from the epicentre and Campotenese station installed on 26 September 2012 by the IMAA-CNR directly in the area interested by the seismic swarm (10 km away from the epicentre).

In this study we investigate the characteristics of the electro-magnetic anomalies associated with the seismic wave passage (Seismo-Electromagnetic signals, SE). Differently from other studies focused on these kind of signals fortuitously recorded during a magnetotelluric survey, we present a large observational database which also includes anomalies related to very low magnitude earthquakes (M_L=2).

The availability of co-located seismic (LE 3D Lite Lennartz tri-axial velocimeter, managed by INGV) and a MT station in the last phase of the seismic swarm occurred in Pollino area (2246 events with $M_L \geq 0.4$ in three months between the mainshock) gave us a rare opportunity to study earthquake-related temporal patterns of electromagnetic signals potentially informative about ongoing seismogenic processes.

The seismo-electromagnetic signals recorded during several earthquakes have been analyzed and compared with the corresponding seismograms by means of the continuous wavelet transform. We found an excellent waveform similarity but also some noteworthy differences.

Therefore a relationship is found between electro-magnetic anomaly amplitudes and earthquake magnitudes.

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IUGG-2786

Towards the identification of pre-seismic electric signals of VAN method in geoelectric data collected by the joint EMSEV-Bishkek RS-RAS Cooperation

N.V. Sarlis[1], *E.S. Skordas*[1], *P.A. Varotsos*[1], *T. Nagao*[2], *J. Zlotnicki*[3], *V. Bragin*[4], *E. Vorontsova*[4], *S. Uyeda*[5]
[1]*National and Kapodistrian University of Athens, Department of Solid State Physics and Solid Earth Physics Institute- Faculty of Physics- School of Science, Athens, Greece*
[2]*Tokai University, Earthquake Prediction Research Center, Shizuoka, Japan*
[3]*Centre National de la Recherche Scientifique, Observatoire de Physique du Globe de Clermont-Ferrand- Laboratoire Magmas et Volcans, Clermont-Ferrand, France*
[4]*Bishkek Research Station, Russian Academy of Science, Bishkek, Kyrgyzstan*
[5]*Japan Academy, Section II- Division 4, Tokyo, Japan*

In the frame of the EMSEV and the Bishkek Research Station of the Russian Academy of Science (RS-RAS) Cooperation, two geo-electric stations (ISA and SHA) have been installed in Kyrgyzstan and supported from the Bishkek RS-RAS since November 2011. Here, we present a preliminary analysis of the collected data focused on the identification of possible Seismic Electric Signals (SES) activity of the VAN method before the occurrence of strong earthquakes (EQs). This analysis showed that almost two and half months before the occurrence of the strongest EQ (mb=5.2) in this region -with epicentral distance at about 130km from both stations- anomalous geoelectric variations were observed with characteristics which seem to be similar to the ones of SES activities. Furthermore, an investigation of “co-seismic” electric signals recorded upon the arrival of seismic waves is presented.

Acknowledgements

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JA05b - JA5 Physical Processes Prior to and During Earthquakes, Reliability of Precursors (IAGA, IASPEI)

IUGG-3596

Robust procedures for the characterization of earthquake-related seismoelectromagnetic signals

A. Siniscalchi[1]*, M. Balasco*[2]*, G. Romano*[1]*, M. Santoro*[1]*, T.A. Stabile*[2]*, L. Telesca*[2]
[1]*University of Bari, Department of Earth and Geo-Environmental Science, Bari, Italy*
[2]*Institute of Methodologies for Environmental Analysis, National Research Council of Italy, Tito Scalo - PZ, Italy*

Seismo-Electromagnetic (SE) coupling occurring in porous media are increasingly matter of study both in the framework of a seismological context and in prospective of applied geophysical one.

As regard earthquake-related SE response, its accurate estimation needs the development of specific techniques in order to remove the background magnetotelluric (MT) signal. As evidenced also by wavelet analysis, SE signals are located in a frequency range known as the 'MT dead band' in which the power spectrum of the natural EM field has a minimum. This is a favourable circumstance for the detection of SE due to the fact that the MT signal can be considered "noise" to be estimated and removed. We will present two different approaches to optimize this removal:

- the first one based on the simultaneous analysis of data coming from MT sites located at different distances from the hypocentre (coseismic signals having different arrival time);

- the second one in which windowed variance estimates are done prior and after the SE signal occurrence.

These procedures were then tested and applied to statically derive the attenuation laws of the SE signals. For this purpose, we used a catalogue of earthquakes with a magnitude spanning in the range 2-7 and a distance between MT sites and hypocentres up to 800 km.

Finally for a sub-set of earthquake recorded from a seismic station located just in correspondence of the MT one, a joint analysis was performed.

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JA05c - JA5 Physical Processes Prior to and During Earthquakes, Reliability of Precursors (IAGA, IASPEI)

IUGG-0419

Monitoring of ULF electromagnetic noise as a component of earthquake prediction: perspectives and problems

V. Pilipenko[1], *V. Surkov*[2], *E. Fedorov*[1], *N. Yagova*[1]
[1]*Institute of Physics of the Earth, Space Environment Lab., Moscow, Russia*
[2]*National Research Nuclear University "MEPhI", Physics Dept., Moscow, Russia*

Monitoring of electromagnetic emission in the ULF-ELF frequency range at an array of ground magnetometers is one of the main tools of the electromagnetic earthquake prediction. These observations provided promising results for many events - an increase of ULF-ELF noise intensity several days-weeks before a seismic shock. In some observations, alterations of the spectral or polarization structure of ULF-ELF noise have been revealed. In particular, we have modeled the electrokinetic and magnetohydrodynamic effects accompanying either pore fluid filtration in the conductive crust or volcanic magma movement. We also showed that the occurrence of the region with modified electrokinetic parameters, due to an elevated impulsive acoustic noise in an area of earthquake preparation, results to anomalous telluric and magnetic fields on the Earth's surface. These theoretical models prove the principal possibility of electromagnetic monitoring of seismic or volcanic activity, which can effectively augment traditional seismic methods. However, there is one important feature of ULF observations that have not been taken into account so far - the influence of distant thunderstorms, because stroke impulses in the ULF band could be reliably detected by standard magnetometers at distances up to 2000 km. Thus, a model of expected ULF response to distant thunderstorms might be very useful for seismo-forecasting community, which would enable a researcher to estimate a possible limit on the contribution of world-wide lightning into recorded ULF noise at any site, and thus to avoid false alarms. We propose such a model based on the database of lightning locations detected by the WWLLN system.

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IUGG-2552

Further development of ULF precursors detection method for short-term earthquake prediction

V. Korepanov[1], *F. Dudkin*[2], *D. Dudkin*[2]
[1]*Lviv Centre of Institute for Space Research, Lviv, Ukraine*
[2]*Lviv Centre of Institute for Space Research, LEMI, Lviv, Ukraine*

Reliable short-term earthquake prediction still remains unattainable in spite of many years of intensive research. The ULF seismo-electromagnetic precursors of earthquake seem to be the most often observed. The main problems for their recognition are: a) their separation from the natural or man-made interference background; b) source localization. A promising method for ULF precursors recognition with use of the polarization ellipse technique was developed and successfully tested [1]. The method is based on synchronous 3-component magnetic field measurements and polarization ellipse calculations in two observation points located at distance 30-100 km. It allows studying the space-temporal distribution of the lithospheric magnetic activity in seismo-active area before earthquake and to get statistically valid position of the earthquake preparation area. Main problem at the method implementation is an absence of the properly organized measuring sites with high-sensitive magnetometers. The attempt to test this method with use of the data from INTERMAGNET observatories network has been done. The results of study the ULF lithospheric magnetic activity in Kanto region, Japan are reported in presentation.

1. F. Dudkin, V. Korepanov. Magnetic field polarization ellipse: a new approach for detection of pre-earthquake lithospheric activity. The frontier of earthquake prediction studies. Ed. M. Hayakawa. Tokyo, The University of Electro-Communications, 2012. P. 212-244.

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JA05c - JA5 Physical Processes Prior to and During Earthquakes, Reliability of Precursors (IAGA, IASPEI)

IUGG-2782

Can the ionospheric plasma turbulence seen over the earthquake be distinguished from the turbulence with another origin? Results of DEMETER

J. Blecki[1], M. Kosciesza[1], M. Parrot[2], J. Slominski[1], R. Wronowski[1]
[1]Space Research Centre PAS, SRC, Warsaw, Poland
[2]LPC2E/ CNRS, LPC2E, Orleans, France

During the time of the DEMETER satellite operation thousands of the earthquakes occured. The disturbances of the electromagnetic field around areas of the earthquakes as preseismic events can appear even few days before main shock. We report the electromagnetic effects registered by DEMETER prior to the earthquakes with magnitude over 6. We selected events with good coverage of the measurements in the burst mode when the wave form of the electric field were registered. It is because the special attention is given to study of the characteristics of the spectra of these variations and search forthe nonlinear effects. Using wavelet and bispectral analysis as well as the statistical characteristics of the measured parameter and structure functions, we find that registered variations are associated with developing of the ionospheric plasma turbulence. It is mainly Kolmogorov type of the turbulence.

In the present work analysis of the low frequency fluctuations of the electric and magnetic fields for the selected strong earthquakes will be given.

The mechanism of the energy transmission from the earthquake to the ionosphere is not clear, but we can discuss the behavior of the ionospheric plasma and search of the instabilities which could be a source of the electromagnetic field variations. Some attempt of this discussion will be given in the presentation. We will present results obtained prior to the some giant earthquakes (Peru2007, Wechuan China 2008, Haiti 2010, Chile 2010).

Some remarks related to the efficiency of the measured parameters as a precursors of the earthquakes and suggestions for future satellites studies will be also given particularly in the connection with ESA SWARM mission.

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JA05c - JA5 Physical Processes Prior to and During Earthquakes, Reliability of Precursors (IAGA, IASPEI)

IUGG-3142

Multi-parameter Integration of space and ground observations for detection pre-earthquake anomalies: Case of M6, Napa and other earthquakes in 2014

D. Ouzounov[1], V. Tramutoli[2], S. Pulinets[3], J.Y. Liu[4], K. Hattori[5], M. Kafatos[1]
[1]Chapman University,
Center of Excellence in Earth Systems Modeling & Observations CEESMO, Orange, USA
[2]University of Basilicata, School of Engineering, Potenza, Italy
[3]Russian Academy of Sciences, Space Research Institite, Moscow, Russia
[4]National Central University, Institute of Space science, Chung-Li, Taiwan Republic of China
[5]Chiba University, Department of Earth Sciences, Chiba, Japan

We integrate multiple space-born and ground sensors for monitoring pre-earthquake geophysical anomalies that can provide significant early notification for earthquakes higher than M5.5. The latest M6.0 event of August 24, 2014 in South Napa, California generated pre-earthquake signatures during our outgoing tests. We process in controlled environment different satellite and ground data for California (and several other test areas) by using: a) NPOES sensors recording OLR (Outgoing Longwave Radiation) in the infrared; b) TIR (Thermal Infrared) data from geostationary satellite (GOES); c) 3/GNSS data (GPS/TEC); and d) ground-based gas observations and meteorological data. On Aug 4th, we detected a large anomaly of OLR transient field at the TOA over Northern California and we issued an internal warning for a M5.5+ earthquake in Northern California within the next 1-4 weeks. TIR retrospective analysis showed significant (spatially extended and temporally persistent) sequences of TIR anomalies starting August 1st just in the future epicenter area and approximately in the same area affected by OLR anomalies in the following days. GPS/TEC retrospective analysis based on GIM and TGIM products show anomalies TEC variations 1-3 days, over region north form the Napa earthquake epicenter. The prospective analysis revealed similar trend of pre-earthquake OLR anomalies for two other major earthquakes for 2014 - M7.0 of July 12 in Honshu, Japan and M 6.1 of Dec 10 in Taiwan. Our real-time and post-event integration of several atmospheric parameters from satellite and ground observations during the M6+ earthquakes in California, Japan and Taiwan demonstrated the synergy of related variations of these parameters implying their connection with the earthquake preparation processes.

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JA05c - JA5 Physical Processes Prior to and During Earthquakes, Reliability of Precursors (IAGA, IASPEI)

IUGG-3843

On the possible origin of earth's emitted anomalous transients observed by infrared satellite sensors in differently degassing earthquake's prone areas

V. Tramutoli[1,2,3], C. Aliano[1], R. Corrado[1], C. Filizzola[2], N. Genzano[1], M. Lisi[1,3], V. Lanorte[4], G. Martinelli[5], N. Pergola[1,2]
[1]University of Basilicata, School of Engineering, Potenza, Italy
[2]National Research Council, Institute of Methodologies of Environmental Analysis, Tito Scalo, Italy
[3]International Space Science Institute, ISSI Team, Bern, Switzerland
[4]Regional Agency for the Environmental Protection, Basilicata, Potenza, Italy
[5]Environmental Protection Agency, Reggio Emilia, Reggio Emilia, Italy

Several studies performed in the past three decades have suggested the existence of anomalous space-time transients in the Earth's thermally emitted radiation - measured by satellite TIR (Thermal InfraRed sensors) in relation with impending earthquakes. A Robust Satellite Technique (RST) have been proposed (and successfully applied to tens of earthquakes occurred worldwide) to discriminate pre-seismic space-time TIR transients from those variations due to other causes. To explain the appearance of such anomalous TIR signal transients a local green-house effect, due to the increase of optical active gases (like CO_2, CH_4, etc.) emission rates, have been suggested. In this paper this hypothesis is evaluated by simulations (performed by using MODTRAN Radiative Transfer code) and by comparison of results achieved by RST in correspondence of earthquakes occurred in areas characterized by different prevailing degassing activity (i.e. CO_2 or CH_4). Results show that, in case of earthquakes occurring in areas where CO_2 degassing is dominant, thermal anomalies can be (in low wind conditions) observed quite close to morphological lineaments and tectonic faults (as it is to be expected for diffusing gases heavier than air). Such an overlapping is instead less marked or absent in case of CH_4 degassing (as it is to be expected for diffusing gases lighter than air). Moreover, results obtained by the MODTRAN simulation highlighted that an increase of only 2–3 times the normal CO_2 mixing ratio level, is already sufficient to justify the observed TIR signal anomalies.

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IUGG-4648

The relationship between ionospheric disturbances detected by HF Doppler observation and ground perturbations associated with earthquakes

H. Nakata[1], K. Takaboshi[1], K. Yoshikawa[1], Y. Shimizu[1], T. Takano[1], I. Tomizawa[2], M. Matsumura[3]
[1]Chiba University, Graduate School of Engineeing, Chiba-shi, Japan
[2]The University of Electro-Communications,
Center for Space Science and Radio Engineering, Chofu-shi, Japan
[3]National Institute of Polar Research, Geoscience group, Tachikawa-shi, Japan

It has been known that ionospheric disturbances occur after earthquakes because acoustic waves excited by surface waves or tsunamis propagate upward and disturb the ionosphere. However, the quantitative relationship of the ionospheric and ground perturbations is still unclear. In this study, therefore, we compared the ionospheric vertical perturbations observed by the HF Doppler (HFD) data and vertical ground motions recorded by seismometers. In the HFD observation, the vertical drift of the ionosphere is determined by the Doppler shift of HF radio waves transmitted from the Chofu campus of the University of Electro-Communications. To obtain accurate vertical drift, we determined reflection altitudes of the radio wave from ionogram data observed at Kokubunji maintained by National Institute of Information and Communications Technology. For seismometer data, we used seismometer data of seismic networks by K-NET, KiK-net, and F-net, which is installed by National Research Institute for Earth Science and Disaster Prevention. We examined the correlation of the maximum values of ionospheric vertical drift velocity and the ground vertical velocity for 20 earthquakes (M>6.0, 2003-2013). Since HFD shows the ionospheric vertical drift in the reflection point of the radio waves, the seismometer located at the closest from the reflection point is selected for each observatories. As for Sugadaira observatory, ionospheric vertical velocity tends to increase in proportion to the square root of the ground velocity. In the presentation, we will discuss these relations as compared to the results of a numerical simulation of atmospheric waves.

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IUGG-3184

Ionospheric precursors of the 11 March 2011 M9.0 Tohoku Earthquake

J.Y. Liu[1], *I.T. Lee*[1], *C.H. Chen*[2], *Y.Z. Su*[1], *K. Hattori*[3]
[1]*National Central University, Institute of Space Science, Jhongli, Taiwan Republic of China*
[2]*National Chung Kong University, Department of Earth Sciences, Tainan, Taiwan Republic of China*
[3]*Chiba University, Graduate School of Science, Chiba, Japan*

In this paper, the total electron content (TEC) of the global ionosphere map (GIM) is used to observe seismo-ionospheric anomalies associated the 11 March 2011 M9.0 Tohoku earthquake, while the Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) is applied to simulate and understand the observed anomalies. The observation shows that the TEC over the epicenter significantly and continuously enhances on 6-8 March 2011, 4-2 days before the earthquake. The spatial analysis further demonstrates that the enhancement anomaly specifically and persistently appears in the northern epicenter area. Simulation results well agree with the observations, which suggest that the eastward electric field around the epicenter has been distorted and significantly affects the TEC during the earthquake preparation period.

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IUGG-3618

Recent advances in remote sensing of natural hazards-induced atmospheric and ionospheric perturbations

Y.M. Yang[1], *A. Komjathy*[1], *X. Meng*[1], *O. Verkhoglyadova*[1], *R. Langley*[2], *A. Mannucci*[1]
[1]*NASA, Jet Propulsion Laboratory, Pasadena, USA*
[2]*University of New Brunswick, Department of Geodesy and Geomatics Engineering, Fredericton, Canada*

Traveling ionospheric disturbances (TIDs) induced by acoustic-gravity waves in the neutral atmosphere have significant impact on trans-ionospheric radio waves such as Global Navigation Satellite System (GNSS, including GPS) measurements. Natural hazards, such as earthquakes, tsunamis and volcanic eruptions are actual sources that may trigger acoustic and gravity waves resulting in disturbances in the upper atmosphere. Trans-ionospheric radio wave measurements sense the total electron content (TEC) along the signal propagation path. In this research, we introduce JPL's novel detection techniques and physics-based modeling capabilities for remote sensing of atmospheric wave-induced TIDs including space weather phenomena induced by major natural hazard events, using TEC time series collected from worldwide GNSS networks.

Furthermore, we demonstrate the ability of using space-based GNSS and other radio frequency signals to improve and enhance the ground-based GNSS observations. Through analysis of the GNSS soundings, we are able to classify major wave trains that are simultaneously observable using ground networks and space-borne GNSS receivers. Dominant physical characteristics of atmospheric wave-induced TIDs are found to be associated with specific natural hazard events. Additionally, comparisons of GNSS observations, corresponding model simulations and other geophysical measurements, are shown to lead to a better understanding of the atmosphere-ionosphere responses to natural-hazard events. We anticipate that observations using GNSS remote sensing of thermosphere-ionosphere disturbances will become cornerstones for future applications in natural-hazards monitoring. It is expected that these novel technologies will become an integral part of future early-warning systems.

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IUGG-4851

Ionospheric seismology : from Earth maturity with waveform modeling to Venus dreams

P. Lognonné[1]*, L. Rolland*[2]*, P. Coisson*[3]*, V. Rakoto*[1]*, K. Khelfi*[1]*, D. Walwer*[4]*,*
M. Drilleau[1]*, E. Astafyeva*[5]*, D. Komatitsch*[6]*, J. Makela*[7]*, G. Occhipinti*[1]
[1]*Université Paris Diderot-Sorbonne Paris Cité,*
Institut de Physique du Globe de Paris, Paris, France
[2]*Université de Nice- CNRS, GeoAzur, Nice, France*
[3]*Institut de Physique du Globe de Paris-Sorbonne Paris Cité,*
Université Paris Diderot, Paris, France
[4]*Ecole Normale Supérieure, Laboratoire de Géologie, Paris, France*
[5]*CNRS- Université Paris Diderot-Sorbonne Paris Cité,*
Institut de Physique du Globe de Paris, Paris, France
[6]*Centre National de la Recherche Scientifique,*
Laboratoire de Mécanique et d'Acoustique, Marseille, France
[7]*University of Illinois at Urbana-Champaign, Airglow group, Urbana-Champaign, France*

Ionospheric seismology, which was at most seen as an exotic way to record doubtful signals in the early 2000 has gain maturity, especially after the worldwide observations made during the Tohoku 2011 earthquake and tsunami.
We focus first on the agreement of observations with normal modes modeling, for either Rayleigh, acoustic or tsunami ionospheric signals, detected with different tools: ground GPS, LEO GPS onboard Cosmic or airglow systems. These confrontations of data and synthetics waveforms are made for the Tohoku 2011 and Haida Gwai earthquake and tsunamis.
We then present for the Tohoku 2011 the impact of the non-linearity of the ionospheric response by showing modeling performed with the Spectral Element Method, and demonstrate that the ionospheric blown-off above the epicenter, well observed on the data, is fairly well reproduced by the modeling. This effect, if not considered properly, might generate artefacts prior the quake when the ionospheric background is removed from the GPS TEC data.
We conclude by the Earth and Planetary perspectives of ionospheric seismology. For the Earth, we discuss therefore the perspectives of inversion for both the source location and the remote observations of tsunami and discuss the limitation of ionospheric seismology for future near real time measurement of the ocean vertical displacement associated to tsunami. We then conclude by showing the perspective

of orbital observation on Venus through full waveform simulation of the 1.27 micrometer airglow perturbation, and demonstrate that detection threshold of Ms=5.5-6.5 can be achieved at 60° of epicentral distances, depending on the performances of the airglow systems.

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IUGG-5123

Numerical simulations of co-seismic electromagnetic signals

Q. Huang[1], *H. Ren*[2]
[1]*Peking University, Department of Geophysics, Beijing, China Peoples Republic*
[2]*University of Science and Technology of China,*
School of Earth and Space Sciences, Hefei, China Peoples Republic

Field reports indicated the existence of the electromagnetic signals accompanying with natural earthquakes. Such co-seismic electromagnetic signals may provide some information of earthquake rupture process. Based on the recently developed numerical technique, which can simulate the coupled seismic and electromagnetic signals in porous media, we investigated numerically the co-seismic electromagnetic signals for a double couple point source and a finite fault planar source. Besides the source effect, the simulation results showed that both medium structure and medium property could affect the co-seismic electromagnetic signals. The waveform of coupled signals for a layered structure is more complicated than that for a simple uniform structure. Different from the seismic signals, the electromagnetic signals are sensitive to the medium properties such as fluid salinity and fluid viscosity. The results may provide some insights of understanding the difference in the detectability of co-seismic electromagnetic signals in different geological regions.

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IUGG-5262

Magnitude estimation by ionospheric detection of Rayleigh waves

G. Occhipinti[1], *F. Aden-Antoniow*[2]
[1]*Institut de Physique du Globe de Paris, Paris, France*
[2]*Institut de Physique du Globe de Paris, Seismology, Paris, France*

Surface waves emitted after large earthquakes are known to induce, by dynamic coupling, atmospheric infrasonic waves propagating upward through the neutral and ionized atmosphere. Those waves have been detected in the past at ionospheric heights using a variety of techniques, such as HF Doppler sounding or GPS receivers. The HF Doppler technique, particularly sensitive to the ionospheric signature of Rayleigh waves is used here to show ionospheric perturbations consistent with the propagation of Rayleigh wave phases R1 and R2 following the Sumatra earthquake on the 28 March 2005 (M = 8.6). This is in our knowledge the first time that the phase R2 is detected by ionospheric sounding. In addition, we prove here that the ionospheric signature of R2 is also observed by over-the-horizon (OTH) Radar (Occhipinti et al., 2010). Adding the OTH Radar to the list of the “ionospheric seismometers” we finally introduce the ionospheric magnitude and we apply it to 65 events observed by “ionospheric seismometers”.

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JA05p-057

Characteristics of seismo-acoustic emission during 'in situ' discontinuity shear experiments

A. Ostapchuk[1]*, D. Pavlov*[1]*, V. Ruzhich*[2]*, E. Vinogradov*[1]
[1]*Institute of Geosphere Dynamics- Russian Academy of Sciences, Laboratory of Deformation Processes in the Earth's Crust, Moscow, Russia*
[2]*Institute of the Earth's Crust- Russian Academy of Sciences Siberian Branch, Laboratory of Tectonophisics, Irkutsk, Russia*

This study presents results of 'in situ' experiments investigating seismo-acoustic emission in shearing a discontinuity at a segment of the Angarsky Overthrust at the Baikal Rift Zone.
Experiments were performed at the setup 'Tribo'. A concrete block 1 x 1 x 0.3 m^3 in size weighing 525 kg was put on an outcropping sliding surface of a natural fault with the dip angle of 43-45^o to the south-west. The contact between the block and the rock was filled with a layer of discrete material, simulating the principal slip zone of a fault. Quartz sand, diorite crumb and rock salt were used as filling materials.
Various sliding modes were realized in experiments – from creep to dynamic failure with various seismic moments realized per one instability act. Experiments shown that different sliding modes can be realized both in the way of quasi-regularly repeated events and in the way of stochastic events. Each mode was accompanied by radiation of precursors – seismo-acoustic signals of different waveforms.
The regularities of seismo-acoustic emission change essentially, depending on the realized sliding mode. In one case there are no precursor pulses, while in another case the signals are registered throughout the whole cycle. The precursor waveform allows to judge about the local processes in the discontinuity, and acoustic emission activity has a potential to indicate the contact damage degree. Statistics of acoustic precursors obeys the Gutenberg-Richter law. The characteristic acoustic events caused by dynamic failures form a separate peak, making a "gap" in the energy. Depending on the sliding regime the probability of dynamic failure occurrence differs essentially.
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JA05p-058

Detection of seismic precursors using D-index for ionospheric total electron content

M.N. DEVIREN[1], F. ARIKAN[1], O. ARIKAN[2], T. GULYAEVA[3], G. GOK[2]
[1]HACETTEPE UNIVERSITY,
ELECTRICAL AND ELECTRONICS ENGINEERING, ANKARA, Turkey
[2]BILKENT UNIVERSITY, ELECTRICAL AND ELECTRONICS ENGINEERING, ANKARA, Turkey
[3]IZMIRAN, INSTITUTE, MOSCOW, Russia

In recent years, detection of seismic precursors from ionosphere has become an important research topic. Dual-frequency GPS receivers can be used to estimate Total Electron Content (TEC), which is one of the main observables to monitor the variability of ionosphere. TEC is defined as the total number of electrons on a ray path and GPS-TEC provides a projection of the total variability in ionization content. Another source of obtaining TEC is from empirical ionospheric models. International Reference Ionosphere Extended to Plasmasphere (IRI-Plas) TEC represents the background ionosphere. Symmetric Kullback-Liebler Distance (SKLD) indicates the variability in the general diurnal form of TEC. In this study, SKLD is computed between GPS-TEC and IRI-Plas-TEC values. D-index is a measure of variability in a neighborhood of GPS station containing the regional disturbance around the earthquake epicenter. In this study, GPS-TEC from Turkish National Permanent GPS Network (TNPGN-Active) are estimated as IONOLAB-TEC (www.ionolab.org) and diurnal SKLD is computed between IRI-Plas-TEC (www.izmiran.ru/services/iweather/SPIM) and IONOLAB-TEC between May 2009 and September 2012. D-index is also computed for each GPS station in TNPGN-Active for neighboring stations within 150 km radius. The disturbance level is grouped with respect to the magnitude, depth and type of the earthquakes. It is observed that D-index is a promising indicator of fault-type earthquakes with magnitudes larger than 4 in Richter Scale. This study is supported by the joint grant of TUBITAK 112E568 and RFBR 13-02-91370-CT_a.

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JA05p-059

Seismogenic ionospheric anomalies possibly associated with the strong Indonesian earthquake: A multi-instrument approach

O.P. Singh[1], *A.K. Singh*[1], *U. Pandey*[1,2], *B. Singh*[3]
[1]*R.B.S. Engineering Technical Campus, Department of Physics, Agra, India*
[2]*Banasthali University, Department of Physics, Tonk, India*
[3]*R.B.S. Engineering Technical Campus,*
Department of Electronics & Communication Engineering, Agra, India

Multi-instrument approach using ULF/VLF radio signal and GPS based TEC measurement method for studying the pre-seismic activity is applied to strong Indonesian earthquake (M = 8.5,11 April, 2012 at 08:38 UT). The earthquake was the 11th strongest earthquake since 1900. We analyzed ± 15 days data of ULF search coil magnetometer, SoftPAL VLF receiver and TEC data of GPS receiver and found anomalous signature before 1-7 days of the main shock. Pulse azimuth and unipolar analysis of ULF data was done to find pre-seismic signature. Using two different analyses approach for VLF signal, that are the study of the night-time signal and shifts in the evening terminator times, clear anomalies were revealed 2 and 3 days before the occurrence of the earthquake. This is in accordance with the ULF observation at our station. The superposed epoch analysis is performed over the basis of 5 days before and 5 days after the EQ to determine the spatial pattern of total electron content (TEC) anomalies in the ionosphere prior to the earthquake. Potential causes of the results are discussed with emphasis given to vertical acoustic gravity waves, as well as the development of lower atmospheric electric fields with transference into the ionosphere along geomagnetic lines.

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JA05p-060

A statistical study for relationship between anomalous transmission of VHF band radio waves and impending Earthquakes at Hidaka Area, Japan

S. Morita[1], *T. Mogi*[1]
[1]*Hokkaido University, Faculty of Science, Sapporo, Japan*

Recently, some researchers have discussed precursory phenomena related to impending earthquakes statistically (Liu et al., 2011; Orihara et al., 2012; Hattori et al., 2013; Han et al. 2014).The observation anomalous VHF-band radio-wave propagation beyond the line of sight prior to earthquakes is one of candidate methods to predict an earthquake (Kushida and Kushida, 2002,Moriya et al.,2010).

We carried out statistical investigation by using received radio-wave intensity data from a FM station beyond the line of sight between 1st January, 2012 and 31st December, 2013, observed at the Erimo observatory, Hokkaido, Japan. We calculated success rate and alarm rate (Utsu, 1977) for the earthquakes of M>3.0 that occurred within the epicentral distance at radius of 100km and 150km from the Erimo observatory. By the simultaneous appearance of anomalous intensity at the long-distance observatory, we inferred the anomalous radio-wave intensity data affected by the sporadic E and removed them.

The result showed that higher success rate than that of an arbitrary occurrence case was obtained with the earthquakes of M>4.5 that occurred within 100km from Erimo observatory. The maximum success rate gain between the real occurrence and arbitrary case was obtained at 10 days after anomalous reception. The results also indicated that the success rate by the anomalous radio-wave propagation was related with the earthquake (M>4) that occurs within 10 days with probability of approximately 30%.

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JA05p-061

Investigation of total electron content variations before the Aegean Sea earthquake (24.05.2014 Mw 6.9)

M. Ulukavak[1], M. Yalçinkaya[1], S. Zengin Kazanci[1], E. Tanir Kayikçi[1]
[1]Karadeniz Technical University, Department of Geomatics Engineering, Trabzon, Turkey

Global Positioning System (GPS) satellites have been used as sensors with the development in space and satellite techniques. Total Electron Content (TEC) variations in the ionosphere before, during and after the earthquake can be identified by means of GPS observations. Thus, the effects of earthquakes over TEC variations can be monitored. In this study, the effects of the Aegean Sea Earthquake (Mw 6.9), occurred off Aegean Sea in 24 May 2014 at 09:25:03 UT, was investigated and pre-seismic TEC variations were examined. 42-days (between DoY 115 and 156) vertical TEC (VTEC) variations of CORS-TR (Continuously Operating Reference System-Turkey) stations at study area, AYVL, IPSA and YENC, were determined and used to monitor the ionospheric TEC variations before the earthquake. In order to investigate these pre-earthquake ionospheric anomalies, two indices related to the space weather conditions which are solar activity index (F10.7) and geomagnetic activity index (Dst) were investigated by eliminating the ionospheric anomalies that arise from solar activities and geomagnetic storms. Potential causes of these activities were discussed. The observations, which showed a significant increase in VTEC, started 8-9 days before the earthquake. This study concludes that the observed possible anomalous variations in GPS-TEC were related to the earthquake.

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JA05p-063

Local changes in the total electron content and coseismic magnetic field disturbances observed around the 2009 L'aquila earthquake shock

P. Nenovski[1], U. Villante[2], M. De Lauretis[2], M. Vellante[2], M. Pezzopane[3], L. Ciraolo[4]
[1]Sofia University- Sofia- Bulgaria,
University Center for Space Research and Technology, Sofia, Bulgaria
[2]Università dell'Aquila- L'Aquila- Italy,
Dipartimento di Scienze Fisiche e Chimiche, L'Aquila, Italy
[3]Istituto Nazionale di Geofisica e Vulcanologia-Rome- Italy, Geofisica, Rome, Italy
[4]ICTP- Trieste- Italy, ICTP, Trieste, Italy

An overview of the local changes both in the TEC (Total Electron Content) and in the magnetic field variations observed around the 2009 L'Aquila earthquake main shock is done. Ionospheric TEC (Total Electron Content) variations derived from GPS measurements recorded at 7 GPS stations in Northern, Central and Southern Italy before and after the 2009 L'Aquila earthquake (EQ) of magnitude M_w6.3 were processed and analyzed. The analysis included interpolated and non-interpolated TEC data. Variations in the TEC of both regional and local characteristics were revealed. Several regional changes were observed in the studied period: 1 January-21 April 2009. After analyzing non-interpolated TEC data of 5 GPS stations in Central Italy (Unpg (Perugia), Untr (Terni), Aqui (Aquila), M0se (Rome) and Paca (Palma Campania, Naples)), a local disturbance of TEC was also found. This local TEC disturbance arises preparatory to the EQ main shock occurred at 01:32 UT on 06 April 2009, maximizes its amplitude of ~ 0.8 TECu after the shock moment and disappears after it. The local TEC disturbance was confined at heights below 160 km, i.e. in the lower ionosphere.

Local magnetic field disturbances of co-seismic character are also discovered at L'Aquila. The event emerges at the EQ shock and it is characterized by a growth of the total magnetic field. Possible mechanical effects connected with the EQ shock itself (lasting ~20 seconds) are filtered off. The form, duration, amplitude and polarization properties are examined. Possible source mechanisms of the co-seismic magnetic field signal are proposed and considered.

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JA05p-064

Network seismic forecasting for Vrancea area

V.E. TOADER[1], *I.A. MOLDOVAN*[2], *I. CONSTANTIN*[3]
[1]*National Institute for Earth Physics, Seismic Network, Magurele, Romania*
[2]*National Institute for Earth Physics, Magnetotelluric and Bioseismic Studies, Magurele, Romania*
[3]*National Institute for Earth Physics, General Manager, Magurele, Romania*

Vrancea (the bending zone of the Carpathians Mountains) is a complex area characterized by intermediate depth earthquakes concentrated and distributed on several depth levels. It generates high energy that spreads on large areas (Istanbul, Moscow). A complex monitoring and alert network operates within “Romanian National Institute for Earth Physics”. Since 2013 Romanian seismicity recorded few important events: the largest seismic quiescence (13/07/05), the shortest sequence of two earthquakes greater than 4.8R (5.5R - 13/10/06,4.9R -13/10/15) in less than 14 days, a very high crustal activity in Galati area (8 events in 13/09/29 – 13/10/05, max magnitude 3.9R), sequence in Marasesti zone (max 5.7R–14/11/22) and starting with 2015 we have 5 earthquake over 4R (max 4.7R–88.4 Km 15/01/24). A multidisciplinary network monitors seismicity, telluric and magnetic field, electric-electrostatic field, radio LF waves, air ionization, radon concentration, solar radiation, infrasound, light and acoustic phenomena, meteorological data, air-ground temperatures, and satellite data with application in the Vrancea seismic area. The most part of data analysis is automatically done into a distributed structure. Data acquisition is followed by their analysis (detection, effects evaluation) and automatic transmission of alerts to beneficiaries specialized in emergency situations. The seismicity and the cumulative energy evolution are part of this analysis. Acoustic manifestation of tectonic stress is a new and original approach. Five stations continuously record data from air and ground. The animal behavior confirms this precursor phenomenon. Network monitoring allows tracking of climate change and information in real time. System structure, software and methods implemented are original.

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JA05p-065

Analysis of the lower ionospheric perturbations: Application to natural hazard risk assessment

M. Solovieva[1], A. Rozhnoi[1], B. Levin[2], V. Fedun[3], M. Hayakawa[4], K. Schwingenschuh[5], H. Eichelberger[5]
[1]Institute of physics of the Earth, Geoelectrodynamics, Moscow, Russia
[2]Institute of Marine Geology & Geophysics of Far Eastern Branch of RAS, direction, Yuzhno-Sakhalinsk, Russia
[3]University of Sheffield, Department of Automatic Control and Systems Engineering, Sheffield, United Kingdom
[4]Hayakawa Institute of Seismo Electromagnetics Co. Ltd. UEC, direction, Chofu Tokyo, Japan
[5]Space Research Institute- Austrian Academy of Science, Experimental Space Research, Graz, Austria

The method of very and low-frequency (VLF/LF) signals monitoring of ionospheric perturbations in connection with natural hazards (earthquakes, tsunamis, volcanic eruptions) is presented. The main objectives of the investigation are: (i) development of models of lithosphere-atmosphere-ionosphere coupling; (ii) practical use of the obtained results for prediction and monitoring of natural hazards. The work is based on data obtained from a network of VLF/LF receivers, sited in the Far East and Europe. We have been investigating electromagnetic precursors of earthquakes more than 25 years. A comparison of the results of joint analysis of ground-based and satellite DEMETER observations during the periods of strong seismic activity in the Far East region in 2004-2010 is considered. Observations at European network are used for the analysis of the earthquake in Vrancea zone in November 2014. Recently this method has been applied to investigation effects in the lower ionosphere driven by tsunamis and volcanic eruptions The response of the lower ionosphere to tsunamis resulting from the 2006 Kuril, 2011 Tohoku and 2010 Chile earthquakes is investigated. Perturbations in the VLF signals have been found during the tsunamis passage along the VLF sensitivity zones. The first result was obtained in analysis of the measurements at three VLF/LF stations during pre-eruptive activity of Mt. Kirishima in January 2011 (South Japan). A spectral analysis made for the disturbed VLF/LF signals caused by natural hazards events reveals the maximum of spectra energy in the interval of periods of about 7-55 min. A qualitative interpretation of the observed

effects is suggested in terms of the interaction of internal gravity waves with the lower ionosphere.

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JA05p - JA5 Physical Processes Prior to and During Earthquakes, Reliability of Precursors (IAGA, IASPEI)

JA05p-066

Identification of thermal anomalies based on satellite image processing as earthquake precursory

F. Taghavi[1], *M.R. Hatami*[2]
[1]*Institute of Geophysics-University of Tehran, Space Physics, Tehran, Iran*
[2]*Institute of Geophysics-University of Tehran, Earth Physics, Tehran, Iran*

Several physical parameters are investigated in earthquake precursory case studies in Iran. Land surface Temperature anomalies signals are the one which could be used as auxiliary data in earthquake prediction scenario. These signals are associated with pre-seismic processes, causing enhanced IR emissions, also called Thermal Infrared anomalies. The purpose of this study is to verify if TIR anomalies can be observed in association with known large earthquakes by systematically applying satellite data analysis techniques to imagery recorded prior-to and immediately after large earthquake.In this study, time series of satellite TIR imaging are used and pre- procesed prior to major earthquakes with Mw >6 occurred in Iran including Firooz Abad Kojoor, Mw 6.2 , 2004/05/29; Varzaghan, Mw 6.2 ,2012/08/11;Boushehr, Mw 6.3, 2013/04/19; Saravan Mw 7.5 , 2013/04/16 earthquakes. These earthquakes are known to associate with fault systems. The corresponding data includeing time series of NDVI and Brightness Temperature of the bands 31, 32 were derived from MODIS images and the Qin Algorithm was then applied to calculate Land surface Temperature.The results confirm the existence of an anomaly in LST data before these events for Saravan and Varzaghan earthquakes. The short-lived anomalies have been reported to appear normally 2-4 days before an earthquake and can affect an area of several thousands square km. Our results show positive deviation of >5 °C and to disappear a few days after the main event. The time scale of the observed variations is a one week before the onset of the seismic event.

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JA05p-067

"Study of the dynamical properties of the five seismically regions in Mexico by using visual recurrence analysis"

A. Ramírez-Rojas[1], *L.R. Moreno-Torres*[1], *R.T. Páez-Hernández*[2], *I. Reyes-Ramírez*[3]
[1]*Universidad Autónoma Metropolitana, Ciencias Básicas, México, Mexico*
[2]*Universidad Autónoma Metropolitana, Ciencias Básicas, Méxioo, Mexico*
[3]*UPIITA-IPN, Física, México, Mexico*

In order to identify properties of the underlying dynamics of five seismically active regions in Mexico, we study the recurrence plot behavior based on the visual recurrence analysis (VRA). We have considered the sequence of events (magnitudes) in time and the inter-events time series. Our analysis shows important differences in the recurrence maps of each region indicating local dynamical properties. Our finding suggest that the patterns obtained could be associated with the local geophysical structures of each subduction and dispersion zones driven by their characteristic nonlinear dynamical features of each region.The present study was partially supported by the Bilateral Project 000000000234790 between CNR(Italy)Italy-Conacyt(Mexico), and Irreversible Physics Processes Research Area of the UAM-A.

*Postgraduate (M. Sc.) student in Universidad Autónoma Metropolitana, Azcapotzalco

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JA05p-068

Visibility graph approach in investigating the magnitude time series of seismicity of the Mexican subduction zone

A. Ramirez-Rojas[1], *L. Telesca*[2], *M. Lovallo*[3], *T.A. Stabile*[2]
[1]*Universidad Autónoma Metropolitana, Ciencias Básicas, México, Mexico*
[2]*National Research Council- Institute of Methodologies for Environmental Analysis , Fisica, Tito, Italy*
[3]*ARPAB, Física, Potenza, Italy*

The seismic sequences extracted from the seismic catalog of the Mexican subduction zone, occurred between 2005 and 2012, were investigated by using the novel statistical approach of Visibility Graph (VG). Five seismic areas of the Mexican subduction zone, Guerrero, Chiapas, Oaxaca, Jalisco and Michoacan, were investigated. Our results evidence that among the five seismic areas, the Jalisco magnitude sequence shows VG properties significantly different from those shown by the other four. Such a difference could be inherent in the peculiar seismo-tectonic settings of Jalisco. Furthermore, the typical seismological b-value of the Gutenberg–Richter law is found to be in close relationship with the topological VG parameter, named k-M slope. The found relationship is also hold by synthetic seismicity generated by an experimental model of stick-slip fault. The present study was supported by the Bilateral Project Italy-Mexico 'Experimental Stick-slip models of tectonic faults: innovative statistical approaches applied to synthetic seismic sequences', jointly funded by MAECI (Italy) and AMEXCID (Mexico) in the framework of the Bilateral Agreement for Scientific and Technological Cooperation PE 2014-2016.

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JA05p-069

Electromagnetic Impact on Geological Medium: Numerical Estimation of Ineraction Parameters

V. Zeigarnik[1], *A. Avagimov*[2]
[1]*Joint Institute for High Temperatures- RAS, Directorate, Moscow, Russia*
[2]*Joint Institute for High Temperatures- RAS, Pulsed Energenics in Geophysics, Moscow, Russia*

Efficiency of initiating impact as well as trigger energy value depend on seismic activity of the medium generally and of future focus space in particular. This statement is supported by experimental data on energetic features of dynamic process obtained in process of physical modeling - threshold values $A_{itr}(k_p)$ for initiating and triggering impacts. Correlation was made between these experimental values and real natural field data concerning to induced seismicity due both to magnetic storms with sudden commencement over Caucus region and to electrical pulses supplied with MHD-generator at Bishkek geodynamical proving ground.

The required energy of initiating impact for given earthquake class K depends on seismic activity of medium and can be estimated by use of $A_{itr}(k_p)$ obtained by authors in experiments. This value is equal to 10^{-8} immediately before disintegration of a sample and $10^{-7} \div 10^{-6}$ for the stage of intensive cracking ($k_p \geq$ 0.95).Thus magnetic storm is liable to initiate seismic events with $K \geq 8$ under condition of increased seismic activity of a medium. Required energy will be defined by threshold value $A_{itr} = 10^{-8}$. Under condition of decreased seismic activity the energy of magnetic storm is sufficient only to initiate more weak seismicity with $7 \leq K \leq 8$, threshold value that defines the impact energy required being equal $10^{-7} \div 10^{-6}$. It was established that for the Tien Shan region magnetic storms initiate events mainly of low energy level: $7 \leq K \leq 8$.

We also consider induced seismicity due to electrical pulses of the MHD generator. Calculation shows the energy of the MHD generator’s pulse is enough to cause an earthquake of K=7 – 10 (for K≤8 the energy is of order of 2 – 3 more than it is needed to initiate such events).

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JA05p-070

Spatial variation Characteristics of the geoelectric field signals originated from heavy currents in the Huadong area of China

Q. Ma[1]
[1]*Earthquake Administration of Shanghai Municipality- Shanghai 200062- China, Shanghai, China Peoples Republic*

In this paper, by studying the signals originated from grounding electrodes 1800_4780 A current of four converter stations in different places around the Shanghai area and recorded at eight geoelectric field stations in the Huadong area in China, we could have a better understanding of the variation of the geoelectric field. The study shows that 1 The magnitude of the additional geoelectric field recorded at different stations present extremely big variation for the different current source. Only the signals originated from Nanqiao grounding electrode are observed at Pudong station which is near the heavy current sources, but that from Tongli, Huaxin and Fengxian grounding electrodes are not recorded at the station, which means there is so-called sensitive site. 2 The furthest distance is 350km between the source and the station that could observe the signals originated from these four heavy current sources, and at more than 350 kilometers of the stations no any additional geoelectric signals from the sources could be recorded. 3 The uniformity degree of the geoelectric field in the area does not follow the regular patterns of homogeneous medium, which illustrates that the characteristics of inhomogeneous medium and anisotropy are obvious at many stations in the area. At each station for the different heavy current the amplitude ratio of the additional geoelectric field on long dipole to short dipole could vary bigly.

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JA05p-071

Laboratory models of seismic and mass-movement process triggering

N. Varamashvili[1], M. Devidze[1], T. Chelidze[2], N. Javakhishvili[1]
[1]I. Javakhishvili Tbilisi state University- M.Nodia Institute of Geophysics, Dynamic of Geophysical fields and computing Geophysics, Tbilisi, Georgia
[2]I. Javakhishvili Tbilisi state University- M.Nodia Institute of Geophysics, Applied Geophysics, Tbilisi, Georgia

In this abstract, we present the results of laboratory experiments on the electromagnetic and mechanical initiation and synchronization of mechanical instability (slip).

The laboratory model for triggering experiments consists of two pieces of basalt; the upper piece can slip on the fixed supporting sample if the latter one is tilted up to the critical angle. The slope of support in the experiment is an analogue of tectonic stress in natural conditions. The laboratory experiments, where strong EM pulses were applied to the mechanical system driven close to the critical state, show that the EM impact can either initiate or hamper instability (here, slip) occurrence, depending on the mutual orientation of the slip surface and electrical field.

Triggering and synchronization of instabilities in experimental spring-slider system were investigated by recording acoustic emission, accompanying the slip events. Experiments on the standard spring-slider system, subjected to a constant pull and superimposed to it weak mechanical or EM periodic force in dry environment show that, at definite conditions, the system manifests the effect of phase synchronization of micro-slip events with the weak periodic excitation. The quality of synchronization depends on the intensity and frequency of the applied field. With increasing external mechanical forcing one can see increasing phase synchronization of the first arrivals (onsets) of stick-slip generated acoustic pulses.

We conclude that our laboratory experiments give a sound principal basis for interpretation of field data on the control of seismic and mass-movement regime by relatively weak natural or artificial perturbations.

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JA05p-072

Do the scaling laws associated with fracture and faulting emerge from geometrical heterogeneities or from critical behavior of earthquake dynamics?

S.M. Potirakis[1], G. Balasis[2], K. Eftaxias[3]
[1]Technological Education Institute TEI of Piraeus,
Department of Electronics Engineering, Athens, Greece
[2]National Observatory of Athens,
Institute for Astronomy- Astrophysics- Space Applications and Remote Sensing, Athens, Greece
[3]University of Athens, Department of Physics, Athens, Greece

One of the largest controversial issues of the materials science community is whether the spatial and temporal complexity of earthquakes and fault structures, above all the interpretation of the observed scaling laws, emerge from geometrical and material built-in heterogeneities or from the critical behavior inherent to the nonlinear equations governing the earthquake dynamics. A number of laboratory studies carried out on a wide range of materials have revealed the existence of EMEs during fracture experiments, while these emissions are ranging in a wide frequency spectrum, i.e., from the kHz to the MHz bands. A crucial feature observed on the laboratory scale is that the MHz EME systematically precedes the corresponding kHz one. The aforementioned crucial feature is observed in geophysical scale, as well. The remarkable asynchronous appearance of these two EMEs both on the laboratory and the geophysical scale implies that they refer to different final stages of faulting process. Accumulated laboratory, theoretical and numerical evidence supports the hypothesis that the MHz EME is emitted during the fracture of process of heterogeneous medium surrounding the family of strong entities (asperities) distributed along the fault sustaining the system. The kHz EME is attributed to the family of asperities themselves. We argue in terms of the fracture induced pre-seismic MHz-kHz EMEs that the scaling laws associated with the fracture of heterogeneous materials emerge from the critical behavior inherent to the nonlinear equations governing their dynamics (second-order phase transition), while the scaling laws associated with the fracture of family of asperities have geometric nature, namely, are rooted in the fractal nature of the population of asperities.

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JA05p-073

Anomalous behavior of ionospheric parameters before and after series of earthquakes 2013 on Kamchatka

V. Bogdanov[1]*, A. Kaisin*[1]*, A. Pavlov*[1]*, A. Polukhova*[1]*, C.V. Meister*[2]
[1]*Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS, Laboratory of Atmosphere Physics, Paratunka, Russia*
[2]*University of Technology Darmstadt, Institute of Nuclear Physics, Darmstadt, Germany*

In the present report the variations of ionospheric parameters and ionospheric turbulence before and during seismic events are studied applying complex radiophysical methods and using a theoretical probability approach, suggested by the authors. The probability approach allowed to detect the growth of seismic activity in the Kamchatka region in 2013. It is found that characteristic ionospheric features as K-layer formation (corpuscular layer due to precipitation of particles from the radiation belts), increase of the characteristic foF2-frequency and formation of F- spread as well as Es-spread occured about one day before some seismic events on February-March (28.02.-02.03) 2013 and some days before series of the events on 19-24 May 2013.

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JA05p-074

Study of seismic electromagnetic signals and their relation with tectonophysics in the central region of Colombia

A. Caneva[1], C.A. Vargas-Jimenez[2], J.M. Solano-Fino[2]
[1]Antonio Narino University, Research Center, Bogota, Colombia
[2]National University of Colombia, Faculty of Geosciences, Bogota, Colombia

Since the 1980s, in different countries (Japan, Russia, United States, Greece, France, among others) a systematic monitoring of changes in the electric and magnetic fields of the Earth have been carried out. These changes are associated with different causes, such as the natural evolution of magnetotelluric field, the action of lightnings, human activities, as well as, seismic activity.

Laboratory experiments have shown that a stress field in a deformed sample, provides some particular values of difference of electrical potential and of magnetization of the sample's material associated to that stress field. These values differ from those in absence of deformation. The stress field variations, and therefore, the deformation, are expressed in the emission and propagation of electromagnetic pulses in the sample.

At a macro-scale, when seismicity is monitored, a similar behavior is observed. In this case the ground plays the role of "sample" that undergoes deformation due to the stress field, generating electromagnetic signals that can be recorded experimentally by using electric dipoles and magnetometers.

The information obtained experimentally, related to these electromagnetic signals, positively complements the information acquired by using other geophysical methods, allowing to reach a better understanding of physical processes.

In the central part of Colombia, an array of 5 multiparametric stations is being deployed. Each station includes 2 perpendicular electric dipoles (approx. 100 m length each), magnetometer, seismic sensor, gas radon sensors, and GNSS receiver. Here we present the preliminary results of instrumental deployment, and the identification of a possible relation between anomalies of these electromagnetic signals and the seismic activity in this region.

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JA05p-075

Scrutiny of non-seismic multi-Geophysical time series of Garhwal Himalaya for earthquake precursory research

<u>N. Kumar</u>[1], G. Rawat[2], C. Vishal[2], S. Dhamodharan[2]
[1]Wadia Institute of Himalayan Geology, Dehradun, India
[2]Wadia Institute of Himalayan Geology, Geophysics Group, Dehradun, India

The first Multi-Parameter Geophysical Observatory (MPGO) of India established at Ghuttu in Garhwal Himalaya has long continuous time series of different geophysical parameters recorded since 2007. The station equipped with gravity, magnetic, radon and a water-level recorder is located close to Main Central Thrust (MCT), situated within a narrow zone of High Himalayan Seismic Belt (HHSB). The northern dipping MCT coincides with Main Himalayan Thrust (MHT) which is further gently dipping towards north. This region is located in between 1905 devastating Kangra earthquake zone and 1934 Bihar earthquake zone and is known as seismic gap in terms of great earthquakes. A careful scrutiny of the data associated with the Kharsali earthquake (Mw5.0) of 2007, the nearest strong event located at ~60 km distance and Ms5.7 Nepal earthquake of 2011 at ~220 km distance, revealed unambiguous co-seismic gravity jump. Similarly, radon fluxes show some definite trend that can be viewed as pre- and co-seismic changes related to Kharsali and similar size earthquakes. Sudden drop of geomagnetic field intensity and dynamic waveform, lasting from several days before to a week after the earthquake, appears to be a manifestation of the thermal agitation on the magnetization of rocks around the source region of the earthquake. The results obtained so far for few moderate magnitude earthquakes (4.0>M>5.0) occurred within 200 km have some promises to earthquake precursors in multi-parameter approach and the presentation shall focus on the success and limitation in quantifying the precursors.

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JA05p-076

Variability of seismo-atmospheric-ionospheric coupling: Dependence on the atmospheric conditions

E. Astafyeva[1], *P. Lognonné*[1]
[1]*IPGP, Department of Planetology and Space Sciences, Paris, France*

Seismic waves generated by large earthquakes as well as by other impulsive vertical displacements, are known to induce perturbations in the atmosphere and ionosphere. However, before the emitted waves reach the ionospheric heights, they endure a number of impacts provided by the propagation medium, i.e. the atmosphere. The properties of the atmospheric “channel” in the vertical propagation depend on a variety of factors such as solar and geomagnetic conditions, latitude, local time, season, and their influence on propagation of co-seismic perturbations is not well understood yet.

In this work, in order to better understand the role of the atmospheric conditions on the energy transfer in the atmosphere/ionosphere system, we use method of normal modes calculation for spherical non-rotating elastic isotropic Earth for Rayleigh spheroïdal solid modes (Lognonné et al., 1998, Geophys. J. Int., 135, 388-406, doi:10.1046/j.1365246X.1998.00665.x). The variability of the atmospheric coupling is investigated by estimating the amount of seismic energy injected in the atmosphere under variable atmospheric and solar-geomagnetic conditions. Our study is based on the example of six large earthquakes (M>6.9) occurred worldwide in 1995-2011. We include in our study 2 events that generated the largest CID ever recorded (the 2004 Sumatra earthquake and 2011 Tohoku-oki earthquake), and also 3 other events with moment magnitude over the known threshold over 6.8, but nevertheless with no CID detected after. We show that the efficiency of seismo-atmosphere-ionosphere coupling depends on various parameters.

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JA05p-077

Short-term warnings for moderate earthquakes based on cluster location of small magnitude events in Vrancea (Romania)

A. Apostol[1], A. Constantin[2], I.A. Moldovan[3], I. Jurca[4], D. Toma Danila[5], V.E. Toader[6]
[1]Center of Bioseismology, Center of Bioseismology, Covasna, Romania
[2]National Institute for Earth Physics, Seismological dep., Magurele, Romania
[3]National Institute for Earth Physics, Magnetoteluric si Bioseismic dep., Magurele, Romania
[4]Geoecomar, Geoecomar, Bucuresti, Romania
[5]National Institute for Earth Physics, Engineering Seismology, Magurele, Romania
[6]National Institute for Earth Physics, Romanian Seismic Network, Magurele, Romania

During November 22, 2013 – January 31, 2015 we monitored the daily activity of red wood ants (RWA) and the stress around a crustal fault in Covasna in correlation to the earthquake activity recorded in Vrancea seismically active region situated at . It was supposed, based on data in the literature, that RWA have a well-identifiable daily routine that can be disturbed hours before local and/or regional earthquakes. However, no RWA activity was disturbed, in spite of normal and intermediate-depth events in Vrancea with magnitudes up to 5.7. With 2-3 weeks before earthquakes with moderate magnitude 4.5 – 5.7 we observed a cluster of small events with magnitude 2.0 – 3.0 recorded at both ends of Vrancea seismically active intermediate-depth region. Three successful short-term warnings have been issued to NIEP before a normal-depth earthquake with magnitude 5.7 and other two intermediate-depth events (M5.0 and M4.6).

During the years 2010 – 2015 the stress across crustal faults situated up to 50-60 km far from the Vrancea seismically active region has been monitored by bio-location. The area of bio-location reaction obtained across these faults increased between the start of 2010 up to 23rd of November 2013. From this date till 25th of January 2015, the bio-location reaction was zero. This situation suggests a slow slip that started at an intermediate-depth in Vrancea and lasted for 14 months. The slow slip was hampered from time to time by small and moderate- size asperities. Before earthquakes with a moderate magnitude, the stress around asperities increased and as a result small magnitude earthquakes clustered at both ends of the Vrancea region. This observation might be applied to be used as a warning for the next large

and destructive intermediate-depth event in Vrancea

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JA05p-078

"Anomalies in geomagnetic secular variations and their relationship to tectonic processes around Japan islands, revisited"

K. Yamazaki[1]
[1]*Miyazaki Observatory- Kyoto University,*
Research Center for Earthquake Prediction- Disaster Prevention Research Institut e, Miyazaki, Japan

In early ages of modern geomagnetic field observations, close relationship between tectonic activities including earthquake preparation processes and anomalies in the geomagnetic secular variations are focused (Tazima et al., 1976; Sumitomo, 1981). However, their results are based on data during a short period of time (<10 years), and on rather rough data analysis. Now we have longer data (~40 years), we can confirm whether their results are reproduced or not.
I use data of repeated surveys of the geomagnetic field published by Geospatial Information Authority of Japan (GSI), together with observatories' geomagnetic data from GSI and the Japan Meteorological Agency. Based on these data, a regional geomagnetic field model is determined, and differences between data and the model are regarded as "anomalies" in the geomagnetic secular variation. The basis functions used for the geomagnetic field model are designed in such way that they satisfy orthogonality over the region of interest. Because the shape of Japan islands are considerably different from spherical cap, for which the revised Spherical Cap Harmonics Analysis (Thebault, 2006) have widely used. The unique basis functions are designed by the Principal Component Analysis of Spherical Harmonic functions over the region of interest.
The result indicate that earlier results (e.g. Tazima et al., 1977) are not reproduced as it was. However, large anomalies in geomagnetic secular variations seem to be related to tectonically active areas.

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JA05p-079

EMSEV - RAS Bishkek Research Station cooperation on electrical and seismic phenomena in Kyrgyzstan: 2011-2014

T. Nagao[1]*, J. Zlotnicki*[2]*, N. Sarlis*[3]*, V. Bragin*[4]*, E. Vorontsova*[4]*, A. Rybin*[4]*,*
P. Varotsos[3]*, S. Uyeda*[5]
[1]*Tokai University, Earthquake Prediction Research Center, Shizuoka, Japan*
[2]*CNRS, OPGC, Clermont-Fd, France*
[3]*University of Athens, Faculty of Physics, Atens, Greece*
[4]*Russian Academy of Science, Bishkek Research Station, Bishkek, Kyrgyzstan*
[5]*Japan Academy, Pure Sciences, Tokyo, Japan*

EMSEV has long been promoting researches on active volcanoes and active faults (http://www.emsev-iugg.org/emsev/). In 2011, EMSEV started a new project on the relationship between the generation of earthquakes and electric/magnetic signals in Kyrgyzstan. In November 2011, the first symposium was held at the Research Station of the Russian Academy of Science (RS-RAS), Bishkek. At that time, RS-RAS and EMSEV signed Memory of Understanding (MOU).

RS-RAS (Director Anatoly Rybin, EMSEV member) has been conducting active monitoring of underground electrical conductivity over thirty years at several stations in the area of Kyrgyz ridge. Their experiment involves daily injection of powerful electrical currents up to 700 A from a 4.5-km long dipole. This is literally one of the world's largest scale electric/electromagnetic prospecting experiments. Through this experiment, resistivity changes were found prior to some moderate earthquakes. They also claimed that these resistivity changes were recovered after the seismic activities.

On the basis of the MOU, two geo-electric potential measurement stations were installed at about 30 and 40 km away from the current dipole in Nov. 2011. At the first workshop on the data processing held in Toulouse in March 2014, a report was made on clear co-seismic, and possibly pre-seismic electric signals for a moderate earthquake (M:5.2, epicenter at about 130km from the observation station). Since some monitoring channels were found noisy, we improved their configuration in June 2014, making data quality much better. In this work, we will describe in detail the results in the 3.5 year period of cooperation.

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JA05p-080

Geoelectrical potential variation observed in the Erimo area associated with 2011 Tohoku Earthquake and Tsunami.

T. MOGI[1]
[1]*Institute of Seismology and Volcanology- Hokkaido University, Sapporo, Japan*

Institue of Seisemology and Volcanology, Hokkaido University have monitored geoelectrical potential variation (EP) at six sites in the east Hokkaodo area. Electric potential difference at multiple directions have been observed in each site. Short line measurements at four directions, a vertical measurement in the borehole and a three components fluxgate magnetometer are installed in the Erimo observatory of Hokkaido Univ.
2011 Tohoku Earthquake (Mw=9.0) occurred at 14:46, 11th March. The P wave and S wave arrived at 14:47:51 and 14:48:47 respectively at the Erimo observatory. Large strain gap were documented at 14:48. Large EP variation in short line began at 14:48:19. No remarkable change was observed in the magnetic field. The EP variation began between the P and S wave arrivals and the variations continued 7 minutes and ceased. Tide changes associated with the tsunami were observed from 15:39. Large changes, higher than 3m, were observed four times until 19:00 and 1m size changes continued until 10am of the next day. Large EP variations began at tsunami arrival time and the variations well correlated with the tide changes during first 3 hours. Small EP variations had been observed at 6 minutes before the first tsunami arrival associated with the tsunami flow back.
Considering that the EP variation is induced by electromotive force due to moving of conductive sea water block in the geomagnetic field, the variation is largest at the direction perpendicular to the tsunami flow. In fact, observed EP variations showed that the electric current flows to the southwest when the tsunami came from the southeast. This suggested that the EP monitoring may forecast the direction of the tsunami arrival.

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JA05p-081

Ionospheric images of seismic fault. The M7.3 pre-Tohoku earthquake.

K. Shults[1], *E. Astafyeva*[1], *P. Lognonné*[1]
[1]*IPGP, Planetary and Space Science, Paris, France*

Earthquakes are known to be a source of atmospheric and ionospheric perturbations. During an earthquake, a sudden impulsive forcing from the ground generates atmospheric pressure waves that propagate upward into the atmosphere and ionosphere. The initial acoustic waves are often described as N-wave consisting of compression and rarefaction phases of a perturbation.

Propagation and spatio-temporal features of co-seismic ionospheric disturbances (CID) have been extensively discussed within last decade. In addition to CID observations, ionospheric GPS measurements have recently proved to be useful to obtain ionospheric images of seismic fault (Astafyeva et al., 2011, Geophys. Res. Letters, 38, L22104). However, so far, such ionospheric images for seismic fault have been done only for the great M9.0 Tohoku-earthquake. In the meantime, smaller magnitude earthquakes occurring much more often can also lead to catastrophic damages and tsunamis, and need to be studied. The question of use of ionospheric measurements for seismic applications is still on, and is of importance for tsunami early-warning system.

In this work, we use 1Hz data from GPS-receivers of the Japanese network GEONET to study the ionospheric response to the 9 March 2011 Tohoku foreshock (hereafter referred to as the pre-Tohoku earthquake). The M7.3 pre-Tohoku earthquake occurred at 02:45:20 UTC ~45 km northeast of the epicenter of the M9.0 mainshock, and caused a small tsunami runups of ~0.6 m. As a response to this earthquake, we observe a commonly known N-wave at the nearest to the epicenter GPS-receivers. Further, use we the same technique as in the case of the Tohoku earthquake to plot ionospheric images of the seismic fault ruptured in the pre-Tohoku earthquake.

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JA05p-082

Automated hourly process for global ionosphere map using near-real-time spaceborne and ground GPS observables

H.F. Tsai[1], *J.Y. Liu*[2,3,4], *Y.Y. Sun*[2], *T. Ho*[5], *C.H. Chen*[1]
[1]*National Cheng Kung University, Dept. of Earth Sci., Tainan, Taiwan Republic of China*
[2]*National Central University, Insitute of Space Sci., Jhongli, Taiwan Republic of China*
[3]*National Space Organization, -, Hsinchu, Taiwan Republic of China*
[4]*National Central University, Center for Space and Remote Sensing Research, Jhongli, Taiwan Republic of China*
[5]*Central Weather Bureau, Taiwan Analysis Center for COSMIC, Taipei, Taiwan Republic of China*

Recently, the global ionosphere map (GIM) has been used to study the seismo-ionospheric precursors (SIPs) intensively. In order to shorten the data latency of SIP monitoring, an automated GPS data processing system is built up to produce the hourly GIM data, which is based on the global GPS-TEC observational network by means of spherical harmonic function, where the global GPS total electron content (TEC) data is combined with the ground-based GPS observables and the spaceborne FORMOSAT-3/COSMIC radio-occultation (RO) observables. The statistical analysis of GIM and suspected seismic precursors based on the global maps are being introduced. The result can be used to find the repeat, duration and distribution of worldwide SIPs and timely estimate the possibility of forthcoming large earthquakes in the future.

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JA05p-083

Inversion of tsunami height using ionospheric observations. The case of the 2012 Haida Gwaii tsunami and earthquake

V. Rakoto[1], P. Lognonné[1], L. Rolland[2], M. Drilleau[1]
[1]Université Paris Diderot-Sorbonne Paris Cité,
Institut de Physique du Globe de Paris, Paris, France
[2]Université de Nice- CNRS, GeoAzur, Nice, France

Large earthquakes (i.e MW≥6) and tsunamis associated are responsible for ionospheric perturbations. These perturbations can be observed in the total electron content (TEC) measured from multi- frequency Global Navigation Satellite systems (GNSS) data (e.g GPS). In this poster we will study the Haida Gwaii earthquake and tsunami case. It happened the 28 october 2012 along the Queen Charlotte fault of the Canada Western Coast. First, we compare data of perturbation of quasi vertical TEC to our model. We model the TEC perturbation in three steps. (1) We model the neutral atmosphere perturbation using a normal modes summation which take into account all coupling effects between the ocean and the solid earth and atmosphere. This enables to compute either the ocean response (i.e. the traditional sea level change) or the atmospheric impact of the tsunami in terms of atmospheric wind. This modeling takes into account dissipation processes in the atmosphere. (2) We couple the ionosphere with the neutral atmosphere (3) We integrate the perturbed electron density along each satellite station line of sight. All the modeling are done for realistic atmospheric or ionospheric models, optimzed for the local time and location of the observations.
At last, we present first results about inversion of TEC data in order to know the water height of tsunamis and discuss the perspectives of real time measurements and inversion from both ground and airbone systems.

Joint Inter-Association Symposium

JA05p - JA5 Physical Processes Prior to and During Earthquakes, Reliability of Precursors (IAGA, IASPEI)

JA05p-606

Ionospheric electron enhancement 20-80 minutes before large earthquakes: Examples from 8 earthquakes with Mw 8.2-9.2

K. Heki[1], *Y. Enomoto*[2]
[1]*Hokkaido University, Dept. Natural History Sci., Sapporo, Japan*
[2]*Shinshu University, SASTec, Nagano, Japan*

Ionospheric electron enhancements have been found immediately before large earthquakes including the 2011 Tohoku-oki earthquake by observing total electron contents (TEC) with global navigation satellite system (GNSS) receivers (Heki, 2011). Its reality has been questioned later by Kamogawa & Kakinami (2013) and Masci et al. (2015), who considered the enhancement an artifact caused by wrongly defining the reference curves for TEC time series with tsunamigenic drops. Heki & Enomoto (2013), in response, suggested that vertical TEC (VTEC) clearly show preseismic increases as well as coseismic drops and that other sensors (foEs, geomagnetic field) show simultaneous anomalies. They also suggested that TEC increases of space-weather origin could be distinguished by checking their propagation properties.

The source of the debate comes largely from the derivation of the reference TEC curves from which anomalies are defined. Here we propose an objective numerical approach to detect significant positive breaks (increased rate of change) in the time series of vertical TEC using Akaike's Information Criterion (AIC). We demonstrate that significant breaks are detected 20-80 minutes before all of the eight recent large earthquakes (M_w 8.2 to 9.2) with appropriate GNSS data. The amplitudes of the breaks of TEC were found to depend on two factors, M_w and the background TEC. The onset times also showed dependence on M_w, but interplate and intraplate earthquakes obeyed different laws. We also performed the same analyses during the period of no earthquakes to evaluate implication of the method for practical earthquake prediction.

Joint Inter-Association Symposium

JA06a - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-0575

The atlas of the Earth's magnetic field 1500–2010

A. Gvishiani[1], *A. Rybkina*[1], *A. Solovyev*[1], *M. Mandea*[2]
[1]*GC RAS, The Russian Academy of Sciences, Moscow, Russia*
[2]*Centre National d'Etudes Spatiales, Responsable des Programmes Terre Solide, Paris, France*

Global study of the Earth's magnetic field is one of the fundamental problems of geophysics. Global modeling of the Earth's magnetic field is one of the main domains of geophysical research. The present Atlas of the Earth's Magnetic Field (EMF) for 1500–2010 was published as a result of a joint project, implemented in the framework of collaboration between the Russian Academy of Sciences (RAS) and the Federal Service for Hydrometeorology and Environmental Monitoring of Russia (ROSHYDROMET).

The authors of the project developed a new technology of digital mapping of EMF. As a result, a series of digital charts of EMF was developed, charting the peculiar characteristics of the mapped phenomenon. Among them are the charts of the Earth's Main Magnetic Field (EMMF), EMF anomalous component, characteristics of the EMF spatial structure, variation cycles etc.

Due to the vastness of the material, the Atlas is designed for a wide range of users from different scientific and applied areas of knowledge. The Atlas is a true original and unparalleled fundamental cartographic product with the most comprehensive and scientifically accurate parameters of EMF for the period from 1500 to 2010. The Atlas demonstrates the scientific advances in the field of geomagnetism in the last centuries. Supported by Grant No. 14.607.21.0058 of the Ministry of Education and Science of Russia.

Joint Inter-Association Symposium

JA06a - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-2899

Størmer's auroral imagery: A space age perspective

A. Egeland[1], *W. Burke*[2]
[1]*University of Oslo, Department of Physics, Oslo, Norway*
[2]*Boston College, Institute of Scientific Research, Boston, USA*

As documented in his Photographic Atlas of Auroral Forms (1930) and his classic monograph The Polar Aurora (1955), Carl Størmer (1874 - 1957) developed precise photographic methods for mapping the physical characteristics of aurorae. In 1909 he and Ole Krogness (1886 –1934) patented an auroral camera that for more than 25 years was the recognized standard in auroral research. In the four subsequent decades Størmer collected vast quantities of data that became the statistical basis for his analyses of visible aurorae. With a team of volunteer observers who manned a network of stations scattered over Norway, Størmer acquired more than 100,000 photographs of visible aurorae. Of these more than 20,000 were parallactic recordings used to establish the height distributions of different types of forms, their locations and geomagnetic orientations. Among the more fascinating of his findings was Størmer's identification of "sunlit aurorae" and their remarkable properties. Auroral characteristics found in Størmer's observations were correlated with the occurrence of sunspots and with the intensities of geomagnetic disturbances.

The solar-terrestrial relations discovered during the space age have been very impressive. It would therefore be interesting to return to Størmer's historical auroral database and examine their contents in the light of present knowledge of solar-terrestrial interactions and the roles played in the creation of auroral dynamics by variations of solar wind and interplanetary magnetic field structures.

Størmer's auroral database, assembled in the first half of the 20th century, is unique. Presservin these data and making them avaiable for future investigatiors would be very important.

Joint Inter-Association Symposium

JA06a - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-3915

Digitization and processing of historical geomagnetic observations from Prague Observatory (1839 – 1917)

P. Hejda[1]
[1]*Institute of Geophysics of the CAS, Prague, Czech Republic*

Regular magnetic observations were started at the Prague Astronomical Observatory in 1839. The observations were carried out manually, at the beginning more than ten times per day but the frequency later decreased to 5 daily observations. Having been a part of Goettingen Magnetic Union, the readings from magnetometers were taken all 5 minutes during appointed days. Even more frequent measurements were carried out during periods of strong magnetic disturbances. The variation measurements were completed by absolute measurements carried out several times per year.

The results were printed in yearbooks Magnetische und meteorologische Beobachtungen zu Prag. As the oldest geomagnetic data have been recently recognized as an important source of information for (not only) Space Weather studies, we have launched a program of digitization of the data. Although all volumes have been scanned with the OCR option, the low quality of original books does not allow for an automatic transformation to digital form. The data were typed to Excel files with a primary check and further processed.

Variation data from 1839 to 1871 were published in measured units (scales of divisions). By their reduction to physical units one must take account of lower data stability and resolution in comparison with later magnetometer generations, large gaps between absolute measurements and unexpected errors due to the missing skill in this quite new branch of science. The presentation will discuss methods of primary data processing and also derivation of IDV index of geomagnetic activity.

Joint Inter-Association Symposium

JA06a - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-4947

Historical data and solar activity

J. Vaquero[1]
[1]*Universidad de Extremadura, Departamento de Física, Mérida, Spain*

Scientists have been recording the presence of sunspots since the telescope was invented more than 400 years ago. Moreover, other historical documents contain different phenomena related with solar activity like naked-eye observations of sunspots and aurorae. In this contribution, I show some initiatives related with the preservation and utilization of historical data related with solar activity. Recently, the "Historical Archive of Sunspot Observations" (HASO; http:/haso.unex.es) was initiated. The objective of HASO is to collect and preserve all documents in any format (original, photocopy, photography, microfilm, digital copy, etc.) with sunspot observations that can be used to calculate the sunspot number in the historical period or related documents. Moreover, these observations can be used to study position (differential rotation, active longitudes, north – south asymmetries, etc.) and area of sunspots during the last centuries. Moreover, I review the last efforts to reconstruct solar activity from historical documents.

Joint Inter-Association Symposium

JA06b - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-0609

Unlocking the archive(s) of historical glacier fluctuation data

M. Zemp[1]*, P. Rastner*[1]*, F. Paul*[1]*, S. Nussbaumer*[1]*, H. Zumbühl*[2]
[1]*University of Zurich, Department of Geography, Zurich, Switzerland*
[2]*University of Bern,*
Institute of Geography and Oeschger Centre for Climate Change Research, Bern, Switzerland

Glacier fluctuations are recognized as high-confidence indicators of climate change with impacts on global sea level, the regional water cycle, and the local hazard situation. Glacier changes over the past decades are well documented by in-situ and remotely sensed observations. Air- and space-borne data enabled a globally almost complete picture of glacier distribution. While the recent state of glaciers is scientifically well explored, the analysis of historical glacier fluctuations is challenged by limitations of the available data. Back in time, the data sample is subject to a decreasing size and an increasing regional bias towards Europe. Assessments of current versus past rates of change, acceleration trends, and variability require a stronger focus on the retrieval and mining of data related to past glacier fluctuations. As such, the large archives of satellite images have a great potential for retrieving information on glacier distribution and changes. Also, the scientific literature can be used for mining of glacier data not (yet) made available through the international data centres. In this presentation, we provide a brief overview of the spatio-temporal coverage of the available datasets from internationally coordinated glacier monitoring (www.gtn-g.org) and discuss three examples unlocking the archive of historical glacier fluctuations: (i) reconstruction of glacier extents from Little Ice Age moraines and trimlines based on satellite images of the Canadian Arctic and of West Greenland, (ii) reconstruction of glacier changes in length, area, and volume since the mid-19th century from historical maps of Zermatt, Switzerland, and (iii) reconstruction of glacier front variations back to the 16th century from pictorial and written sources in the French Alps.

Joint Inter-Association Symposium

JA06b - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-1198

Out of archives: using historical sources of data in the atmospheric sciences

K. Harper[1]
[1]*Florida State University, History, Tallahassee, USA*

Finding and reanalyzing old geophysical and geodetic data certainly provides a method of moving our knowledge of extant conditions back in time. It also provides a way to extend the timeline of data that can be used in predictive models. However, there is a considerable amount of data stored in archives that has probably been explored by historians more than by scientists. However, these data—including those recorded by “civilians,” i.e., non-scientists—can be used as evidence to narrow down the timeframes for hurricanes or to support evidence of climatic changes and concomitant changes in day-to-day-weather, among others. Some atmospheric scientists and interdisciplinary terms have already started using such sources, but there is more that could be done. What kinds of historical sources exist? How might they be accessed? For what purposes might they be used to illuminate current and future atmospheric conditions? And how might atmospheric scientists and historians team-up in mutually beneficial ways to take advantage of them? This paper will review how such materials have been used to date, and how an expansion of their use could benefit multiple scholarly communities.

Joint Inter-Association Symposium

JA06b - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-2068

Documentary evidence in historical climatology and hydrology in Central Europe

R. Brázdil[1]
[1]*Masaryk University- Faculty of Science, Institute of Geography, Brno, Czech Republic*

Central Europe is a region with a long history of systematic meteorological and hydrological observation networks, most of which started in the second half of the 19th century. Pre-instrumental period can by characterised, besides natural climate proxies, by documentary evidence. The paper concentrates on documentary evidence which includes direct and proxy data about weather and related phenomena. Several groups of such evidence (chronicles, annals, memoirs; daily weather records; personal and official letters; special prints; economic and financial records; religious sources; log-books; newspapers; pictorial documentation; market songs; chronograms; epigraphic data; early instrumental observations; early scientific papers and communications) gather data covering generally past millennium and also overlapping with the instrumental period. Documentary evidence is evaluated with respect to its advantages and drawbacks in comparison with other natural proxies and existing uncertainties in data. Basic methodology of dealing with documentary evidence in climatology and hydrology is presented with particular emphasis on the creation of long-term series of weighted monthly temperature and precipitation indices, different (bio)physically based series (freezing of water bodies, phenological data) and series of various hydrometeorological extremes (HMEs – droughts, floods, windstorms, tornadoes and hailstorms). The paper shows examples of climate reconstructions and of the analysis of selected HMEs in Central Europe based on documentary evidence from viewpoint of their occurrence, severity, seasonality, meteorological causes, perception and human impacts during the past millennium. Finally, future research perspectives and potentials are presented and generally discussed.

Joint Inter-Association Symposium

JA06c - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-0600

Earth Science DataBase Project – ESDB

M. Nisilevich[1], *E. Kedrov*[1], *A. Astapenkova*[1], *V. Nechitailenko*[1], *N. Sergeeva*[1]
[1]*Geophysical Center of RAS,*
Laboratory of Geophysical Data Storage and Dissemination Technologies,
Moscow, Russia

ICSU-World data System, CODATA, DataCite, CrossRef, Force 11 and other organizations join forces and collaborate for the purpose of facilitation of access to high-quality scientific data for researchers and acknowledgement of the scientific data as valuable result of the research that is used during the creation of scientific products and is to be cited as well as other scientific sources of information such as articles, books etc.

In the Geophysical Center of RAS on the basis of the WDC for Solar-Terrestrial Physics that is the regular member of ICSU-WDS the action for converting of old geomagnetic data into digital form and implementing information technologies for its placement on the WDC website is conducted. This is also important since the old data are not completely protected from natural disaster and human factor. The entire archive of K-indices, data on the magnetic storms and geomagnetic sudden commencements for the period from 1957 to 2005 from the observatories of Russia and other republics of the Former Soviet Union has been processed in such way. Database containing digital geomagnetic data is placed on the WDC website for free access.

At the same time Earth Science DataBase – ESDB project was started. The focus of ESDB project is on creation of the modern system of geophysical data registration, publication and DOI assignment used for unique identification of intellectual property.

The system of registration and publication of geophysical data being developed is a structure for persistent intellectual content identification and management of intellectual content, metadata management, connection of users with content suppliers. Metadata base including detailed description of data itself and information about data producer and data publisher is formed. Supported by Grant No. 14.607.21.0058 of the Ministry of Education and Science of Russia.

Joint Inter-Association Symposium

JA06c - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-1679

Value of original pictorial and cartographic materials for historical earthquakes' studies.

J. Kozak[1]
[1]*Institut of Geofysics- Acad. Sci., Seismic, Prague, Czech Republic*

The maps of seismicity have been successfuly used – especially in Europe – for more than 100 last years for the assessment of seismic risk in the regions under study. Historical records of the earthquake effects, including macroseismic intensity maps complemented by original, in situ created depictions of (macro)seismic damage, often carry data important especially in the regions of low and medium level of seismic aktivity, in which the disastrous earthquake's impacts occurr distant in time each other.

In the text below the first seismic maps prepared prior to 1900 are introduced together with the pertinent images of seismic damage. The examples of elaboration of these „graphic" data for the seismic intensity analyses of concrete earthquakes are presented: for the 1693 Jamaica earthquake (Kozák, Ebel 1996), for the Central European earthquakes (Kozák and Vanek, 2008), for the European and Russian earthquakes of the late 19th century (Kozák and Nikonov), for the 1856 Visp earthquake (Kozák and Vanek 2008), for the 1858 *ilina earthquake (Vanek and Kozák 2004), for the South Polish earthquake of the late 19th century (Guterch and Kozák), etc. In some cases, as shown in the above papers, intensity re-classifying of the tested seismic event can be proposed, which is based on the interpretting original depictions of seismic damage.

In the paper conclusion, both merits and weak points linked with the use of pre-photo pictorial and cartographic materials for studying historical earthquakes are named and discussed.

Joint Inter-Association Symposium

JA06c - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-2183

The future for global sea level data archaeology – A GLOSS perspective

E. Bradshaw[1]*, L. Rickards*[1]*, A. Matthews*[2]
[1]*British Oceanographic Data Centre, British Oceanographic Data Centre, Liverpool, United Kingdom*
[2]*Permanent Service for Mean Sea Level, Permanent Service for Mean Sea Level, Liverpool, United Kingdom*

Historical sea level data are rare and unrepeatable measurements with a number of applications in climate studies (sea level rise), oceanography (ocean currents, tides, surges), geodesy (national datum), geophysics and geology (coastal land movements) and other disciplines. However, long-term time series are concentrated in the northern hemisphere and there are no records at the Permanent Service for Mean Sea Level (PSMSL) global data bank longer than 100 years in the Arctic, Africa, South America or Antarctica. Data archaeology activities will help fill the gaps in the global dataset and improve global sea level reconstruction.

The Global Sea Level Observing System (GLOSS) is an international programme conducted under the auspices of the WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology. It was set up in 1985 to collect long-term tide gauge observations and to develop systems and standards 'for ocean monitoring and flood warning purposes'.

Analogue tide gauge data come in two main formats, paper charts created by tracing on a rotating drum and handwritten ledgers of observations. GLOSS wants to promote the automatic digitisation of charts by providing the community with access to software but is also considering a Citizen Science approach, making images available to the public to digitise. GLOSS also wants to pursue developments in Handwritten Text Recognition technology for automatic digitisation of ledgers.

The GLOSS Group of Experts data archaeology group is collating tools and producing guidelines for historic sea level data. They aim to aid discovery, scanning, digitising and quality control of analogue tide gauge charts and sea level ledgers and to improve the quality, quantity and availability of long-term sea level data series.

Joint Inter-Association Symposium

JA06c - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-3608

History of monitoring Earth orientation

J. Vondrák[1]
[1]*Astronomical Institute- Acad. Sci., Galaxies and planetary systems, Prague, Czech Republic*

The history of monitoring Earth orientation goes back to the end of 19th century, when polar motion was discovered. Description of international efforts in organizing coordinated observations to determine Earth's orientation is presented. The services, such as International Latitude Service (ILS), Bureau International de l'Heure (BIH), International Polar Motion Service (IPMS) and, finally, International Earth Rotation and Reference Systems Service (IERS), are described, as well as the observational techniques used by them. It is demonstrated how each improvement of the techniques and their accuracies led to new discoveries and corresponding improvements of the theory of Earth's rotation. At the very beginning of these efforts, classical astrometric observations were used. Re-analysis of these observations, made between 1899 and 1992, is shortly presented. Later on, as more precise modern data obtained by space geodesy were used, new and more accurate theories necessarily appeared. Finally, to explain the differences between the observations and theory, more and more data from other sources (mainly of geophysical origin) became necessary to be included. These data and their effects are also commented.

Joint Inter-Association Symposium

JA06c - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-4373

Fabra Observatory seismological heritage: Projects for use and dissemination

J. Batlló[1], *M.T. Merino*[2], *J. Fleta*[1], *T. Susagna*[1]
[1]*Institut Cartogràfic i Geològic de Catalunya, -, Barcelona, Spain*
[2]*Observatori Fabra, -, Barcelona, Spain*

Here we aim to expose the status and projects related to the Fabra Observatory pre-WWSSN seismic heritage. This observatory was created and maintained by the Royal Academy of Science and Arts of Barcelona (RACAB) and it is a relatively small and independent institution placed in Barcelona (Spain) with a limited budget and personnel but with a significant historical scientific patrimony, for both scientific and outreach purposes. Since many of the pre-WWSSN data are owned and maintained by similar institutions, we think sharing our related experiences, problems, ideas and projects could be of interest for this audience.

Seismic observations at Fabra started in 1906 and still continue. They include instrumental registers and macroseismic data, mainly from eastern Spain. The historical archive includes thousands of seismograms and complementary documentation (manuscript and printed bulletins, registers and station notebooks, letters and scientific correspondence, printed publications from many other institutions, etc.). Almost all instruments from that epoch are conserved in our small museum or still being used for different purposes.

During the last decade we have increasingly devoted more of our resources to preserve, use and share our seismic heritage. We collaborated with TROMOS and EUROSEISMOS. With projects sustained by the ICGC and the unit SISMOS of INGV, record inventories, restorations, studies and scanning have been undertaken.

The amount of classified and scanned documents is increasing and as a next step we plan to open freely these records to the scientific community and public. We'll show the different records and documents available, the scientific opportunities arising from its classification and digitalization and their accessibility on the web.

Joint Inter-Association Symposium

JA06d - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-1113

Collection of instrumental parametric data from printed seismological stations bulletins

D. Di Giacomo[1], *D. Storchak*[2], *A. Villanseñor*[3], *J. Harris*[2]
[1]*International Seismological Centre, Thatcham, United Kingdom*
[2]*International Seismological Centre, ISC, Thatcham, United Kingdom*
[3]*Institute of Earth Sciences Jaume Almera, ICTJA-CSIC, Barcelona, Spain*

This contribution summarizes the collection of parametric data of seismic stations (e.g., phase arrival times, amplitude-period measurements of seismic phases, etc.) which has been digitized starting from a multitude of early instrumental paper-based seismological bulletins. Such bulletins contain fundamental parametric data for relocating and reassessing magnitude of earthquakes that occurred between 1904-1970. The digitization and organization of the data into the International Seismological Centre (ISC, www.isc.ac.uk) database is carried out in the context of the ISC-GEM Global Earthquake Instrumental Catalogue project funded by the GEM Foundation (www.globalquakemodel.org) and recently also by two commercial companies based in UK and US.

The parametric data obtained and processed during this work fills a large gap in electronic bulletin data availability and complements the data freely available from the ISC bulletin starting in 1964.

This work was fundamental for producing the ISC-GEM Global Instrumental Earthquake Catalogue (www.isc.ac.uk/iscgem), which starts with large earthquakes occurred at the beginning of last century.

To facilitate earthquake relocation, different sources have been used to retrieve body-wave arrival times. These were entered into the database with the support of optical character recognition methods (e.g., ISS bulletins, 1918-1959) or manually (e.g., BAAS bulletins, 1913-1917). With respect to the amplitude-period data necessary to re-compute earthquake magnitude, we considered the global collection of paper-based bulletins stored at the ISC and other sources and entered relevant station parametric data into the database. The paper bulletins were also scanned and made available at the http://storing.rm.ingv.it/bulletins/ISC-GEM/ website

Joint Inter-Association Symposium

JA06d - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-2373

Not only science not only culture: the preservation and use of historical data in seismology

G. Ferrari[1]
[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy*

The recovery and preservation of the historical data of the geosciences show a double opportunity: scientific and cultural. In some of these disciplines (seismology, geomagnetism, meteorology etc.) the use of historical data, albeit within the limits of the technology in which they were produced, represent a great opportunity to reconstruct geophysical processes that take place over long time spans.

In particular, the study of great earthquakes is very important in analyses of seismic potential, hazard and risk. The study of the seismograms of historical earthquakes plays a crucial role in these analyses.

In view of the long Italian tradition, in the past 27 years INGV set up two important projects for research, recovery, reproduction of this outstanding historical and scientific heritage: the Tromos and Sismos projects.

The recovery and reproduction of historical seismograms and of the complementary documentation, on the relevant instruments, often become difficult and laborious operations. Sismos Project was set up to solve these problems, with the research, recovery, high resolution scanning of old seismograms and complementary documentation of Italian and European observatories. Particular attention is also payed to the restoration and conservation of old materials relating to Italian and international seismology, with scientific as well as cultural aims. By a complex database are stored, managed and distribuited the more than 200.000 scans of seismograms and more than 500.000 pages of complementary data.

Two restoration laboratories are also operating at Sismos, one for historical papers and one for historical instruments. The first acting especially upon the seismograms, the second provides conservative and functional restoration of old instruments of geosciences.

Joint Inter-Association Symposium

JA06d - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-2877

Data in danger: The worldwide standard seismograph network

R.M.W. Musson[1]
[1]*British Geological Survey, Edinburgh, United Kingdom*

The Worldwide Standard Seismograph Network (WWSSN) was a global seismic monitoring network that operated between the early 1960s and mid-1990s. Originally designed for monitoring nuclear tests, the data it collected were of fundamental importance in developing the theory of plate tectonics. Each station, of which there were over 100, operated both short-period and long-period three-component sets; the seismograms were sent to the Albuquerque Seismological Laboratory for microfilming.

In many cases, the original seismograms have been lost or destroyed, so the microfilm copies are a crucial resource of major historical significance. Only two copies of the complete microfilm set are known to exist; one is in Albuquerque NM, the other is currently in Edinburgh. Neither is currently accessible to researchers. The earlier part of the collection exists as diazo film chips, and these are physically deteriorating through a process known as “vinegar rot”. In a few years, much of the data may be lost, but because of the sheer size of the collection, the scanning necessary to save the data for posterity has been found to be unaffordable, despite the search for support.

Joint Inter-Association Symposium

JA06d - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-2999

New information from old seismograms and intensity reports: A Canadian perspective

A. Bent[1], *J. Adams*[2], *M. Lamontagne*[3]
[1]*Geological Survey of Canada, Ottawa, Canada*
[2]*Geological Survey of Canada, Canadian Hazards Information Service, Ottawa, Canada*
[3]*Geological Survey of Canada, Public Safety Geoscience, Ottawa, Canada*

Seismographs have been operating in Canada for more than one hundred years. Since the mid-1980s most of the data have been digital and relatively easy to store and access. However, analog records dating back to the early 1900s have also been preserved. With on the order of one million paper records, storage space is a significant issue and the question about whether to continue to preserve them is often raised. Given the large number of records, scanning the complete data set is an expensive option whose priority must be weighed against other activities in light of finite resources. Access to the data, which are stored off-site, has become increasingly difficult due to the combined effects of increased security requirements for access and a decrease in staff to handle requests for data. Yet, there have been many occasions when these data have proved invaluable and we consider their preservation vital. The successive application of new analysis methods has time and time again resulted in the determination of source properties and an improved understanding of large, historical earthquakes. Analog records have also been used to verify that the episodic tremor observed in the Cascadia region is a recurring phenomenon and to establish its recurrence period. This example would argue for preserving all seismograms, not just those currently considered to be of value. Yesterday’s noise may be tomorrow’s data. In addition to the seismograms, there are felt reports for Canadian earthquakes that sometimes pre-date the instrumental data. Through external contracts much of this felt information has been compiled and we are now working toward converting these compilations to an accessible digital database of felt information.

Joint Inter-Association Symposium

JA06d - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

IUGG-3956

Digital filming of the Jakarta, Indonesia seismological archives: A pilot program

E. Okal[1], *S. Kirby*[2]
[1]*Northwestern University, Evanston, USA*
[2]*US Geological Survey, Western Branch, Menlo Park- CA, USA*

Because of the long duration of most seismic cycles with respect to the history of seismological instrumentation, seismograms from the first half of the 20th century constitute an invaluable resource, allowing significant constraints on the regional chronology of earthquake occurrence, and their modern quantification through the calculation of seismic moments.

In this context, the preservation of seismograms in a digital format is an important challenge to the scientific community.

Under funding from the Earth Observatory of Singapore, we initiated in July 2014 a pilot project, administered by IASPEI, to test the feasibility of photographing records of the Wiechert and Bosch instruments operated at the Jakarta (ex-Batavia) station since 1910 and archived at the BMKG regional office in Ciputat. We used a 24 MP SONY alpha NEXT 7 camera with a nearly distortion-free wide angle lens mounted on a copy stand with underside light-table illumination. We encountered many challenges, including the fragility of acidic paper, serious dark-brown age-toning of the paper, as well as many missing records. However, this pilot test showed that this inexpensive system is effective in providing well-resolved waveforms, and reaped more than 500 digital copies of seismograms of earthquakes earmarked for their global or regional importance, going back to 1910. Including the compilation of metadata necessary for future search capability, 15 to 20 seismograms can be scanned per hour. Following successful capacity building through on-site training of BMKG Staff, it is hoped that this project can be pursued at BMKG, and complement similar endeavors, especially in the critically important Southern Hemisphere, either ongoing (e.g., at Canberra, Silverton), or desirable (e.g., at Lower Hutt,La Paz).

Joint Inter-Association Symposium

JA06p - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

JA06p-201

Evaluation of the accuracy of Robert Sterneck's gravity pendulum measurements in the Czech territory

M. Lederer[1], A. Peskova[2], O. Nesvadba[1]
[1]Land Survey Office, Gravimetry, Prague, Czech Republic
[2]Czech Technical University in Prague, Department of Geomatics, Prague, Czech Republic

More than one hundred pendulum gravity observations were performed by Robert

Daublebsky von Sterneck (* 1839, † 1910), Bohemian prominent aristocrat, scientist and

geodesist, between 1889 and 1895 in the Czech territory. He used pendulum instrument

of his own construction. Measurements can be divided to the two different files, which are

different both by the time and with locations. For the first group - Bohemia - the stations

were chosen mainly at the tops of hills (triangulation points) on the contrary - Moravia -

the stations were chosen in the towns.

Until present, thorough evaluation of the accuracy of these measurement was not

accomplished. On the basis of the original Sterneck’s field books the station locations

were investigated and correct positions identified. For this purpose many by hand written

notes were translated and often even puzzled out. The observed values have been compared with the novel gravity data (present knowledge of the Earth's gravity field).

Systematical shifts for the Bohemian group and for the Moravian group, were found

within the comparison with the interpolated gravities. Internal accuracy of Sterneck's

pendulum measurement is of about 10 mGal. The data give us an unique possibility to

take a look into the state of Earth's gravity field in the locality more than one hundred

years ago.

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JA06p-202

Rescue of Historical Data in the World Data Center for Solid Earth Physics

M. Nisilevich[1], *N. Sergeyeva*[1], *A. Rodnikov*[1], *L. Zabarinskaya*[1]
[1]*Geophysical Center of RAS,*
Laboratory of Geophysical Data Storage and Dissemination Technologies,
Moscow, Russia

The World Data Center for Solid Earth Physics (WDC for SEP) in Moscow collects and stores seismological, gravity, magnetic, heat flow and bathymetric data obtained in Russia and other countries. Dissemination of the large arrays of modern digital geophysical data through web-based approaches is recognized as positive development of WDC for SEP.

In view of the importance of old data for science the WDC for SEP gives particular attention to the collection of historical data presented mainly in a traditional paper-printed form. The Center undertakes active actions to convert old data into digital form, to increase the amount of data that can be presented on the web site and to rescue valuable historical information from loss.

The WDC for SEP previously participated in the international projects on rescue of old data, for example such as the project 'Historical seismograms'. Later separate historical data sets were converted to electronic documents in TIFF or PDF formats and were made widely available via the Internet for scientific community.

Currently WDC for SEP is provided with the most modern digital equipment and software to scan images and printed text and convert them to digital forms. The collection of earthquake catalogues for different regions and historical periods were converted to a digital form and placed on the WDC web site. Furthermore, with new technologies became possible to transform maps. For example geological maps of the Okhotsk Sea and Kara Sea regions were converted into digital maps.

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JA06p-203

Historical geophysical data of two Austrian (research) expeditions during the 19th Century

B.P. Besser[1], H.U. Eichelberger[1], S. Meindlhumer[1], T. Stachel[1], K. Schwingenschuh[1], M. Stachel[1]
[1]Austrian Academy of Sciences, Space Research Institute, Graz, Austria

The Austrian-Hungarian Empire did not organise major exploring expeditions mainly due to the point that Austria had no historical background as a colonial power and therefore no well-equipped navy. Mid of the 19th Century the first plans for a research ship expedition circulated and due to support by influential peers in the proximity of the Emperors family such an undertaking was realized. During the circumnavigation of the vessel Novara (1857 to 1859) measurements of several geophysical/meteorological parameters have been performed routinely. They included geomagnetic as well as atmospheric/sea surface temperature and wind field records.

The second research expedition performed by Austrian mariners in the second half of the 19th Century was directed towards the North of the European continent. Being stuck in the polar ice for one and a half years, Captain Carl Weyprecht and his crew carried out extensive geophysical measurements (1872-1874) in this harsh environment. At least some of the records were preserved during the odyssey across the drifting ice on the way back after abandoning the ship.

We are presenting historical data from these two expeditions and compare them with data collected concurrently by a few observatories on the ships route. Additionally, we contrast the records with satellite data gathered in the 20th Century and other available geophysical models.

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JA06p-204

From historical to modern seismology: The case of the 1917 Monterchi (Italy) earthquake.

T. Braun[1]*, M. Caciagli*[2]*, J. Batllo*[3]*, S. Cesca*[4]*, S. Pucci*[5]
[1]*Ist. Naz. Geofisica e Vulcanologia, Osservatorio Sismologico, Arezzo, Italy*
[2]*Ist. Naz. Geofisica e Vulcanologia, Bologna, Arezzo, Italy*
[3]*ICGC, Barcelona, Barcelona, Spain*
[4]*GFZ-Potsdam, Earthquakes and Volcano-Physics, Potsdam, Germany*
[5]*Ist. Naz. Geofisica e Vulcanologia, Seismology & Tectonophysics, Rome, Italy*

Modern seismology has produced a huge variety of methodologies and tools to investigate earthquake source characteristics from waveforms recorded in digital form acquired in a very large dynamic range. The instrumental seismology started, however, at the end of the XIX century and the preserved recordings on the analogical seismograms, as well as bulletins, represent an enormous heritage of information on over 100 years of global seismicity. The improvement of the knowledge is remarkable especially in those cases where the only data available, for a given earthquake, is the macroseismic analysis but which is not sufficient to associate the corresponding seismogenic source. This is the case of an earthquake occurred in the Sansepolcro Basin (the northernmost portion of the High Tiber Valley – Central Italy) on April 26, 1917 at 9:35:59 (GMT), noted as Monterchi earthquake. The maximum and epicentral intensity was determined as Io=IX-X degree (MCS) with an equivalent magnitude of Me=6. The Sansepolcro Basin was generated on the hanging-wall of the Altotiberina Fault (ATF) system. The ATF system is composed by an E-dipping low-angle normal fault and by its antithetic W-dipping high-angle normal faults. Although the southern part of the ATF was demonstrated to creep, its capability to generate strong or moderate earthquakes is still debated and the historical seismicity that affected the region was not associated to specific geologic sources. In this work, we use historical seismograms and coeval station bulletins with the aim to locate the instrumental hypocenter, to assess the main seismic parameters, to constrain the focal mechanisms and to implement the solutions obtained in the framework of the regional tectonic setting.

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JA06p-205

Using historical data to determine the past seismicity in Georgia

N. Tsereteli[1], *O. Varazanashvili*[1]
[1]*Institute of Geophysics of Iv. Javakhishvili Tbilisi State University, Seismology- Seismic Hazard and Disaster Risks, Tbilisi, Georgia*

Georgia is a region with a couple of thousand years of data on earthquakes. Long-term seismic history is an important information basis for allocation of earthquakes sources, a reliable assessment of seismic hazard and risk. Such information about the strong earthquakes is contained mainly in the seismological, historical, archaeological and geological sources and in the end it accumulates in the earthquakes catalogues. Therefore, the completeness of these catalogues, especially in their very long, historical part (before 1900) and also in very early of instrumental period, also investigation of spatial distribution of earthquakes and the attenuation of intensities with source distance and magnitude are very important steps in seismic hazard analysis. Such a study required reliable epicentral distances and focal depths, uniformly calculated average magnitudes for shallow earthquakes and an estimation of the associated errors. With this point of view we have reviewed the data on historical earthquakes and from the beginning of the instrumental period in the region.Some calculation results of magnitudes of the region between 1903 and 1908 were obtained and 32 events were identified for which magnitudes were calculated with the Bosh instruments. Locations of the events were determined by using a combination of the Bosh magnitude instrumental readings. For historical earthquakes results have been presented not only as a catalogue of key parameters of historical earthquakes, but as a "descriptor" for each event introduced in the catalogue. The "descriptor" contains: a description of the earthquake based on various sources and evaluation of the intensity by MSK, a short analysis of these data; final earthquake parameters indicating the precision of their determination.

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JA06p-206

Preservation of historical tsunami data: Know the past to better understand the future

K. Stroker[1], A. Sweeney[1], G. Mungov[1], P. Dunbar[2], H. McCullough[2], J. Gradone[1]
[1]University of Colorado,
Cooperative Institute for Research in Environmental Sciences CIRES,
Boulder- Colorado, USA
[2]National Oceanic and Atmospheric Administration NOAA,
National Geophysical Data Center NGDC, Boulder- Colorado, USA

The National Oceanic and Atmospheric Administration (NOAA) has primary responsibility for providing tsunami warnings to the Nation, and a leadership role in tsunami observations and research. The National Geophysical Data Center (NGDC) provides the long-term archive, data management, and access to national and global tsunami data for research and mitigation of tsunami hazards. Archive responsibilities include global historic tsunami event and runup data, deep-ocean and coastal water level data, event-specific tide-gauge data from historic marigrams, photos showing effects and damage from tsunamis, tsunami publications, as well as other related hazards data and information. Much of these data are contained in historic documents and photographs. NGDC has rescued over 10,000 digital photographs dating from the 19th century, over 3,500 historic tide gauge records from 1850-1980, and over 6,100 publications dating from the 15th century. Scientists, emergency managers, and planners use long-term data from these events, including photographs, to establish the past record of tsunami event occurrences. The data are also important for planning, response, and mitigation of future events and are in danger of being lost if they are not converted to a digital format. The paper will present the current data rescued and discuss future steps that may be taken to make these data valuable to both the tsunami community and beyond.

Joint Inter-Association Symposium

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JA06p-207

ERS-ENVISAT compatible altimetry for longer term, coherent, continental surfaces studies

B. LEGRESY[1,2,3], *F. BLAREL*[2], *F. NINO*[2], *F. FRAPPART*[2]
[1]*CSIRO, Oceans and Atmosphere Flagship, Hobart, Australia*
[2]*LEGOS, CTOH, Toulouse, France*
[3]*University of Tasmania, ACE-CRC, Hobart, Australia*

Satellite altimetry has been a very powerful tool in oceanography and continental surface studies over the last 25 years. While the processing and reprocessing has been operationally and optimally adjusted over the years for all satellite missions toward ocean applications, such is not the case for continental studies. While the ESA ENVISAT mission has been updated regularly for continental data, ERS altimetry was not process optimally over these surfaces. We have reprocessed ERS2 altimetry to make it most compatible with ENVISAT in order to ensure a maximum of continuity and longer-term surveys. We processed the data with the ICE2 retracking, showing significant improvements over the latest REAPER reprocessing. We added new orbit products (Rudenko et al., 2012 updated version of the REAPER one), a dry troposphere correction using ERA fields valid over all surfaces (Blarel and Legresy, 2013), a new Doppler correction valid over all surfaces using range rates (Blarel and Legresy, 2012). We further cross-validated ERS-2 and ENVISAT during the tandem phase when they flew with 30min time separation. We show the main validation and cross validation of the two missions. We find some good general agreement and discuss the differences. We also detect some anomalies like the 13degree north anomaly on the ERS-2 waveforms. We show global figures of the validation, as well as of the actual height and radar measurements over the continents, over inland water bodies and over ice sheets. The high level (geophysical data record and beyond) product will be publicly distributed by the LEGOS based CTOH altimetry service.

Joint Inter-Association Symposium

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JA06p-208

An online digital archive of magnetograms from 1846 to 1987

E. Clarke[1], T. Humphries[1], J. Williamson[1], S.J. Reay[1], E. Dawson[2], B.M. McIntyre[3], R.P. McIntosh[4], G.V. Nash[5]
[1]British Geological Survey, Earth Hazards and Observatories, Edinburgh, United Kingdom
[2]Formerly British Geological Survey, Earth Hazards and Observatories, Edinburgh, United Kingdom
[3]British Geological Survey, Photographic- Science Services, Edinburgh, United Kingdom
[4]British Geological Survey, Informatics, Edinburgh, United Kingdom
[5]British Geological Survey, Communications and Publications, Keyworth- Nottingham, United Kingdom

The magnetic measurements from current UK observatories, together with those from their historical predecessors, provide some of the longest running continuous sets of geophysical observations in the world. A lengthy campaign to capture and distribute high quality digital images of >300,000 analogue magnetograms (front and back) was completed in 2013, with every single magnetogram now available to search, view and download from the on-line archive at www.bgs.ac.uk/data/magnetograms. In parallel with the capture of the magnetograms, the related published yearbooks were scanned and are available online as PDF documents at www.geomag.bgs.ac.uk/data_service/data/yearbooks/yearbooks.html. This work has helped to ensure that these valuable long-term data sets are not lost, irrespective of what may happen in the future to the original photographic paper records. The additional benefit of immediate worldwide access to the data contained within these historic documents has also been established.

In this paper we present the BGS OpenGeoscience service, which the magnetogram image archive forms part of. We also show some results of on-going work to acquire digital data from the images and the yearbooks. We highlight past and potential future use of the data for scientific research, such as space weather studies of the magnetograms during the period of the Carrington storm and studies into the homogeneity of long term geomagnetic activity indices that are used in space climate research.

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JA06p-209

Sunspots during the Maunder Minimum from "Machina Coelestis" by Hevelius

V.M.S. Carrasco[1], J. Villalba-Álvarez[2], J. Vaquero[3]
[1]Universidad de Extremadura, Departamento de Física, Badajoz, Spain
[2]Universidad de Extremadura, Departamento de Ciencias de la Antigüedad, Cáceres, Spain
[3]Universidad de Extremadura, Departamento de Física, Mérida, Spain

We have revisited the sunspot observations published by Johannes Hevelius in his book Machina Coelestis (1679). These observations (1653-1675) lie in the period named Maunder Minimum whose main feature was a prolonged low solar activity. Here, we show some detailed translations of the original Latin texts describing the sunspot records and provide the general context of these sunspot observations. From this source, we present an estimate of the annual values of the Group Sunspot Number based only on the records that explicitly inform about the presence or absence of sunspots. Thus, we obtain very low values of the Group Sunspot Number, in accordance with a grand minimum of solar activity, but significantly higher in general than the values provided in the database of the Group Sunspot Number index for the same period.

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JA06p-210

Building a geophysical historical data archive in Brazil

M. Bianchi[1]*, D.R. Franco*[2]*, G.A. Hartmann*[2]*, O. Hannesch*[3]*, A.C.O. Garcia*[3]*, A.F.D. Santos*[2]*, J.R. Barbosa*[1]*, R. Trindade*[1]*, A.R.R. Papa*[2]*, M.F. Rangel*[3]*, P. Koki*[4]*, C.M. Moreira*[1]*, V. Cardoso*[1]*, A. Abdulmalek*[2]*, V. Bernardes*[2]
[1]*Universidade de São Paulo, Institute of Astronomy- Geophysics and Atmospheric Sciences, São Paulo, Brazil*
[2]*Observatório Nacional, Department of Geophysics, Rio de Janeiro, Brazil*
[3]*Museu de Astronomia e Ciências Afins, Coordination of Filing and Documentation, Rio de Janeiro, Brazil*
[4]*Universidade de São Paulo, Institute of Geology, São Paulo, Brazil*

A joint effort from three Brazilian institutions (Instituto de Astronomia, Geofísica e Ciências Atmosféricas of Universidade de São Paulo, Observatório Nacional and Museu de Astronomia e Ciências Afins), will provide full access to the academic community to more than 100,000 seismograms and 36,000 magnetograms that currently have been deteriorating by time.

The 100,000 seismogram profile (12 hours records each) through 25 seismographic stations that operated throughout the eastern portion of Brazilian territory from 1976 to 2008. The magnetograms profile is one of the longest, almost continuous geophysical records in South America, comprising a 92-yr geomagnetic record (1915–2007) from the Magnetic Observatory of Vassouras (state of Rio de Janeiro, Brazil) and a 50-yr (1957–2007) recording from the Magnetic Observatory of Tatuoca (state of Pará, Brazil).

This work comprises four different steps: (a) cleaning-up and recoverage of deteriorated documents by restoration procedures, (b) cataloging the associated metadata to each record into appropriated databases, (c) rasterizing each record and assign the obtained raster image to the metadata previously stored, (d) on demand vectorization and archive of the digital data (probably in a joint effort with the community). Currently ongoing activities involve stages (a) to (c).

The digital outcome recording has being made by using a specially designed web platform for that purpose. A special care is being taken to guarantee that all associated information, such as seismographic stations clock correction and magnetogram's base lines are also being saved not rendering the data unusable in

the long run. Current stage of our efforts can be accessed at http://www.dadosraros.iag.usp.br.

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JA06p - JA6 Data on the Edge: Preservation and Utilization of Historical Data in the Geosciences (IAGA, IASPEI, IAMAS, IAG, IAHS, IACS)

JA06p-211

Early pyrheliometer measurements from Astronomical Observatory of Madrid (1903-1934)

A.J.P. Aparicio[1], M. Antón[1], M.C. Gallego[1], J. Vaquero[2]
[1]Universidad de Extremadura, Departamento de Física, Badajoz, Spain
[2]Universidad de Extremadura, Departamento de Física, Mérida, Spain

The Astronomical Observatory of Madrid (AOM) staff began the sunspot observing program in 1876. Subsequently, it was expanded to other types of observations such as solar protuberances, solar flocculi, and pyrheliometer measurements. Pyrheliometer measurements began in 1903 and were abandoned in 1934. The AOM had three Ångström electrical compensation pyrheliometers and several observational campaigns were conducted. In this contribution we present a series of the atmospheric column transparency derived from pyrheliometer data for the period from January 1911 to December 1928 in Madrid. Our results showed the great effects of the Katmai eruption (June 1912, Alaska) on transparency values during 1912–1913 with a stable behaviour for the remaining period. In addition, we are currently studying the correlation between pirheliometric measurements and sunspot number for 1910-1928.

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JA06p-607

Preservation of Historical Tsunami Data: Know the Past to Better understand the Future

K. Stroker[1], *G. Mungov*[1], *A. Sweeney*[1], *P. Dunbar*[2], *J. Gradone*[1]
[1]*University of Colorado,*
Cooperative Institute for Research in Environmental Sciences CIRES,
Boulder- CO, USA
[2]*National Oceanic and Atmospheric Administration NOAA,*
National Geophysical Data Center NGDC, Boulder- CO, USA

NOAA has primary responsibility for providing tsunami warnings to the Nation, and a leadership role in tsunami observations and research. The NESDIS/National Geophysical Data Center (NGDC) provides the long-term archive, data management, and access to national and global tsunami data for research and mitigation of tsunami hazards. Archive responsibilities include global historic tsunami event and runup data, deep-ocean and coastal water level data, event-specific tide-gauge data from historic marigrams, photos showing effects and damage from tsunamis, tsunami publications, as well as other related hazards data and information. Much of these data are contained in historic documents and photographs. NGDC has rescued over 10,000 digital photographs dating from the 19th century, over 3,500 historic tide gauge records from 1850-1980, and over 6,100 publications dating from the 15th century. Scientists, emergency managers, and planners use long-term data from these events, including photographs, to establish the past record of tsunami event occurrences. The data are also important for planning, response, and mitigation of future events and are in danger of being lost if they are not converted to a digital format. The paper will present the current data rescued and discuss future steps that may be taken to make these data valuable to both the tsunami community and beyond.

Joint Inter-Association Symposium

JC01a - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-2610

The dependence of Arctic sea ice albedo on its age

A. Riihelä[1]
[1]*Finnish Meteorological Institute, Helsinki, Finland*

The recent changes in the Arctic sea ice zone have led to a substantial decrease of its multi-year sea ice, as old ice melts and is replaced by first-year ice during the next freezing season. At the same time, we have observed clear decreasing trends in the surface albedo of Arctic sea ice. It is generally known that younger sea ice tends to have a lower albedo than older ice because of several reasons. Firstly, snow cover on younger sea ice is often quite shallow and wet. Secondly, young sea ice is flatter than older ice and thus melt ponds cover large areas of it early in the melt season, enhancing the overall melting and driving albedo even lower. However, the quantitative correlation between sea ice age and sea ice albedo has not been extensively studied to date, excepting in-situ measurement based studies which are, by necessity, focused on a limited area of the Arctic Ocean.

I propose to quantitatively assess the correlation of sea ice age and sea ice albedo over the whole Arctic Ocean using two datasets: sea ice age is obtained from the MEaSUREs Arctic Sea Ice Characterization dataset and the sea ice albedo from the CLARA-A1-SAL dataset. The studied period is 1982-2009. The datasets are spatiotemporally collocated and analysed. The changes in sea ice albedo as a function of sea ice age are presented for the whole Arctic Ocean and for potentially interesting marginal sea cases, such as the Beaufort Sea.

Finally, I will analyse the trends in the albedo of the various sea ice age classes in order to assess how the albedo of the diminishing multi-year ice and increasing first-year ice has evolved during the past three decades.

Joint Inter-Association Symposium

JC01a - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-3209

Anomalous dispersion of sea ice in the Fram Strait region

A. Gabrielski[1], *G. Badin*[2], *L. Kaleschke*[2]
[1]*University of Reading, Department of Meteorology, Reading, United Kingdom*
[2]*University of Hamburg, Institute of Oceanography, Hamburg, Germany*

The Fram Strait region is the main gateway for the ice export from the Arctic into the North Atlantic and it is subject to a strong background flow due to strong meridional winds and the East Greenland Current. Lagrangian statistics are used to study the turbulent component of the sea ice motion in this region, a knowledge that can be used to improve ice drift models. The single-particle dispersion of sea ice is investigated using ice drift buoys deployed in the winters 2002 to 2009 within the Fram Strait Cyclones and the Arctic Climate System Study campaigns. The bias in the dispersion introduced by the mean flow is eliminated considering only the displacements of the buoys in the cross-stream direction. It is shown that the sea ice motion in the Fram Strait region exhibits an anomalous dispersion regime growing with t^5/4. The non-Gaussian distribution of the velocity fluctuations as well as the slope of the Lagrangian frequency spectrum between -2 and -1 are in agreement with the anomalous dispersion regime. Comparison with data from the International Arctic Buoy Program supports the findings. The results suggest the presence of deformation and shear acting on the sea ice dispersion. The high correlation between the cross-stream displacements and the cross-stream wind velocities shows the important role of the wind as a source for the anomalous dispersion.

Joint Inter-Association Symposium

JC01a - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-3453

A wind-driven, hybrid latent and sensible heat Coastal Polynya at Barrow, Alaska

D. Hirano[1], Y. Fukamachi[2], E. Watanabe[3], K. Iwamoto[4], A. Mahoney[5], H. Eicken[5], D. Shimizu[6], K.I. Ohshima[2], T. Tamura[7]
[1]National Institute of Polar Research, Arctic Environment Research Center, Tachikawa, Japan
[2]Hokkaido University, Institute of Low Temperature Science, Sapporo, Japan
[3]Japan Agency for Marine-Earth Science and Technology, Research and Development Center for Global Change, Yokosuka, Japan
[4]Niigata University, Faculty of Science, Niigata, Japan
[5]University of Alaska, Geophysical Institute, Fairbanks, USA
[6]National Institute of Polar Research, Center for Antarctic Programs, Tachikawa, Japan
[7]National Institute of Polar Research, Polar Meteorology and Glaciology Group, Tachikawa, Japan

The nature of the Barrow Coastal Polynya (BCP) formed off the Alaska Coast in winter is examined using mooring, atmospheric re-analysis (ERA-Interim) and AMSR-E derived sea-ice concentration and production data. Previously, the BCP has been considered to be a latent heat polynya formed by predominantly offshore winds. Recently, it has been suggested that the sea-ice production rate in the BCP is suppressed by warm Pacific- or Atlantic-origin waters distributed beneath the BCP. In this study, we focus on the oceanographic conditions such as water mass distribution and ocean current structure beneath the BCP, which have not been fully documented. A mooring was deployed off Barrow, Alaska in the northeast Chukchi Sea shelf from August 2009 to July 2010. During the freeze-up period from December to May, five BCP events occurred in the same manner; 1) dominant northeasterly wind parallel to Barrow Canyon, with an offshore component near Barrow, 2) high sea-ice production followed by sudden cessation of ice growth, 3) upwelling of warm (>2K above freezing point) and saline (>34) Atlantic Water (AW) beneath the BCP, 4) strong up-canyon flow associated with density fluctuations. A baroclinic current structure, established after the upwelling, resulted in enhanced vertical mixing. The mixing event and open water formation occurred simultaneously, once sea-ice production had stopped. Thus, mixing events accompanied by ocean heat flux from AW into the surface layer were likely to form/maintain the open water area that is a sensible heat polynya. The transition

from a latent to a sensible heat polynya was well reproduced by a pan-Arctic ice-ocean model. We propose that the BCP is a hybrid latent and sensible heat polynya, with both processes driven by the same offshore wind.

Joint Inter-Association Symposium

JC01a - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-4809

Sea ice decrease in the arctic and increase in the Antarctic- discussions from the bi-polar perspectives -

H. Enomoto[1], *T. Tamura*[2], *M. Hori*[3], *T. Yamanouchi*[2], *H. Yabuki*[1]
[1]*National Institute of Polar Research, Arctic Environment Research Center, Tokyo, Japan*
[2]*National Institute of Polar Research, Polar Meteorology and Glaciology, Tokyo, Japan*
[3]*JAXA, EORC, Tsukuba, Japan*

Arctic sea ice declining has been rapidly in 2000's with the summer minimum record in 2012. Sea ice in 2013 and 2014 summers recorded increase however the ice situation is still low expand level. On the other hand, Antarctic sea ice is increasing in winter. Sea ice in the Antarctic in 2014 austral winter recorded the maximum area since the satellite observation became available. This study summarizes common feature and differences in these evidences and current understanding of possible causes. Arctic and Antarctic sea ice show different annual cycle, inter annual variations and trend. Summer decline of sea ice is focused in the Arctic, winter expand of sea ice is focused in the Antarctic. Both variations were considered to be occurring under the influence of global warming. There are common and different characteristics in the Arctic and Antarctic: Common aspects are, changes in polar region, phenomena in sea ice and/or cryospheric and polar components, ice area changes associated with thickness change.Different aspects are, decreasing or increasing in sea ice, geographical condition in Ocean and continent, summer or winter, seasonal march, long-term trend.Sea ice information are oftenindicated separately in the arctic or Antarctic. This study tried to put together and summarized characteristics of their extent, seasonal differences, seasonal march and long-term trends.

Joint Inter-Association Symposium

JC01a - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-4862

Internal Kelvin Waves in Ice-Covered Seas

S. Muzylev[1], *T. Tsybaneva*[1]
[1]*P.P.Shirshov Institute of Oceanology, Physical Department, Moscow, Russia*

Theoretical foundation of the linear theory of the Kelvin internal waves in a stratified sea under the ice cover is represented. The ice is assumed to be a thin elastic plate with constant thickness and constant values of the Young module, the Poisson coefficients and compression. Normal velocity on the bottom is assumed to equal zero; on the lower ice boundary the linearized kinematic and dynamic conditions are fulfilled. Explicit solutions for the Kelvin internal waves and the corresponding dispersion equations are found. The problem is considered within the framework of the unified theory of waves under the ice cover without application of hydrostatics approximation.

Joint Inter-Association Symposium

JC01a - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-5065

Damping of surface waves propagating below solid ice

A. Marchenko[1]
[1]*The University Centre in Svalbard, Arctic Technology, Longyearbyen, Norway*

Surface waves can propagate below the drifting ice and create ice failure over big distances in relatively short time. These effects are important for sea ice dynamics and energy exchange between the atmosphere and ocean. Liu and Mollo-Christensen (1988) introduced physical mechanism of the surface waves damping below the solid ice due to the ice-water friction. They have shown that the eddy viscosity generated by the water turbulence in ice adjacent boundary layer can explain damping of swell of 18 s period over several tens kilometers. In the present paper the eddy viscosity was calculated with using of the ADV measurements performed on the drifting ice in the Barents Sea during several events of swell propagation. Typical period of swell in the Barents Sea is 10-12 s. It was discovered that tidally induce ice drift near the East coast of Spitsbergen influences high values of the eddy viscosity with mean value 100 cm^2/s. The swell is damped over 14 km distance in this case.

Wave attenuation coefficient introduced by Liu and Mollo-Christensen (1988) doesn’t depend on the wave amplitude. Analysis of storm event in the North-West Barents Sea performed by Collins et al (2014) shows that wave amplitudes below the ice increased significantly after the ice break up. Possible physical mechanism explaining this effect is the energy dissipation related to the creep rheology of sea ice. In the present work basic equations describing wave propagation in the water layer covered by thin plate with creep rheology are formulated, and the dispersion equation is derived. The analysis shows that the influence of ice creep explains strong damping of swell with amplitudes of several tens centimeters.

Joint Inter-Association Symposium

JC01b - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-1253

The significant increase of Southern Ocean sea ice extent during the satellite era

J. Turner[1]
[1]*British Antarctic Survey, Cambridge, United Kingdom*

Since 1979 the extent of Southern Ocean sea ice has increased throughout the year, with the annual mean extent having increased at a statistically significant rate ($p < 0.01$) of 1.5% per decade. However, this overall increase masks large regional changes, and particularly a couplet of decrease/increase across the Bellingshausen/Ross Seas. But the increase in the Ross Sea is the dominant factor in the overall Southern Ocean positive trend. Off West Antarctica there is a high correlation between trends in sea ice extent and trends in the near-surface winds, although other processes, such as freshwater injection from basal ice shelf melting, oceanic change and ice-ocean feedback processes have also been suggested as controlling factors. The stronger meridional flow over the Ross Sea has been driven by a deepening of the Amundsen Sea Low (ASL), which is the climatological area of low pressure to the west of the Antarctic Peninsula. The depth of the ASL is significantly correlated with sea surface temperatures across the tropical Pacific Ocean and the phase of the El Nino – Southern Oscillation, but the area also has a large intrinsic climate variability. The pre-industrial control simulations from CMIP5 indicate that the observed deepening of the ASL and stronger southerly flow over the Ross Sea are within the bounds of modeled intrinsic variability, suggesting that the recent increase of sea ice may also be a result of natural variability.

Joint Inter-Association Symposium

JC01b - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-1388

Sea ice production variability in the Antarctic coastal polynyas

T. Tamura[1], K. Ohshima[2], A. Fraser[2], G. Williams[3]
[1]National Institute of Polar Research, Tachikawa, Japan
[2]Hokkaido University, Institute of Low Temperature Science, Sapporo, Japan
[3]University of Tasmania, ACE CRC, Hobart, Australia

The sinking of dense water in the polar oceans plays a key role in global thermohaline circulation, leading to heat and material exchange between the atmosphere and deep ocean. High ice production in Antarctic coastal polynyas is responsible for the dense water formation, leading to Antarctic Bottom Water (AABW) formation. Our past studies gave the mapping of sea ice production in the Southern Ocean, based on heat-flux calculation with ice thickness data derived from satellite data. This study presents the interannual and seasonal variability of sea ice production in the 13 major coastal polynyas from 1992 to 2013. In general, the interannual variability of sea ice production shows a good correlation with polynya extent rather than surface air temperature. The Ross Ice Shelf polynya experienced large ice production reduction events in 2000 and 2002 due to the effects of the giant icebergs B-15 and C-19, which calved from the Ross Ice Shelf, and the ice production later recovered to the same level as that in the 1990s. The Mertz Glacier polynya also experienced a large ice production reduction event in 2010 due to the calving of the Mertz Glacier Tongue, and new minimum ice production records have been set every year since.

Joint Inter-Association Symposium

JC01b - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-1614

Antarctic Sea Ice Response in CMIP5 Pre-industrial, Historical and Ozone Perturbation Simulations

S. O'Farrell[1], *P. Reid*[2], *R. Massom*[3]
[1]*CSIRO, Ocean and Atmosphere Flagship, Aspendale, Australia*
[2]*Bureau of Meteorology and Antarctic Climate and Ecosystems CRC, Antarctic Section, Hobart, Australia*
[3]*Australian Antarctic Division and Antarctic Climate and Ecosystems CRC, Antarctica & the Global System, Hobart, Australia*

Multi-decadal Antarctic sea-ice trends from three CMIP5 modelling systems (ACCESS1.0, ACCESS1.3 and CSIRO Mk3.6) are compared against recent observations. Several hypotheses are advanced to explain the recent small positive trend in overall extent. Area weighted trends in some ensemble members of the CSIRO Mk3.6 system match the observations reasonably well. Whilst the CSIRO results with ozone forcing are more realistic than runs without the recent ozone perturbation, with regional patterns being enhanced in the Bellingshausen and Weddell seas and East Antarctica, from these results we do not exclude the hypothesis that the current positive trend in observed net sea ice extent is due to natural variability. The regional patterns of ice advance and mid-winter ice maximum are well represented in the ACCESS1.0 and 1.3 modelling systems and are driven by atmospheric pressure, air and ocean temperature trends; inclusion of ozone forcing did not have a discernible effect.

The ice-ocean fluxes and other forcings of the ocean multi-decadal variability have been investigated in the 500 year long pre-industrial control for both the CSIRO and ACCESS systems, to determine how the natural variability of the system is aligning with the signal in the historical runs.

Joint Inter-Association Symposium

JC01b - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-3320

Effect of a Maxwell-elastic-brittle rheology on the simulation of sea ice with NEMO-LIM3

J. Raulier[1], *T. Fichefet*[1], *V. Legat*[2], *J. Weiss*[3], *V. Dansereau*[4]
[1]*Université catholique de Louvain,*
Georges Lemaître Centre for Earth and Climate Research, Louvain-la-Neuve, Belgium
[2]*Université catholique de Louvain,*
Institute of Mechanics- Materials and Civil Engineering, Louvain-la-Neuve, Belgium
[3]*CNRS-UJF, Institut des Sciences de la Terre, Grenoble, France*
[4]*Université Joseph Fourier,*
Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France

Satellite observations of the Arctic sea ice show the existence of a dense mesh of leads constantly opening and closing over short time scales. Those leads are highly linked to the presence of linear kinematic features which are quasi linear patterns present in the strain field that stretch all across the Arctic basin. Current sea ice models fail to reproduce those linear kinematic features and the observed statistical distribution of deformation rate. In order to refine the physical representation of sea ice dynamics into sea ice models, a new approach has been adopted for the rheology of sea ice. This approach, based on a Maxwell-elasto-brittle rheology, is integrated in the NEMO-LIM3 global ocean-sea ice model (www.nemo-ocean.eu ; www.elic.ucl.ac.be/lim). In the present study, we analyse the impact of this new rheology for sea ice on the simulation of leads and the ability of the model to reproduce the main observed characteristics of the Arctic and the Antarctic ice packs. We will also address the effect of the rheology on the modelled air-ice-ocean fluxes.

Joint Inter-Association Symposium

JC01b - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-4412

Cyclone-induced rapid creation of extreme Antarctic sea ice conditions

Z. Wang[1], *J. Turner*[2], *B. Sun*[3], *B. Li*[3], *C. Liu*[1]
[1]*Nanjing University of Information Science and Technology, Polar Climate System and Global Change Laboratory, Nanjing, China Peoples Republic*
[2]*British Antarctic Survey, Climae Program, Cambridge, United Kingdom*
[3]*Polar Research Institute of China, Physical Oceanography Division, Shanghai, China Peoples Republic*

Sea ice movement is strongly affected by the atmospheric circulation. On synoptic time scales, winds associated with cyclones can be very intense, particularly in the coastal regions of East Antarctic as cyclones often enhance strong katabatic wind events. Two polar vessels, Akademik Shokalskiy and Xuelong, were trapped by thick sea ice in the Antarctic coastal region just to the west of 144^{o}E and between 66.5^{o}S and 67^{o}S in late December 2013. This event demonstrated the rapid establishment of extreme Antarctic sea ice conditions on synoptic time scales. The event was associated with cyclones that developed at lower latitudes. Near the event site, cyclone-enhanced strong southeasterly katabatic winds drove large westward drifts of ice floes. In addition, the cyclones also gave southward ice drift. The arrival and grounding of Iceberg B9B in Commonwealth Bay in March 2011 led to the growth of fast ice around it, forming a northward protruding barrier. This barrier blocked the westward ice drift and hence aided sea ice consolidation on its eastern side. Similar cyclone-induced events have occurred at this site in the past after the grounding of Iceberg B9B. Future events may be predictable on synoptic time scales, if cyclone-induced strong wind events can be predicted.

Joint Inter-Association Symposium

JC01b - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

IUGG-5632

Comparison of different sea ice product and data of drifting buoys

N. Marchenko[1]
[1]*The University Centre in Svalbard, Arctic Technology, Longyearbyen, Norway*

Information of sea ice movement in the Arctic is very important for science and practice. Growing industrial activities in High North demand estimation of risks of damage due to collision with ice. Sea ice is a critical component of Nature because it influences and reflects global climate.

Several institutions and agencies provide now “Sea ice products”, showing ice concentration, motion vectors and thickness, derived from passive microwave, visible and infrared sensors, and other sources.

We investigate ice drift characteristics in the Barents Sea and analyze data from: 1)IFREMER (France); 2) OSI SAF(international); 3) NSIDC (US); 4) Anistiamo (Finland); 5)TOPAZ (International).

The first three sources show the whole Arctic. **IFREMER** has data sets and images/maps showing everyday ice drift vectors with displacement for 3 and 6 days. There is data for 1991-2015, but various algorithm cover various time periods. **OSI SAF** has 2 days interval for each day since 2009 per now. **NSIDC** shows ice drift vector mean speed and direction for weeks, months and years for 1979-2012. Anistiamo and TOPAZ are local products for Barents and Kara Seas region. **Anistiamo** data on ice drift (speed vector m/s) is available for every day in 13 January- 14 May 2014.**TOPAZ** shows speed vector since 23 February 2011 up to 27 May 2013. So they do not have overlap.

We compare the data of these products with each other and with own data, provided by drifting buoys, deployed on sea ice in 2008 – 2014, with sampling interval 10-20 min.

Comparison revealed that products mostly had similar appearance and coincided with the movement of buoys. But in some cases they showed opposite ice drift patterns. It has specific reasons related to local actions of wind and tidal currents and will be discussed.

Joint Inter-Association Symposium

JC01p - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

JC01p-084

Large-scale patterns of Arctic sea ice variability and links to climatic forcing

S. Close[1], C. Herbaut[1], M.N. Houssais[1], A. Martin[1]
[1]*Université Pierre et Marie Curie, LOCEAN, Paris, France*

In this study, we examine the large-scale spatial and temporal patterns of Arctic sea ice variability over the period 1979-2009, employing sea ice concentration data from passive microwave measurements (Special Sensor Microwave Imager/Sounder) in conjunction with two data-assimilating (PIOMAS / NEMO-LIM2) model simulations and output from a coupled ice-ocean model (NEMO-LIM2) forced using reanalysis data. The timing of the onset of the recent tendency towards rapid ice loss is analysed, and found to be strongly regionally dependent, suggesting the need for caution in Arctic-wide studies. Using the model data, patterns of ice thickness variability are described using empirical orthogonal function (EOF) analysis, and the links between ice thickness and sea ice concentration variability studied. Consistency between the model responses indicates certain robust features; this is particularly true of the primary EOF modes, which, considered in combination with a singular value decomposition analysis of the co-variability between sea ice and atmospheric forcing, suggest a coherent response to the Arctic Oscillation.

Joint Inter-Association Symposium

JC01p - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

JC01p-085

Impact of sea ice cover on phytoplankton primary production in polar seas: The case study of the Barents Sea

V. Ryabchenko[1], *V. Gorchakov*[2], *A. Dvornikov*[1]
[1]*P.P.Shirshov Institute of Oceanology- Russian Academy of Sciences, St.Petersburg Branch, St.Petersburg, Russia*
[2]*P.P.Shirshov Institute of Oceanology-Russian Academy of Sciences, St.Petersburg Branch, St.Petersburg, Russia*

This study is aimed at elucidating the role of sea ice in the seasonal and inter-annual variability of ocean circulation and marine ecosystems in the Barents Sea in the modern period. A dynamic - thermodynamic sea ice model HELMI having 7 ice categories and providing detailed description of ice thickness and area has been embedded into the Princeton Ocean Model. Pelagic ecosystem model developed in the St. Petersburg Branch of Shirshov Institute of Oceanology has been coupled with the above hydrodynamic model and used to calculate the seasonal and inter-annual changes in the characteristics of marine ecosystems. With this coupled model a run for the period 1998-2007 was performed on a fine grid under atmospheric forcing of National Center for Environmental Prediction (USA). For prescribing the boundary conditions at the open boundary all the necessary information was taken from the results of calculations with the global ocean general circulation model of the Max Planck Institute for Meteorology (Hamburg, Germany) . The resulting model solution with a sufficiently high accuracy simulates the seasonal and inter-annual variability of sea surface temperature and the area of sea ice cover which are estimated from satellite data. The solution for the period 1998-2007 correctly reproduces the start and end of the vegetation period, and the level of the spring phytoplankton bloom comparing with the SeaWiFS surface concentration of chlorophyll 'a'. The analysis of correlations between the physical and ecosystem characteristics was performed. In particular, found that the primary production of the sea in the spring (April to mid-June) is inversely proportional to the area of ice cover in the Barents Sea with a correlation coefficient of about 0.9.

Joint Inter-Association Symposium

JC01p - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

JC01p-087

Operation IceBridge data products and access: data management and airborne campaigns

S. Tanner[1]
[1]*National Snow and Ice Data Center, Boulder, USA*

Operation IceBridge (OIB) is a National Aeronautics and Space Administration (NASA) funded series of airborne campaigns in the Arctic and Antarctic regions meant to “bridge” the transition between the Ice, Cloud, and land Elevation Satellite (ICESat) and ICESat-2 satellite missions. The OIB effort is now slated to cover at least 10 years of measurements, with 6 years of data already available through the NASA Distributed Active Archive Center (DAAC) at the National Snow and Ice Data Center (NSIDC). This data includes over 60 products covering a wide range of measurements over both land and sea ice. In addition, the number of campaigns flown each year is increasing, for example planning is underway for a possible melt season campaign in 2015. The wide range of data is beginning to be used in a number of research efforts, and the number of derived products based in part on OIB data, is growing significantly.

This presentation will cover the wealth of data available from IceBridge, and the best methods of finding and accessing this information. This includes the data products and measurements from the standard IceBridge campaigns as well as atmospheric data gathered during the recent Arctic Radiation IceBridge Sea and Ice Experiment (ARISE) campaigns. Data management issues, challenges and approaches will also be presented, including the efforts to standardize the formats and the generation of significant amounts of metadata for each data product.

Joint Inter-Association Symposium

JC01p - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

JC01p-088

The impact of surface mixing on the Arctic river water distribution and stratification in global models

Y. Komuro[1], *H. Tatebe*[1]
[1]*Japan Agency for Marine-Earth Science and Technology,*
Department of Integrated Climate Change Projection Research, Yokohama, Japan

The impact of oceanic vertical mixing on the Arctic river water distribution is investigated in the context of global modeling. When an ice-ocean model is used, lowering surface background vertical diffusivity and ignoring the effects of surface wave breaking under sea-ice on turbulent kinetic energy improve the model simulation of the horizontal Arctic river water distribution. This improvement is largely responsible for the freshening of the Arctic surface salinity in the model used in this study. Although these modifications are applied over the whole global ocean, the change in the surface salinity over the Arctic is larger than that in the rest of the global ocean by one to two orders of magnitude. Weaker surface vertical mixing in the Arctic Ocean also causes sea ice to thicken even without changes in the parameters for the sea ice component. Results of an atmosphere-ice-ocean coupled model will also be presented.

Joint Inter-Association Symposium

JC01p - JC1 Sea Ice in the Arctic and Southern Oceans (IACS, IAMAS, IAPSO)

JC01p-089

Sea ice of the Eurasian Arctic seas from models and historical data

L. Bobylev[1], *O. Johannessen*[2], *S. Kuzmina*[3], *S. Sandven*[4], *V. Volkov*[5]
[1]*Nansen Centre, St. Petersburg, Russia*
[2]*Nansen Environmental and Remote Sensing Centre, Climate Department, Bergen, Norway*
[3]*Nansen Centre, Climate Group, St. Petersburg, Russia*
[4]*Nansen Environmental and Remote Sensing Centre, Satellite Observations, Bergen, Norway*
[5]*Nansen Centre, MetOcean Group, St. Petersburg, Russia*

An analysis is performed how well the current climate models reproduce observed regional changes of sea ice extent (SIE) in the five Eurasian Arctic seas in the second half of the 20th century and how they assess the future changes of the sea ice cover in these seas in the 21st century. For this analysis the ensemble of CMIP5 global climate models and unique historical observational data were used. It is shown that the model ensemble overestimates SIE and underestimates its negative trend during the past decades - sea ice decreases faster than projected by models. For getting more reliable projections of SIE in the Eurasian Arctic seas in the 21st century the selection of models from CMIP5 ensemble which best match SIE observations was performed. Selected models show trends for September SIE in the 21st century larger by 21% than the CMIP5 ensemble mean. Model projections were compared with the results of extrapolation of the observed SIE. Analysis of model projections and extrapolation of observed data shows that the sea ice will be decreasing in all Eurasian Arctic seas with more rapid decline in Chukchi Sea, where the extrapolation of the observed values shows that to the middle of the 21st century this sea will become ice free in summer. Slower decrease is expected for Laptev and East Siberian seas, where extrapolation shows that the sea ice extent will be about 0.2×10^6 km^2 for Laptev Sea and 0.4×10^6 km^2 for East-Siberian Sea up to the middle of the 21st century. The length of the navigation season on the Northern Sea Route (NSR) is estimated and the perspectives of NSR development in the 21st century are assessed using CMIP5 climate models with moderate anthropogenic scenario RCP 4.5.

Joint Inter-Association Symposium

JC02a - JC2/C13 Cold Regions Cryosphere and Hydrosphere (IACS, IAHS/ICSIH, IAMAS, IPA)

IUGG-0551

Climatic trends in avalanche activity since the Little Ice Age in a temperate low altitude mountain range

F. Giacona[1], *N. Eckert*[2], *B. Martin*[1], *M. Lafaysse*[3], *M. Deschâtres*[2], *F. Besson*[4], *S. Morin*[3]
[1]*Mulhouse University, CRESAT, Mulhouse, France*
[2]*Irstea, UR ETNA, Saint Martin d'Hères, France*
[3]*Météo-France - CNRS, CNRM-GAME, Saint Martin d'Hères, France*
[4]*Météo-France, Direction de la climatologie, Toulouse, France*

This work grounds on a record of ~750 avalanches from the last ~250 years. It results from comprehensive inventory of all available historical sources referring to the Vosges, a temperate low altitude mountain range in North-East France. Homogenization techniques are used to remove the bias towards fewer event retrievals far in the past, and a Hierarchical Bayesian approach permits extraction of the predominant temporal signal at the massif scale, both in terms of interannual fluctuations and underlying low frequency trend. The second is shown to be consistent with main trends in different coarse climate indicators: measurements from distance stations, results from large scale climate simulations and atmospheric indexes. The first is shown to follow, in addition, the year-to-year variability of the local winter snow climate assessed since 1958 by reanalyzes performed with the Safran-Crocus-Isba model chain. All in all, the response of Vosgian avalanche activity to combined changes in winter temperature and precipitation / snow cover characteristics appears very clear, documenting with unprecedented accuracy an irregular decrease from a strenuous stage at the little ice age to a current residual stage mostly limited to highest glacial circs.

Joint Inter-Association Symposium

JC02a - JC2/C13 Cold Regions Cryosphere and Hydrosphere (IACS, IAHS/ICSIH, IAMAS, IPA)

IUGG-1648

A review of climate change effects on snow and avalanches in western Canadian Mountains

B. Jamieson[1], *S. Bellaire*[2], *A. Sinickas*[1], *S. Thumlert*[3]
[1]*University of Calgary, Civil Engineering, Calgary, Canada*
[2]*University of Innsbruck, Institute of Meteorology and Geophysics, Innsbruck, Austria*
[3]*Simon Fraser University, School of Resource and Environmental Management, Burnaby, Canada*

In the mountains of western Canada, the best records of weather, snowpack and avalanching over the last 30 to 50 years are from transportation corridors through seven mountain passes. In one study at Rogers Pass, warming, a decrease in snowpack height and an increase in early winter melt-freeze crusts are evident at the elevation of avalanche start zones. At this pass, no trend in avalanche activity could be detected, likely due to changes in explosive control over the decades. The other study used Hierarchical Bayesian Method to assess trends in six other passes, using only paths in which at least 75% of the avalanches occurred naturally, i.e. they were not triggered by explosives. There was only a weak trend toward more wet avalanches in one low elevation pass. Given the weak or insignificant trends, we looked snow cover models forced with climate change scenarios from similar elevations and latitudes in France and Switzerland. They suggest an increasing wet snowpack, and shorter runout distances are likely.

Joint Inter-Association Symposium

JC02a - JC2/C13 Cold Regions Cryosphere and Hydrosphere (IACS, IAHS/ICSIH, IAMAS, IPA)

IUGG-1887

Impact of climate and land cover changes on snow cover in a small Pyrenean catchment

S. Gascoin[1], *C. Szczypta*[2], *T. Houet*[3], *P. Fanise*[4]
[1]*CNRS, Centre d'Etudes Spatiales de la Biosphère CESBIO, Toulouse, France*
[2]*CNRS, Centre National de Recherches Météorologiques CNRM, Toulouse, France*
[3]*CNRS, Géographie de l'Environnment Laboratoire GEODE, Toulouse, France*
[4]*IRD, Centre d'Etudes Spatiales de la Biosphère CESBIO, Toulouse, France*

The seasonal snow in the Pyrenees Mountains is an essential source of runoff for hydropower production and crop irrigation in Spain and France. The Pyrenees are expected to undergo strong environmental perturbations over the 21st century because of climate change (rising temperatures) and the abandonment of agro-pastoral areas (reforestation). Both changes are happening at similar timescales and are expected to have an impact on snow cover. The effect of climate change on snow in the Pyrenees is well understood, but the effect of land cover changes is much less documented. Here, we analyze the response of snow cover to a combination of climate and land cover change scenarios in a small Pyrenean catchment using a distributed snowpack evolution model. Climate scenarios were constructed from the output of regional climate model projections, whereas land cover scenarios were generated based on past observed changes and an inductive pattern-based model. The snowpack model was validated over a season using in situ snow depth measurements and high-resolution snow cover maps derived from SPOT satellite images. Model projections indicate that both climate and land cover changes reduce the mean snow depth. However, the impact on the snow cover duration is moderated in reforested areas by the shading effect of trees. Most of the significant changes are expected to occur in the transition zone between 1500 m a.s.l. and 2000 m a.s.l. where (i) the projected increase in air temperatures decreases the snow fraction of the precipitation and (ii) the land cover changes are concentrated. However, the consequences on the runoff are limited because most of the meltwater originates from high-elevation areas of the catchment, which are less affected by climate change and reforestation.

Joint Inter-Association Symposium

JC02a - JC2/C13 Cold Regions Cryosphere and Hydrosphere (IACS, IAHS/ICSIH, IAMAS, IPA)

IUGG-2907

Snowpack characteristics and primary causal factors in the Japanese Central Mountains

S. Ikeda[1], *H. MATSUSHITA*[1], *K. AKIYAMA*[1], *K. Izumi*[2]
[1]*Public Works Research Institute,*
Snow Avalanche and Land Slide Research Center, Myoko-shi, Japan
[2]*Niigata University, Research Institute for Natural Hazards and Disaster Recovery, Niigata, Japan*

To identify the regional characteristics of mountain snowpacks that are related to avalanches in the central mountains of Japan, snow pit observations were carried out over eight winters. Six study sites were selected in the area, including three major mountain ranges: the Northern, Central, and Southern Japanese Alps. We find the area sees all three types of snow climate categories for North America (Maritime, Intermountain, and Continental snow climate) in a small horizontal range of around 100 km. The fact that a variety of snow conditions are seen in such a small island is because major snowfalls in Japan are caused by “the Japan Sea effect snowfall” that is similar to the lake effect snowfall. However, the mountainous area located on the Pacific Ocean side of Japan has unique characteristics in that both depth hoar and melt forms dominate the snowpack. In this area, air temperature was not high in comparison with North America, and enough temperature gradient to grow depth hoar existed in the snowpack. This unique snowpack was formed by frequent rainfall events that brought about a dramatic change in the snowpack over a very short period. Our study shows that the amount of rainfall and the timing of the rainfall events in each year was a determining factor for the dominant snow grain types, and the density and hardness of the snowpack in this area.

Joint Inter-Association Symposium

JC02a - JC2/C13 Cold Regions Cryosphere and Hydrosphere (IACS, IAHS/ICSIH, IAMAS, IPA)

IUGG-3138

Mountain snow distribution and how it will change

M. Lehning[1]
[1]*WSL/SLF and CRYOS/EPFL, Davos, Switzerland*

The distribution of snow in the mountains is highly heterogeneous, and the processes behind the heterogeneity are not yet understood quantitatively. Based on (i) increasing accuracy and spatial coverage of remotely sensed snow depth maps, which have become available in recent years, (ii) improved atmospheric modeling of precipitation and particle dynamics and (iii) better distributed measurements of solid precipitation (radar), it is possible to improve the characterization of processes leading to the observed snow distributions. We present results that show the relative importance of local precipitation variability, preferential deposition of snow and wind driven as well as and gravity driven snow transport. The current evidence suggests that all these processes significantly contribute to shaping the snow distribution in alpine terrain. On average snow height and water equivalent increase up to a certain elevation but then show a distinct maximum and a subsequent decrease around the ridge/summit elevations. Only recently this could be shown in a reliable and quantitative way for diverse mountain regions worldwide.

In a second part of the presentation we address the influence of climate change and show, how much different elevations (and therefore climate zones) in the Swiss Alps are affected by global warming as predicted by a set of regional climate models. We conclude that above the tree-line, snow distribution and the relative importance of associated processes is not expected to change significantly, despite the fact that warming will lead to a strong decrease in snow at mid elevations.

Joint Inter-Association Symposium

JC02b - JC2/C13 Cold Regions Cryosphere and Hydrosphere (IACS, IAHS/ICSIH, IAMAS, IPA)

IUGG-1165

Trends of breakup dates in Finnish lakes in 1963-2014

E. Kuusisto[1]
[1]*PhD, SYKE- Water Centre, Helsinki, Finland*

Long data series of freezing and breakup observations are available from the lakes in Finland. Some of these series were started already in the former half of the 19th century. In this study, the breakup dates during the last fifty years have been analyzed from 51 lakes covering the whole country. A statistically significant linear trend (99.9%) towards an earlier breakup was detected on 40 lakes. Eight lakes had a trend with a significance of 99 per cent and the rest, three lakes with a significance of 95 per cent.

In 70 per cent of the lakes, the shift towards an earlier breakup has been 10–14 days during the fiftytwo year period. In 23 per cent, it has been 15–18 days. In southern and western parts of the country and in the former Oulu province the trends have been slightly stronger than elsewhere in the country. Smallest trends have occurred in Lapland.

Significant trends can be detected also in most of the breakup data series, which are longer than one hundred years. However, these trends are considerably milder than those calculated from the last fifty years.

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IUGG-1527

Future scenarios of the water balance of Switzerland: setup, verification and propagation of climate projections

L. Bernhard[1]*, C. Pflugshaupt*[1]*, D. Viviroli*[2]*, S. Kotlarski*[3]*, M. Zappa*[1]
[1]*Research Institute WSL, Mountain Hydrology, Birmensdorf, Switzerland*
[2]*Department of Geography, Hydrology and Climate Unit, Zürich, Switzerland*
[3]*ETH Zürich, Institute for Atmospheric and Climate Science, Zürich, Switzerland*

There is a strong evidence that climate is changing – both at global and regional scales – and that some of these changes are very likely caused by anthropogenic greenhouse gas emissions. A changing climate and its hydrological effects contribute to an increasing uncertainty regarding future demand and availability of water. The water cycle reacts sensitively to temperature change, particular in the alpine region. Changes in snow and ice accumulation and ablation due to temperature changes have a huge influence on the available water resources. A detailed and quantitative analysis of the impact of climate change on the hydrological cycle and in particular on runoff and hydrological storages in Switzerland was missing. In 2008 the study Climate Change and Hydrology (CCHydro) was started, in which the impact of climate change on hydrological resources in Switzerland on a high temporal and spatial resolution was investigated. In contrast to the CCHydro project, where only A1B emission scenarios were considered, two additional emission scenarios were used and a different post-processing of the climate data was applied. This enables a comparison of the hydrological impacts associated with different emission scenarios and thus a quantitative assessment of the resulting uncertainty. The aim of this project is the probabilistic projections of temperature and precipitation to gain more robust information about the influence of different emission scenarios on hydrological quantities. It is important to highlight the similarities and differences of the climate scenarios to force the hydrological model, because these data are responsible for all hydrological impacts.

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IUGG-1591

Can temperature extremes in East Antarctica be replicated from ERA Interim reanalysis?

A. Xie[1], *C. Xiao*[1], *S. Kang*[1], *S. Wang*[1], *J. Ren*[1], *D. Qin*[1], *M. Ding*[2], *C. Li*[1], *J. Gong*[1]
[1]*Cold and Arid Regions Environmental and Engineering Research Institute- Chinese Academy of Sciences, State Key Laboratory of Cryospheric Sciences, Lanzhou, China Peoples Republic*
[2]*Chinese Academy of Meteorological Sciences, Institute of Climate System, Beijing, China Peoples Republic*

Based on daily minimum, maximum and mean surface air temperature (T_{min}, T_{max}, T_{mean}) from European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis from 1979 onwards (ERA Interim), the accuracy of daily 2-meter T_{min} and T_{max} from ERA Interim reanalysis is assessed against in-situ observations from Automatic Weather Stations in East Antarctica for 2005 to 2008. The reanalysis explains more than 80% of the annual average variance, and has annual root mean square errors of 2.4°C, 2.6°C, 3.0°C and 4.3°C for the daily T_{min}, and 2.2°C, 3.1°C, 3.4°C and 4.9°C for the daily T_{max} at Zhongshan, LGB69, Eagle and Dome A, respectively. In general, the errors tend to increase from the coast to the interior of the East Antarctic ice sheet, although there are regional differences between the performance of T_{min} and T_{max}. ERA Interim generally shows the warm bias for T_{min} and the cool bias for T_{max}, which indicates that ERA Interim underestimates the diurnal temperature range. On average, T_{min} performs more similarly to T_{mean} than T_{max}. ERA Interim performs better in the austral spring and worse in winter and autumn, especially at Dome A. ERA Interim can capture most of the temperature extremes at the same day as the observation, and the forecasting ability decreases from the coast to the interior of the East Antarctic ice sheet. Although the deficiencies, limitations and biases exist, ERA Interim can replicate the variability of temperature extremes obtained from observations, and can be applied to investigate temperature extremes to some extent. However, more in-situ observations are required, especially from the vast interior of Antarctica.

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IUGG-3524

Snow water resources monitoring in Switzerland – integrating longterm observational datasets with advanced modelling approaches

T. Jonas[1], A. Winstral[1], N. Helbig[1], J. Magnusson[1], N. Griessinger[1]
[1]WSL Institute for Snow and Avalanche Research SLF, Snow Hydrology, Davos Dorf, Switzerland

The distribution of seasonal snowcover is known to be highly variable in space and time. While data from longterm snow monitoring sites provide valuable information about the temporal dynamics of snowcover formation and depletion, these data do not adequately describe the spatial variability of available snow water resources. Snowcover models on the other hand can replicate the spatial distribution of snow but often deviate from observations due to shortcomings related to input data and process representations within the models.

To provide accurate information about available snow water resources in Switzerland at high spatial (1km) and temporal (daily) resolution, we have developed a monitoring system that combines different types of snowcover models with data assimiliation techniques to incorporate available observational data. This system is primarily in use for operational snowmelt forecasting purposes but is also an excellent tool for deriving longterm datasets of distributed snow water equivalent.

We will first detail the setup of the monitoring system and the contributing models. We will then discuss model performance and validation. The model system has been set up to create a temporally consistent dataset of distributed daily snow water equivalent for all of Switzerland at 1km resolution. This dataset covers the past 44 years from 1971 to 2015 and is available for follow-up studies.

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IUGG-4175

A factor controlling long-term variations of the Siberian river discharges during the past two centuries

K. Oshima[1], *K. Ogata*[2], *H. Park*[1], *Y. Tachibana*[2]
[1]*Japan Agency for Marine-Earth Science and Technology,*
Research and Development Center for Global Change, Yokosuka, Japan
[2]*Mie University, Climate and Ecosystem Dynamics Division, Tsu, Japan*

Among all the rivers flowing into the Arctic Ocean, the three great Siberian rivers; Lena, Yenisei and Ob, are the three largest in terms of discharge (R), and they are sources of freshwater, organic matter and heat. While long-term variation and trend of the Rs have been examined in many previous studies, causes of the R variabilities are still unclear. Fukutomi et al. (2003) indicated a negative correlation between the Rs of the Lena and Ob during the 1980s to mid-1990s. They also showed that the variations were affected by an east-west seesaw pattern of moisture transport over Siberia. Based on this study, we examine long-term variations of Rs of the Lena and Ob Rivers during the past two centuries and aim to reveal a factor controlling the variations.

As in Fukutomi et al., the observed Rs of the Lena and Ob were negatively correlated during 1980s to mid-1990s, whereas the correlation becomes weak after the mid-1990s and the correlation was positive during the mid-1950s to 1960s. This indicates that the relationship between the Rs of the Lena and Ob differed in each epoch during the past seven decades. Reconstructed Rs based on the tree-ring also showed positive and negative correlations in each of the epochs during the past two centuries. Interestingly, the correlations of the reconstructed Rs tend to be distributed on the negative side. This implies that the east-west seesaw pattern frequently appeared over Siberia. A 300-yr control simulation with an atmospheric general circulation model indicated that correlations between simulated precipitation over eastern and western Siberia were negative in most of the epochs. This suggests that the east-west seesaw pattern appears as an atmospheric natural internal variability over Siberia.

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IUGG-5099

Glaciers of the semiarid chilean Andes: are they becoming precipitation-starved?

C. Kinnard[1], S. MacDonell[2], P. Ginot[3]
[1]Université du Québec à Trois-Rivières, Sciences de l'environnement, Trois-Rivières, Canada
[2]Centro de Estudios Avanzados en Zonas Aridas, Glaciology, La Serena, Chile
[3]Institut de Recherche pour le Développement,
Laboratoire de Glaciologie et de Géophysique de l'Environnement, Saint-Martin d'Hères, France

In the Andes mountain range of North-Central Chile snow, and glaciers to a lesser extent, provide meltwater runoff during the dry summer when water demand for irrigation is at its peak. The upper Huasco River catchment (29°S, 70°W,) lies at the limit of the extremely arid Atacama Desert but still receives enough precipitation in the mountains to generate surface runoff which supports productive fruit agriculture in the lower valley. The several small (< 2 km^2) glaciers found at the highest altitudes (> 4000 m a.sl.) have become valued freshwater reservoirs as well as icons of the environmental pressures exerted by the mining industry on water resources in Chile. In this contribution we examine the recent evolution of six glaciers in the upper Huasco River catchment in the light of historical, paleoglaciological, and climate data. Specifically, we present and contrast: (i) glaciological mass-balance data for 2002-2011; (ii) geodetic mass balance between 1955, 1978 and 2005; (iii) pre- ~1850 mass-balance estimated from an ice core recovered from one glacier; (iv) regional climate data. It is shown that glaciers have likely been out of balance with climate since at least 1955, with a noticeable acceleration toward more negative mass-balance measured since 2002. Ice-core stratigraphy and derived mass balance suggests that the glaciers formed under a much more humid climate than today with enhanced accumulation and melting compared to present day climate dominated by low accumulation and strong sublimation.

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IUGG-0529

Permafrost distribution in the maritime Southern Alps, New Zealand

K. Sattler[1], *B. Anderson*[2], *A. Mackintosh*[1,2], *K. Norton*[1], *M. de Roiste*[1]
[1]*Victoria University of Wellington,*
School of Geography- Environment and Earth Sciences, Wellington, New Zealand
[2]*Victoria University of Wellington, Antarctic Research Centre, Wellington, New Zealand*

Research on the geographic extent of alpine permafrost in maritime mountain regions has been limited. In this talk, we present the results of a regional spatially-distributed permafrost estimate for the maritime Southern Alps, New Zealand.

We derived our distribution model from the statistical analysis of topoclimatic conditions at 280 active and relict rock glacier sites. We used logistic regression to identify the relationship of mean annual air temperature and potential incoming solar radiation to permafrost presence. Statistical relationships were subsequently employed to calculate the spatially-distributed probability of permafrost occurrence, using a probability of ≥ 0.6 to delineate the potential permafrost extent. We validated the model results in the Ben Ohau Range, central Southern Alps, by BTS (bottom temperature of snow cover) data, derived from two-year continuous ground surface temperature measurements, and the distribution of perennial snow patches. Both datasets indicated a reasonable model result.

Our results suggest that topoclimatic conditions are favourable for permafrost occurrence above ~ 2000 m in the central Southern Alps and above ~ 2150 m in the warmer northern ranges. Considering a latitudinal control on global distribution patterns, the calculated limits are unusually low in comparison to other mountain ranges. Reduced ice-loss due to moderate summer temperature extremes, characteristic for maritime climates, may facilitate the occurrence of permafrost at lower altitudes than in the continental European Alps at similar latitude. We encourage further research into this possible oceanic influence; clarification of related climatic controls could provide new insights into the occurrence of mountain permafrost around the world.

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IUGG-1492

Estimating non-conductive heat flow leading to intra-permafrost talik formation in an ice-rich rock glacier

R. Luthi[1]*, M. Phillips*[1]*, M. Lehning*[1]
[1]*WSL Institute for Snow and Avalanche Research SLF, Snow and Permafrost, Davos Dorf, Switzerland*

Non-conductive heat flow plays an important role in the evolution of rock glacier temperatures and the degradation of permafrost ice. Quantification of these types of heat flow is a challenge. At Ritigraben rock glacier (Switzerland) intra-permafrost talik formation at around 12m depth was observed and related to rainfall and snow melt (Zenklusen Mutter and Phillips, 2012). The aim of this study is the quantification of non-conductive heat flow leading to talik formation within this rock glacier. For this purpose measured borehole temperature data, meteorological data and all other available information on the rock glacier were used in combination with modelling experiments. The latter were conducted with a modified version of SNOWPACK - a physically based 1D snow cover model that has previously been used for modelling thermal conditions in rock glaciers. The simulations were run with Dirichlet boundary conditions based on borehole temperature data measured below the active layer and with a simulated heat sink/source controlled by modelled snow cover, measured meteorological data and borehole temperature measurements. This allowed to estimate heat flow for different stratigraphic profiles based on borehole logs and with varying physical properties. The numerical experiments suggest that mean advective heating of approximately 1 $Wm^{-2}h^{-1}$ is consistent with the observed talik development and that the mean heat sink is one order of magnitude smaller. Model results corroborate the assumption that purely conductive heat exchange is incompatible with the observed talik formation.

Zenklusen Mutter, E., Phillips, M., 2012. Thermal evidence of recent talik formation in Ritigraben rock glacier: Swiss Alps, 10th International Conference on Permafrost, Salekhard, Russia, pp. 479-483.

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IUGG-2772

Birth of rock glaciers from debris-covered glaciers: New insights from the central Andes of Chile

S. Monnier[1], *C. Kinnard*[2]
[1]*Universidad Católica de Valparaíso, Instituto de Geografía, Valparaíso, Chile*
[2]*Université du Québec à Trois-Rivières,*
Département des Sciences de l'Environnement, Trois-Rivières, Canada

The glacier to rock glacier transformation problem is revisited from a previously unseen angle. In the central Andes of Chile, various debris-covered glaciers exhibit rock glacier morphology in their lower part. In particular, at Presenteseracae, in the upper part of the Aconcagua River catchment (32.88º S., 70.03º W.), we study the case of a debris-covered glacier whose morphology has turned into rock glacier morphology during the last 60 years. This debris-covered glacier has moreover advanced whereas, in the region, all glaciers have been receding. The common criteria that define a rock glacier are discussed and tested, in particular permafrost occurrence, surface stability, and consistence of the sediment store in the feature with common rates of rock wall retreat. We conclude that the debris-covered glacier is currently transforming into a rock glacier. We do not place our study in the dichotomous debate of the 'ice-cored vs. ice-cemented' rock glacier; the case must be seen as an illustration of how glacial landscapes may shift toward periglacial landscapes.

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IUGG-3245

Heterogeneous snow distribution determines small scale variability of rock wall temperatures

A. Haberkorn[1], M. Hoelzle[2], M. Phillips[1], R. Kenner[1]
[1]WSL Institute for Snow and Avalanche Research SLF, Snow and Permafrost, Davos, Switzerland
[2]University of Fribourg- Unit of Geography, Department of Geosciences, Fribourg, Switzerland

The influence of a continuous snow cover on permafrost ground is well known in flat terrain. Although steep, rough and rocky slopes are widespread in the Alps, knowledge of the influence of the snow on the rock thermal regime is limited. The assumption of a total lack of snow due to gravitational processes is in general not valid, as is shown by our observations in such complex topography. The heterogeneous distribution of the snow significantly affects the energy balance of the rock walls.

To assess the small-scale variability on snow depth and rock temperatures in a steep north and south facing rock wall at Gemsstock, Switzerland, a spatially distributed multi-method approach is applied combining 35 continuous near-surface rock temperature measurements and high resolution snow depth observations using terrestrial laser scanning at different stages of two particularly long and snow-rich winters.

Strong small-scale variability in the distributed rock temperature data due to the strongly variable snow cover accumulation in the rock walls are evident and reveal the heterogeneity and complexity of thermal processes occurring in permafrost rock walls. It is therefore necessary to characterize the sectors of rock walls where snow is preferentially deposited or not, using spatially distributed snow depth and terrain roughness data. This is crucial, since strong temperature gradients over a few metres distance and rapid changes in temperature in snow free sectors, lead to thermal stress and possibly induce rock slope instability, which may endangers human lives and infrastructure in the densely populated Alps.

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IUGG-5469

Characteristics of mountain permafrost at multiple scales in western and eastern Canada

A. Lewkowicz[1]*, A. Bevington*[1]*, R. Way*[1]*, P. Bonnaventure*[2]
[1]*University of Ottawa, Geography, Ottawa, Canada*
[2]*Queen's University, Geography, Kingston, Canada*

This presentation reports on more than a decade of field investigation and modeling of mountain permafrost within northwest Canada (British Columbia and Yukon) and more recently in Labrador (eastern Canada). Broad patterns of permafrost distribution across elevational and latitudinal gradients can be described using empirical-statistical modeling based on climate data from official and unofficial air and ground temperature monitoring stations. Finer scale determinations within the regions require physical modeling but are limited by a lack of baseline information on substrate characteristics, snow and the surface organic layer. New techniques, such as the use of electrical resistivity tomography and low level aerial imaging using an unmanned aerial vehicle have proved critical to site-level investigations, allowing field observations to move from a single point to examine local spatial variability in two or three dimensions. However, traditional ground probing and temperature measurements in boreholes continue to meet many information needs, especially concerning temporal trends. The major difference in mountain permafrost distribution between the two ends of Canada is the varying degree of continentality which leads to higher lapse rates in eastern Canada than in the west, and therefore more rapid change in permafrost conditions with elevation.

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JC02p-181

Combined influence of enso and PDO on mountain glaciers in the Cordillera Blanca, Peru: case study on Nevado Huascaran (9os)

B. KOZHIKKODAN VEETTIL[1], *U. FRANZ BREMER*[1], *E. LEANDRO BAYER MAIER*[1], *J. CARDIA SIMÕES*[1]
[1]*UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL, CENTRO POLAR E CLIMATICO, PORTO ALEGRE, Brazil*

Snowline altitude of mountain glaciers in the outer tropics can be used as good indicators of annual mass balance change. In the outer tropics, highest snowline of the year towards the end of dry season can be used as a proxy for the equilibrium line altitude of the year. We calculated the snowline of selected glaciers radiating from the Nevado Huascaran in the Cordillera Blanca, Peru, from the early 1980s to the present using Landsat series of images acquired during the dry season (May-August). Monthly precipitation and temperature data from the University of Delaware in the form of gridded datasets were used to calculate their monthly anomalies at the study site. These gridded datasets were processed using two cells by applying linear interpolation in MATLAB due to its resolution of 0.5^{o} lat-long. ENSO index at the Niño 3.4 region and PDO indices were obtained from NOAA. It is observed that the snowline of Nevado Huascaran has been fluctuated with the occurrence of ENSO in such a way that an increased snowline is found when the El Niño periods occurs during the positive regime of PDO. This is most visible during the 1997/98 El Niño event. However, it is seen that the accelerated retreat of mountain glaciers in the Cordillera Blanca of Peru is highly correlated with positive phases of ENSO and PDO events after 1977-78, when the PDO entered in its recent and prolonged warm regime until 2008.

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JC02p-182

Glacier changes and glacial lake variations on the debris-covered Baltoro and Bilafond glaciers, Karakoram Himalayas (1978-2014)

B. KOZHIKKODAN VEETTIL[1], *U. FRANZ BREMER*[1],
E. LEANDRO BAYER MAIER[1], *J. CARDIA SIMÕES*[1]
[1]*UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL,*
CENTRO POLAR E CLIMATICO, PORTO ALEGRE, Brazil

Recent studies suggest that high altitude debris-covered Karakkoram glaciers in the Himalayas have been undergoing an expansion irrespective of global warming. However, glaciers in the low altitudes in this region are not showing such a positive mass balance. We mapped the debris-covered glaciers – Baltoro, which is one of the longest glaciers outside the polar region and Bilafond in the Karakoram region. We also calculated the formation, expansion and disappearance of glacial lakes during the past four decades using Landsat series of images and digital elevation models from SRTM. Debris-covered glaciers are difficult to map using visible and infrared imagery. When combined with digital elevation models, this type of glaciers can be mapped with a good accuracy. We also calculated the anomalies in precipitation and temperature in this region using gridded datasets from the University of Delaware. Despite of their high altitudes, these two glaciers were found to have undergone a retreat during the study period. However, the rate of retreat is very low when compared with glaciers in the tropical region such as Bolivia or Peru. Debris-covered glaciers show an altered sensitivity towards climate change, compared to clean glaciers. We could map more glacial lakes during 2000s than the present.

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JC02p-183

Variation trend of snowfall in the Japanese Alps region

K. Suzuki[1]
[1]*Shinshu University, Department of Environmental Science, Matsumoto, Japan*

The Japanese Alps region is known to experience some of the heaviest snowfall in the world. In this region, precipitation brought by snowfall is more important as a water resource than rainfall. This region experiences exceptionally heavy snowfall that is extreme even by world standard, and in spring, the melting snow becomes a valuable water resource for the region. Snow plays the role of a natural white dam by accumulating in watersheds during winter. Recent studies have reported that the amount of snowfall in Japan will decrease as a result of global warming. However, these studies used data observed at low altitudes. The question arises whether the same theory can be applied to high-altitude mountain areas. Observations of the amount of snow have not been carried out in high-altitude mountain in Japan where the temperature is colder than the threshold temperature of snow/rain even with the temperature rise observed in recent years. Therefore, we cannot discuss the effect of global warming on the change in the amount of snow in the mountainous region of Japan based on observation data. Therefore, in this study, we discuss the relationship between temperature and the amount of snow using observation data for the Japanese Alps region and present the results of some meteorological observations we carried out at high-altitude sites in the Japanese Alps region.

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JC02p-185

SLF permafrost borehole temperature monitoring network: data processing and selected results

R. Lüthi[1], *M. Phillips*[1]
[1]*WSL Institute for Snow and Avalanche Research SLF,*
Permafrost and Snow Climatology, Davos Dorf, Switzerland

The SLF permafrost borehole temperature monitoring network comprises 25 boreholes at 12 sites in the Swiss Alps. Nine of these are included in the Swiss Permafrost Monitoring Network (PERMOS). The boreholes are located at elevations above approximately 2400 m asl and cover different landforms with contrasting temperatures and ice contents, like crests, rock walls, talus slopes and rock glaciers. The boreholes not included within PERMOS will be presented here. They are up to 24 m deep and the longest measurement series reach back to 1996. Temperatures are measured with high precision thermistors (and at one location with UTL3 loggers) at various depths in 2-hourly to daily resolution. The data deliver valuable information on the depth of the active layer, the thickness of the permafrost and on temperature changes and thermal anomalies occurring at various depths and over different time scales.

Borehole temperature data was carefully checked and if necessary corrected or removed. For this purpose specific processing routines were developed and applied to all data. These tools are introduced and illustrated here with specific examples.

Metadata was included into the Swiss Experiment platform (www.swiss-experiment.ch) and processed data is available on the internet via a GSN middleware. Finally, selected results of temperature measurements are shown and various challenges of long-term ground temperature monitoring are discussed.

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JC02p-187

"Preliminary study on permafrost and periglacial phenomena of Gokyo Valley, Sagarmatha (Everest) National Park, Nepal"

T. Shrestha[1], *S. Sharma*[2], *J. Merz*[3], *R. Garton*[3]
[1]*International Centre for Integrated Mountain Development, Water and Air, Kathmandu, Nepal*
[2]*Kathmandu University, Department of Environmental Science and Engineering, Dhulikhel, Nepal*
[3]*The Glacier Trust, Glacier Trust, Northwing, United Kingdom*

Alpine glaciers, permafrost and frost-related geomorphological processes are sensitive to climate change providing an important record of environmental change used for reconstructing past climates. However studies on periglacial phenomena are few in the Himalayan region compared to other parts of the world where only the cryohydrospheric component i.e. glaciers and their impacts are studied. Thus, this preliminary study attempts to provide a baseline study with respect to periglacial phenomena and permafrost in Gokyo Valley which lies in Everest National Park, Khumjung, Nepal. Different periglacial landforms and hill slope processes such as rock glacier, hummocky ground, rock ploughing, frost shattered bedrock, nivation, solifluction and slope wash were documented and mapped in the valley. These landforms occur above an altitude of 4800m. The lowest distribution of rock glaciers are 4759m at north facing sites, 5377m at south facing sites, 5123m at east facing sites and 5095m at west facing sites with variable orientations. In comparison to other parts of the world, most rock glaciers in Gokyo Valley appear to be young, active and talus derived. Rock glaciers on the eastern side of Ngozumpa glacier are near to the supra glacial ponds which may enhance the possibility of rock slides due to climatic warming in the future, eventually enhancing risk of hazard. Furthermore, the results of temperature data loggers used during thawing period at two depths (5 cm and 40 cm) revealed heterogeneous ground temperature conditions at micro scales attributing towards enormous challenges in quantification of the mountain periglacial and permafrost conditions.

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JC02p-188

Estimating the effect of different influencing factors on rock glacier characteristics and frequency in the Swiss Alps

R. Kenner[1]
[1]*WSL-Institut für Schnee und Lawinenforschung, Davos Dorf, Switzerland*

Rock glaciers are characteristic features of mountain permafrost. Their occurrence is highly heterogeneous in size, frequency, shape and environment. There is little knowledge on factors controlling this heterogeneity. Our study uses a GIS based approach to estimate the effect of different influencing factors on rock glacier characteristics. Potential influencing factors to be tested were compiled from the literature and supplemented by own suppositions; these are: precipitation, mean annual air temperature, erosion, glaciers, lithology, slope, aspect, altitude and snow cover. The factors were analysed using a rock glacier cadastre of two partially contrasting regions in the Swiss Alps: the Albula Alps and the Glarner Alps. The spatial characteristics within the mountain regions were identified by adding topographical, geological and meteorological data to the GIS. Taking into account the interaction of these different influences, the effect of each factor on rock glacier occurrence and characteristic was determined. The particular significance of the influencing factors precipitation, lithology and erosion on rock glacier distribution became evident; the interaction of the factors precipitation and lithology seems to play a key role. Snow distribution was shown to cause a different rock glacier frequency in different aspects. Rock glaciers interact with all of the factors analysed and are shown to have complex relations with their regional environments.

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JC02p-189

The separated effects of atmospheric forcing and changes in ice cover on runoff in the Ötztal catchment

K. Helfricht[1,2], *R.R. Wijngaard*[2], *M. Huttenlau*[2], *K. Schneider*[2]
[1]*Institute of Interdisciplinary Mountain Research, Austrian Academy of Sciences, Innsbruck, Austria*
[2]*alpS, Centre for Climate Change Adaptation, Innsbruck, Austria*

Climate warming will alter the reservoirs snow and ice and consequently have an impact on the water balance of mountain regions. Glacierized catchments like in the Ötztal region (Tyrol, Austria) are particularly sensitive to changes in the cryosphere and the hydrological changes related to them. In this study the effects of changes in atmospheric forcing and the effects of changes in the glacierization of the Ötztal mountains on mean runoff and annual runoff maxima were investigated separately. The low-pass-filtered daily signal of changes in temperature and precipitation of the periods 2010-2039, 2040-2069 and 2070-2099 compared to the reference period 1985–2014 was added to the original meteorological measurements of 1986 to 2012. Scenarios of changes in glacier area distribution were calculated for the same periods based on observed volume changes and a modelled ice thickness distribution. Runoff was simulated using the hydrological model HQsim, which was calibrated for the runoff gauges at Brunau (890 km², 11 % glacierized), Obergurgl (72.5 km², 28 % glacierized) and Vent (165.4 km², 31 % glacierized). The climate forcing solely causes an increase in mean runoff from glacier melt in the summer months and a more concentrated occurrence of annual maximum runoff towards the days of highest glacier melt contribution. The reduction in glacier area in a constant climate would result in runoff reduction and an annual maximum runoff more pronounced at the start of melt season at high altitudes. The combination of climate forcing and glacier scenarios increases this effect to a more frequent occurrence of annual maximum runoff earlier in year.

Joint Inter-Association Symposium

JC02p - JC2/C13 Cold Regions Cryosphere and Hydrosphere (IACS, IAHS/ICSIH, IAMAS, IPA)

JC02p-191

Spatiotemporal changes in the Austrian snow cover 1948-2009

T. Marke[1]*, F. Hanzer*[1]*, U. Strasser*[1]*, W. Schöner*[2]*, R. Koch*[3]
[1]*University of Innsbruck, Department of Geography, Innsbruck, Austria*
[2]*University of Graz, Institute of Geography and Regional Science, Graz, Austria*
[3]*Zentralanstalt für Meteorologie und Geodynamik, Climate Research Section, Vienna, Austria*

Snow depth and snow cover duration in the Alps are both characterized by a high spatial and temporal (interannual to decadal) variability, indicating a high sensitivity to climatic conditions. Knowledge of this natural variability and changes in snow conditions is essential for science and stakeholders not only to understand past and present snow conditions, but also for the interpretation of future snow scenarios. While instrumental time series of the relevant meteorological and snow cover variables are an important requisite for climate studies, generally only few long-term climate and snow observation time series are available, and their spatial representativity is mostly limited.

To improve the spatial density of snow information in Austria we use the hydroclimatological model AMUNDSEN to continuously simulate the daily snow cover evolution on a 1x1 km^2 grid for the period 1948–2009. The model is driven with homogenized and quality-checked meteorological station recordings of daily minimum and maximum temperature and precipitation, and produces daily maps of snow water equivalent, snow depth, and fresh snow. Prior to the analysis of changes in the snow cover, the model is thoroughly validated using homogenized snow observations (point scale) as well as remotely sensed snow cover patterns.

The results are analyzed by investigating decadal changes in snow conditions at the model's grid scale of 1x1 km^2, providing a detailed picture on the spatial characteristics of snow cover change. Moreover, temporal trends are elaborated by statistical analyses of mean snow cover change for selected regions in Austria (e.g. the northern, southern, western and eastern part of Austria) giving more detailed insights in the temporal variability and changes in snow cover conditions.

Joint Inter-Association Symposium

JC02p - JC2/C13 Cold Regions Cryosphere and Hydrosphere (IACS, IAHS/ICSIH, IAMAS, IPA)

JC02p-192

Condensation water hydrological process in the alpine meadow region of Hulu watershed in the Qilian Mountain

C. Han[1], R. Chen[1], Z. Liu[1]
[1]Cold and Arid Regions Environmental and Engineering Research Institute- CAS, Qilian alpine ecohydrology research station, Lanzhou- Gansu, China Peoples Republic

Atmospheric water and heat conditions near earth surface at Alpine mountain region changes dramatically. Condensation-evaporation interaction occurs frequently. Those process could significantly affect ecological and hydrological cycle of Cryosphere effect zone. Previous studies of the condensate are mainly concentrated in arid zone. By comparison, few work was carried out on alpine region. But quantity of condensation water in the alpine region is greater than arid zone, and also condensation process and hydrological and ecological significance are quite different. Alpine mountain condensate mainly mitigates periodic physiological water induced by hypothermia, rather than no water is supplied. So, reason of frequent occurrence and enrichment process of condensate is a potential exploration in the study of invisible water in alpine mountains.
The author set up two mini-lysimeter observation in the alpine region at Hulu watershed of Qilian Mountains, 3009m in altitude, named A and B, from November 1, 2009 to March 31, 2014, the condensation water collected in A and B is 79.77mm and 82.41mm, respectively. Since no precipitation and snow were observed in precipitation gauges during that period, the condensation water was not counted in precipitation estimation process. Percentages of condensation water in annual precipitation from 2010 to 2013 monitored using A and B are 2.82%, 2.99%, 3.19%, 6.06% and 2.87%, 3.07%, 3.31%, 6.33%, respectively. Therefore, in the Alpine mountain region, condensation water cannot be ignored in estimating water quantity. It not only can offset the solar radiation, reduce evaporation, and reduce vegetation physiological water, but also has certain contribution to water storage capacity of hydrological processes during freezing period.

Joint Inter-Association Symposium

JC02p - JC2/C13 Cold Regions Cryosphere and Hydrosphere (IACS, IAHS/ICSIH, IAMAS, IPA)

JC02p-193

The CHARIS project - The contribution to high asian runoff from ice and snow

R. Armstrong[1]*, M. Williams*[2]*, R. Kayastha*[3]*, A. Barrett*[1]*, M.J. Brodzik*[1]*, S.J. Singh Khalsa*[1]*, B. Raup*[1]*, A. Racoviteanu*[1]*, K. Rittger*[1]*, A. Wilson*[2]
[1]*University of Colorado, CIRES/NSIDC, Boulder, USA*
[2]*University of Colorado, INSTAAR, Boulder, USA*
[3]*Kathmandu University, Department of Environmental Science and Engineering, Kathmandu, Nepal*

The goal of the USAID funded CHARIS project is to improve understanding of the regional water resources of High Asia. CHARIS is a cross-boundary exercise with University of Colorado scientists working directly with research partners at ten institutions in eight different nations where significant ice and snow resources are located (Bhutan, Nepal, India, Pakistan, Afghanistan, Kazakhstan, Kyrgyzstan, Tajikistan). In this region the amount, timing, and spatial patterns of snow and ice melt play key roles in providing water for downstream irrigation, hydropower generation, and general consumption. The project has achieved significant levels of effective cross-boundary collaboration and capacity building through partner participation in three glaciology and hydrology short courses facilitated by University of Colorado staff. Our current specific research goal is to develop a melt model that can distinguish between seasonal snow and glacier ice melt at a large regional scale. We use a combination of MODIS-derived data sets to distinguish three surface types at daily resolution: 1) exposed glacier ice, 2) snow over ice and 3) snow over land. We currently run two melt models that use this surface classification scheme, a temperature index model and an energy balance model. We are comparing the melt volume time series with measured river discharge volumes and comparing the regional scale results with local sub-basin studies based on full energy balance modeling and isotopic and geochemical tracers to identify and quantify the sources of water (ice melt, snow melt, rainfall and ground water). We present preliminary results for the Upper Indus Basin.

Joint Inter-Association Symposium

JC02p - JC2/C13 Cold Regions Cryosphere and Hydrosphere (IACS, IAHS/ICSIH, IAMAS, IPA)

JC02p-497

The cryosphere, its future and ongoing trends

C. de Riedmatten[1], *M. Lehning*[2]
[1]*WSL Institute for Snow and Avalanche Research SLF, Snow and Permafrost, Davos Dorf, Switzerland*
[2]*EPFL, ENAC, Lausanne, Switzerland*

Bla Bla Bla,

It's a great pleasure **to** write something you don't need to think about ;-)

And I will not count my mood as character.

See you soon in Prague

Charles

Mais je dois donc pouvoir fair ça en utilisant des charactères français dans le texte. Ai-je raison? Essayons: é à è ë ê etc.

Joint Inter-Association Symposium

JG01a - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-1901

CryoSat-2 calibration/validation in Antarctica: Quantifying uncertainties utilising different satellite, airborne and ground-based techniques

C. Knöfel[1]*, L. Schröder*[1]*, U. Strößenreuther*[1]*, M. Scheinert*[1]*, V. Helm*[2]*,*
M. Horwath[1]*, R. Dietrich*[1]
[1]*Technische Universität Dresden, Institut für Planetare Geodäsie, Dresden, Germany*
[2]*Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Glaciology, Bremerhaven, Germany*

ESA's CryoSat-2 mission has been designed in order to monitor changes of the ice sheets in Greenland and Antarctica, and of the sea-ice coverage in polar seas.
The objective of the CryoSat Validation Experiments (CryoVEx) is to collect and analyse airborne and ground-based measurements providing independent data sets in order to facilitate the validation of the CryoSat-2 products.

Since 2000, our group has realised several CryoVEx campaigns in the blue-ice area close to Schirmacher Oasis, Dronning Maud Land, Antarctica. Since altimetric returns at blue ice are dominated by surface reflection, such areas are particularly suited for cal/val activities. Already since 1991 ground-based observations along traverses utilising kinematic GNSS measurements have been carried out in order to determine long-term surface-height changes and surface velocities. The CryoVEx campaigns of the past few years provide an excellent continuation of the long-term observations.

Up to 2008 the repeated measurements yielded a surface-height decrease of up to -20cm/a in this area. In contrast to this, the observed rates of the surface-height change between 2009 and 2011 revealed a significant positive trend. In order to classify the anomalous trend change and to continue the long-term observation a further CryoVEx campaign was carried out during the last Antarctic season.

We will present the results of the latest CryoVEx campaign accomplished in February 2015, compare the recent outcome to former measurements and show possible inferences. The ground-based results will be linked to coordinated airborne measurements including radar (ASIRAS) and laser altimeter data. Finally, comparative investigations of ground-based determined surface heights, airborne data and CryoSat-2-products will be presented.

Joint Inter-Association Symposium

JG01a - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-2259

Observing ice-volume change in Greenland and Antarctica using CryoSat-2 altimetry

V. Helm[1], *A. Humbert*[1]
[1]*Alfred Wegener Institute, Glaciology, Bremerhaven, Germany*

Estimating the contribution of ice sheets to sea level change is a major goal of glaciologists. For this purpose we analyse altimeter data of different satellite-borne satellites and estimate by this the volume change, the first major step towards mass change estimates. For the assessment of the contribution of ice sheets to sea level change robust, consistent processing, as well as the estimation of uncertainties is important. There are numerous sources for uncertainty, ranging from instrumental errors towards the interpolation between sparsely distributed data. Here, we aim to present a time series of the volumetric change using different sensors and different interpolation techniques.
This presentation focuses on the present-day ice-volume changes of the Greenland and Antarctic ice sheets. Based on four years (January 2011 to January 2015) of CryoSat-2 data acquisition we derived elevation change maps and volume change estimates for both ice sheets. We will present a set of estimates derived from different interpolation methods. Additional we will compare our results to elevation change rates obtained from ICESat data covering the time period from 2003 to 2009. In contrast to our study of last year we extented the time series of CryoSat-2 by one year and used the new data release 34 of ICESat. The new results will be presented and compared.

Joint Inter-Association Symposium

JG01a - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-2771

Trends and interannual changes of the Antarctic ice sheet from radar altimetry and satellite gravimetry

A. Memin[1], *F. Rémy*[2], *T. Flament*[2], *M. Llubes*[3], *C. Watson*[4]
[1]*Univ. Nice Sophia Antipolis, Géoazur UMR 7329, Valbonne, France*
[2]*CNRS/OMP, LEGOS/UMR 5566, Toulouse, France*
[3]*Université Paul Sabatier/OMP, GET/UMR 5533, Toulouse, France*
[4]*University of Tasmania, School of Land and Food, Hobart, Australia*

Quantifying the Antarctic Ice Sheet (AIS) mass balance still remains challenging as several processes compete to differing degrees at the basin scale with regional variations, leading to multiple mass redistribution patterns. For instance, analysis of linear trends in surface-height variations from 1992–2003 and 2002–2006 shows that the AIS is subject to decimetric scale variability over periods of a few years.

We combine the surface-elevation and surface-mass change derived from Envisat data and GRACE solutions, respectively, to estimate regional changes in air and ice content of the surface of the AIS between January 2003 and October 2010. This leads, upon certain assumptions, to the separation of the rates of recent snow-accumulation change and that of ice-mass change. Our results confirm that the height of ice in Thwaites and Pine Island glaciers sectors decreases while that in the Kamb glacier sector increases. The central part of the East AIS is mostly stable while the whole Dronning Maud Land coast is dominated by exceptional accumulation in the last 2 years of the observation period. The Kemp land regions show an ice-mass gain that accounts for 67–74% of the observed rates of elevation change in these regions. A good agreement is obtained over 68% of the investigated area between our estimated rates of snow accumulation change and the predicted rates of the monthly surface mass balance derived from a regional atmospheric climate model.

The map for the rates of snow-height change we have obtained shows a regional pattern along the coast that may be related to the interannual variability. We characterize this variability showing anomalies in surface-mass and elevation changes that propagate eastward around the AIS.

Joint Inter-Association Symposium

JG01a - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-3629

Inter-annual ice mass variations over Antarctica combining grace gravimetry and envisat altimetry

X. Su[1], C.K. Shum[2], J. Duan[1], J. Guo[1], I. Howat[2], K. Jezek[3], Y. Yi[1]
[1]The Ohio State University, School of Earth Sciences, Columbus, USA
[2]The Ohio State University, School of Earth Sciences- Byrd Polar Research Center, Columbus, USA
[3]The Ohio State University, Byrd Polar Research Center, Columbus, USA

Inter-annual mass variations of the Antarctic ice sheet (AIS) driven by the variability in accumulation have an important impact on the mass balance of AIS, and evaluating the fidelity of global or regional atmospheric models. The GRACE twin-satellites provide observations of ice sheet mass change at spatial scales longer than 350 km since 2002. Continuous near-polar observing satellite radar altimeter data became available since the 1990s, and have more than an order of magnitude (~50 km) better in spatial resolutions than GRACE. However, radar altimetry measures elevation or volume changes and has no knowledge of the firn nor ice column density to accurately estimate ice-sheet mass balance. Here we investigate the inter-annual variations using GRACE and Envisat data from 2003 through 2009 over the AIS. We find high correlation on the order of 0.6 mostly over West and part of East Antarctica. Focusing on the Amundsen Sea sector where regional mass loss remains concentrated, we estimate the nominal density by combining GRACE and Envisat data—GRACE data provide mass change, while Envisat data provide volume change—with the objective of estimating higher resolution mass change using altimeter data at the inter-annual scale. The estimated density is close to snow density during the period from 2003 to 2006, and is much closer to ice density from 2006 to 2009, which is related to the temporal variation of accumulation in the region. Negative correlations are found over some regions of East Antarctica. The definitive explanation of these negative correlations at present remains elusive. Based on the density-corrected Envisat data, high-resolution inter-annual ice mass variations are estimated over the Amundsen Sea sector and the rest of Antarctica with positive correlation.

Joint Inter-Association Symposium

JG01a - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-3944

ICESat-2: The next generation laser altimeter mission for polar research

T. Neumann[1], T. Markus[1], A. Martino[1], . ICESat-2 Science Definition Team[1]
[1]NASA Goddard Space Flight Center, Cryospheric Sciences Laboratory, Greenbelt, USA

NASA's Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) mission objectives are to quantify polar ice sheet contributions to sea level change, quantify regional signatures of ice sheet changes to assess driving mechanisms, estimate sea ice thickness, and to enable measurements of global canopy height as a basis for estimating large-scale biomass. Its predecessor ICESat, which operated from 2003 to 2009, pioneered the use of laser altimeters in space to study the elevation of the Earth's surface and its changes. Among other contributions to the cryospheric sciences, ICESat proved adept at making centimeter-level elevation measurements over both ice sheets and sea ice. Since ICESat stopped collecting data in October 2009, the IceBridge and CryoSat-2 missions continue these important observations. The well-documented and ongoing dramatic and rapid changes in the Earth's ice cover have strengthened the need for sustained observations beyond what CryoSat-2 and IceBridge are expected to provide. Lessons learned from ICESat demonstrated the need for cross-track slope information over the ice sheets (realized through ICESat-2's multiple beams), a smaller footprint size, and gapless along-track data collection. These needs resulted in a different measurement concept for ICESat-2.

The presentation will provide a brief summary of the measurement concept, the status of hardware development plans for operations beginning in 2017, and progress on geophysical algorithm development.

Joint Inter-Association Symposium

JG01a - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-5573

Mass balance of Greenland from combined estimation with GRACE, satellite altimetry and airborne lidar

R. Forsberg[1]*, L. Sandberg Sørensen*[1]*, J. Nilsson*[1]*, S. Sebastian*[1]
[1]*DTU Space, Geodynamics, Lyngby, Denmark*

With 12 years of GRACE satellite data now available, the ice mass loss trend of Greenland are clearly demonstrating ice mass loss in marginal zones of the ice sheets, and increasing mass loss trends in some regions such as the north-western marginal zones, as well as large yearly anomalies, especially in 2012 (record loss) and 2013 (near-zero mass loss). The latter highlights the need to augment the GRACE results with other data from satellite and airborne altimetry to pinpoint the detailed timewise and spatial nature of the mass loss. In the presentation we use satellite altimetry from EnviSat, IceSat and CryoSat, as well as airborne IceBridge and CryoVex data, to point out the detailed location of areas of change. We also use a novel direct inversion method, where relevant remote sensing data are utilized in combination with firn compaction models in a single general inverse estimation scheme, yielding composite mass change results minimizing leakage from neighbouring ice caps. We demonstrate overall mass change results from Greenland and Eastern Canadian Ice Caps 2003-14, highlighting the increasing melt in the marginal zones both in NW and NE Greenland. Most of the used data used are provided by the ESA Ice Sheets CCI project, which makes available long term Essential Climate Variables such as Surface Elevation Changes, Ice Velocity and Calving Front Locations for the Greenland ice sheet.

Joint Inter-Association Symposium

JG01b - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-1942

Glacial-isostatic adjustment in Antarctica: an new regional estimate derived from space-geodetic data (ESA-STSE Project REGINA).

I. Sasgen[1], M. Horwath[2], V. Klemann[1], E.J. Petrie[3], B. Wouters[4], A. Horvath[5], A. Martin[4], R. Pail[5], J.L. Bamber[4], P.J. Clarke[6], H. Konrad[1], M. Drinkwater[7]
[1]GFZ German Research Centre for Geosciences, Department of Remote Sensing, Potsdam, Germany
[2]TU Dresden, Faculty of Environmental Sciences, Dresden, Germany
[3]University of Glagow, School of Geographical and Earth Sciences-, Glagow, United Kingdom
[4]Bristol University, School of Geographical Sciences, Bristol, United Kingdom
[5]TU München, Institute of Astronomical und Physical Geodesy, Munich, Germany
[6]Newcastle University, School of Civil Engineering and Geosciences, Newcastle, United Kingdom
[7]ESA, ESTEC, Noordwijk, Netherlands

A major uncertainty in determining the mass balance of the Antarctic ice sheet from satellite gravimetry, and to a lesser extent altimetry, measurements is the poorly known correction for the ongoing deformation of the solid Earth caused by glacial isostatic adjustment (GIA). Although much progress has been made in consistently modelling ice sheet evolution and related bedrock deformation, predictions of GIA remain ambiguous due to the lack of observational constraints. Here, we present an improved regional GIA estimate based on GRACE, Envisat/ICESat and GPS measurements. Making use of the different sensitivities of the satellite observations to surface-mass and solid Earth processes, we estimate GIA using an ensemble of viscoelastic response functions to a disc load forcing. The estimated GIA signal is interpreted for recent ice load changes in West Antarctica in the presence of a low-viscosity upper mantle and a ductile layer in the elastic lithosphere. We compare the GIA estimate with published GIA predictions and evaluate its impact on the determination of ice-mass balance in Antarctica from GRACE and CryoSat-2. The results presented here were derived within the Support To Science Element Project REGINA and its Supplementary Study of the European Space Agency, www.regina-science.eu.

Joint Inter-Association Symposium

JG01b - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-3536

Using geodetic measurements to improve estimates of Antarctica's GIA and present-day mass balance

B. Gunter[1,2], O. Didova[2], R.E.M. Riva[2], V.R. Barletta[3], R. Meister[4], A. Shepherd[5], A. Muir[6], M.A. King[7], S.R.M. Ligtenberg[8], J.T.M. Lenaerts[8], M.R. van den Broeke[8], H. Hashemi Farahani[2], P. Ditmar[2]
[1]Georgia Institute of Technology, School of Aerospace Engineering, Atlanta, USA
[2]Delft University of Technology, Geoscience and Remote Sensing, Delft, Netherlands
[3]Ohio State University, School of Earth Sciences, Columbus, USA
[4]Technical University of Denmark, National Space Institute, Copenhagen, Denmark
[5]University of Leeds, School of Earth and Environment, Leeds, United Kingdom
[6]University College London, Earth Sciences, London, United Kingdom
[7]University of Tasmania, School of Land and Food, Hobart, Australia
[8]Utrecht University, Institute for Marine and Atmospheric research Utrecht IMAU, Utrecht, Netherlands

This presentation will provide an overview and discussion of a methodology in which satellite altimetry, satellite gravimetry, and climate data sets are used to generate empirical estimates of present-day Antarctic glacial isostatic adjustment (GIA), as well as corresponding ice mass change estimates. One of the benefits of this approach is its ability to provide more reliable uncertainties of these estimates based on the error characteristics of the input observations. The resulting empirical GIA uplift rates show both similarities and differences from traditional GIA models based on ice history reconstruction. This presentation will explore some of these differences, in particular for regions such as the Amundsen Sea Sector in West Antarctica and the Phillipi/Denman sectors of East Antarctica. Comparisons will also be made between empirical estimates made with a range of satellite gravimetry (GRACE) and satellite altimetry (ICESat, Envisat) data sets. The combinations suggest that the approach has the potential to reduce the uncertainty surrounding both Antarctic GIA and ice mass change estimates and provide new insights into the impact that recent ice load changes may have on present-day uplift rates.

Joint Inter-Association Symposium

JG01b - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-3984

Re-assessing present day global mass transport and glacial isostatic adjustment from altimetry, gravity, ocean bottom pressure and GPS observations

Y. Jiang[1], *X. Wu*[2], *S. Simonsen*[3], *M. Van Den Broeke*[4], *S. Ligtenberg*[4], *P. Munneke*[4], *W. van der Wal*[5], *B. Vermeersen*[5]
[1]*Natural Resources Canada, Geological Survey of Canada, Sidney, Canada*
[2]*Jet Propulsion Lab- Caltech, Division of Geodesy and Geodynamics, Pasadena, USA*
[3]*National Space Institute- Technical University of Denmark, Department of Geodynamics, Lyngby, Denmark*
[4]*Utrecht University, Institute for Marine and Atmospheric Research, Utrecht, Netherlands*
[5]*Delft University of Technology, Faculty of Aerospace Engineering, Delft, Netherlands*

The earth may have entered an intensive ice-melting episode, possibly due to anthropogenic global warming rather than natural orbit variations. Current technologies enable us to observe mass transport in the earth system. However, determining present-day mass transport is complicated by the fact that most observations contain signals from both present day ice melting and residuals from past glacier mass changes. Despite decades of progress in geodynamic modeling and new observations, significant uncertainties remain in both.

The key to separate present-day ice mass change and signals from past melting is to include data of different physical characteristics. We conduct a new global kinematic inversion to estimate both present-day ice melting and past glacier signatures simultaneously and assess their contribution to global mean sea level change. Our approach is designed to invert past and present-day melting signals in the spherical harmonic domain using globally distributed data with distinct physical information. By including satellite altimetry data in the center of Greenland and Antarctica ice sheets, we reduce the uncertainty in the Glacial Isostatic Adjustment (GIA) by a factor of 3. Improved precision of GIA determination will benefit the global mass transport results. We will present our results in both Greenland and Antarctica ice sheets as well as other regions where significant mass changes occur.

Joint Inter-Association Symposium

JG01b - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-4477

13 Year Space Gravimetry Record of Graham Land and Palmer Land Mass Imbalance and Inferences for GIA Models and Corrections

E. Ivins[1], D. Wiese[1], M. Watkins[1], F. Landerer[1], D.N. Yuan[1], A. Simms[2], C. Böning[1], A. Gardner[1], E. Domack[3]
[1]Jet Propulsion Lab, California Institute of Technology, Pasadena, USA
[2]Dept. Earth Science, University of California- Santa Barbara, Santa Barbara, USA
[3]College of Marine Science, University of South Florida, St Petersburg, USA

Mascon solutions developed at JPL now provide a high-resolution look at the evolution of mass in the Antarctic Peninsula from 2003-2014. We employ a time-series from these solutions and discuss the evolution of mass changes over the past 12-150 years, the GNSS uplift rates and the GIA correction that can be retrieved from modeling. The solutions for Graham Land for 2002-2014 yield a trend of -29.8 ± 5.8 Gt/yr using a GIA correction of 6.9 ± 1.0 Gt/yr. The result compares favorably to the recent study of Scambos et al. (2014) that determined an imbalance trend at -24.9 ± 7.8 Gt/yr using satellite laser altimetry and satellite stereo-image topography for 2001 – 2010. In contrast, Palmer Land has gone from near balance during 2002-2007, to a substantial mass loss after. When averaged over 2002-2014, the rate of loss is –14.2 ± 4.5 Gt/yr. We infer that much of this mass loss in the northern Peninsula began at least 50 years ago, and we attempt to quantify this ice mass history as it drives a substantial viscoelastic flow in the mantle.

Joint Inter-Association Symposium

JG01b - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-4810

The Antarctic Peninsula Mass Balance from the altimetry approach, the gravimetry approach and the input-output approach (ESA STSE Project APMB)

K. Briggs[1], M. Horwath[2], T. Nagler[3], A. Shepherd[1], A. Hogg[1], N. Barrand[4], A. Muir[5], L. Gilbert[5], A. Horvath[6], V.R. Barletta[7], R. Forsberg[7], J. Wuite[3], M.R. van den Broeke[8], S. Ligtenberg[8], M. van Wessem[8]
[1]University of Leeds, School of Earth and Environment, Leeds, United Kingdom
[2]Technische Universität Dresden, Institut für Planetare Geodäsie, Dresden, Germany
[3]ENVEO IT GmbH, ., Innsbruck, Austria
[4]University of Birmingham, School of Geography- Earth and Environmental Sciences, Birmingham, United Kingdom
[5]University College London, Mullard Space Science Laboratory, London, United Kingdom
[6]Technische Universität München, Institut für Astronomische und Physikalische Geodäsie, München, Germany
[7]National Space Institute DTU-Space, Geodynamics, Lyngby, Denmark
[8]Utrecht University, Institute for Marine and Atmospheric Research Utrecht IMAU, Utrecht, Netherlands

The ice mass of the Antarctic Peninsula (AP) responds dramatically to changes in the oceanic and atmospheric boundary conditions. However, assessments of ice sheet mass change face exceptional difficulties in this part of Antarctica, due to its small-scale partitioning into more than 1000 glacier basins, the rugged terrain, and large glacial isostatic adjustment (GIA) uncertainties. Building on the experiences of the Ice-sheet Mass Balance Inter-comparison Exercise, the ESA Support to Science Element project 'Antarctic Peninsula Mass Balance' has aimed to improve the certainty of AP mass balance estimates.

For the gravimetric approach, we exploit the spatial resolution limits of the GRACE mission to resolve up to five subregions, with thorough account for the related errors and with a dedicated GIA correction. For the geometric approach, observations from the satellite altimeters on ERS-2, ENVISAT, ICESat, and

CryoSat-2 as well as from the Airborne Topographic Mapper were combined providing, in some regions, a 19 year time series. For the input output method, new mass change evidence is derived using flow velocity fields from ALOS PALSAR and Terra-SAR-X/TanDEM-X, a thorough evaluation of ice thickness data, and new, high resolution surface mass balance from the RACMO2.3 model.

We present results from the three methods, an inter-comparison and their synthesis. Tailoring the methods to the specific conditions of the AP has led to substantial improvements in the spatial and temporal sampling. We show excellent agreement between the methods over regions and time intervals where their domains overlap. By combining the results we are able to present a reconciled estimate of mass balance, allowing detailed examination of the spatial and temporal patterns of mass change.

Joint Inter-Association Symposium

JG01b - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-5137

Cryosphere changes as constrained by the LARISSA high-density cGPS network across the northern Antarctic Peninsula

E. Domack[1], *M. King*[2], *T. Scambos*[3], *A. Leventer*[4]
[1]*University of South Florida, College of Marine Science, St Petersburg, USA*
[2]*University of Tasmania, Geography and Engineering, Hobart, Australia*
[3]*University of Colorado, National Snow and Ice Data Center, Boulder, USA*
[4]*Colgate University, Department of Geology, Hamilton, USA*

In 2009 a series of continuous GPS stations were installed across the northern Antarctic Peninsula in order to help constrain GIA in response to past and current changes in the cryosphere. At present eight stations are recording data and this network is integrated with two other longer term stations, previously established during an earlier SCAR campaign. Our analysis of the resulting data now provides a framework for understanding three characteristics of past ice loading events which include: (1) current viscoelastic response to the deglacial events related to the 2002 disintegration of the Larsen Ice Shelf. (Nield et al., 2013), (2) interannual changes in ice mass adjustments to seasonal accumulation and melting and/or calving, and (3) longer term adjustments of the crust in relation to past deglacial episodes.

Analysis of (1) has allowed for a refined estimate of the mantle viscosity , the value of which must have allowed rapid viscoelastic relaxation of the crust in response to ice mass unloading events following the collapse of the Larsen B ice shelf in 2002.

We remove this portion of the rebound and examine inter annual changes in individual glacial systems--as each cGPS station has local significance to accumulation and ice loss within fjord drainages. We compare these local records across the region in order to highlight those processes tied to ocean ice interaction and atmosphere.

Finally, we use the improved knowledge of mantle properties and a new glacial reconstruction for the NAP to evaluate relaxation curves following shelf wide deglaciation. We do this in order to help interpret sediment records from across the region in terms of changing paleoenvironmental factors that would be in large part controlled by changing base levels.

Joint Inter-Association Symposium

JG01c - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-0602

Decorrelation and filtering of GRACE time variable gravity field solutions using full covariance information

A. Horvath[1], *M. Murböck*[1], *R. Pail*[1], *M. Horwath*[2]
[1]*Technische Universität München, IAPG, München, Germany*
[2]*Technische Universität Dresden, IPG, Dresden, Germany*

Aiming for an as accurate as possible estimation of mass trends in Antarctica based on global GRACE gravity field solutions, calls for a number of tasks. Decorrelation filters employing static covariance information have already been developed in the past (e.g. DDK filter series by Kusche), but covariance information for a decade long recent time series was not publicly available since the publication of the ITSG temporal gravity field model in October 2014.

With this work we aim to use this time series with its evolving correlation structures due to changing mission configuration (e.g. orbital height) and instrument characteristics over time.

Proper reduction of correlated errors is a crucial step towards trend estimation. For this purpose we pursued two options:

(A) We employ a Swenson & Wahr type filter setup, with its parameters tailored towards the expected signal and noise content for optimal trend estimates in Antarctica. We perform full covariance propagation throughout all processing steps to gain better understanding of the impact of such filtering on deriving mass trend signals.

(B) We compute an estimate based on a setup of an anisotropic decorrelation filter constructed with information taken from the covariance matrices time series and signal covariance information deducted from coinciding monthly AOHIS climate model data.

Final step in our approach for mass trend estimation is a competitive comparison between the results obtained from A and B. The comparison is carried out with respect to signal amplitudes, leakage, achievable spatial resolution, and formal errors of trend estimates derived by error propagation.

Joint Inter-Association Symposium

JG01c - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-3294

Interpreting horizontal GPS rates in Antarctica using a 3D Glacial Isostatic Adjustment Model

P. Whitehouse[1], *M. King*[2], *W. van der Wal*[3]
[1]*Durham University, Department of Geography, Durham, United Kingdom*
[2]*University of Tasmania, Geography and Environmental Studies, Hobart, Australia*
[3]*Delft University of Technology, Aerospace Engineering, Delft, Netherlands*

GPS-derived observations of present-day deformation across Antarctica reflect the combined response of the solid Earth to past and present ice mass changes. The first-order pattern of uplift and subsidence predominantly depends on the regional ice-loading history, but the details of this pattern – the magnitude, wavelength and time dependence of the deformation – ultimately depend on the rheology of the Earth.

Recent improvements in Antarctic GPS coverage have allowed substantial advances to be made in i) identifying the pattern of present-day deformation across the continent, and ii) inferring past ice load changes and the viscosity structure of the Earth via glacial isostatic adjustment (GIA) modelling. To date, the vast majority of data-model comparisons have been made using vertical GPS rates. Higher precision horizontal GPS rates have so far been under-utilized, partly due to the difficulty of disentangling the response to ice mass change from the underlying plate motion and the potential effects of tectonic deformation. However, an additional problem arises if there are strong lateral variations in Earth rheology, as is thought to be the case across the transition between East and West Antarctica, because the presence of such structure will not only alter the magnitude of the Earth response to surface load changes, but also the direction of the horizontal components.

In this study we present the first comparison between horizontal GPS rates and GIA model predictions in which the GIA model accounts for 3D variations in mantle viscosity, as derived from seismic velocity perturbations. Our findings suggest that lateral variations in Earth structure must be taken into consideration when interpreting the horizontal component of the response to ice mass change.

Joint Inter-Association Symposium

JG01c - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-3428

Cryospheric dynamics cause crustal deformations at the Southern Patagonian Icefield

H. Lange[1], G. Casassa[2], E. Ivins[3], L. Schröder[1], M. Fritsche[4], A. Richter[1], A. Groh[4], R. Dietrich[1], M. Scheinert[1]
[1]Technische Universität Dresden, Institut für Planetare Geodäsie, Dresden, Germany
[2]Universidad de Magallenes, Direccion de Programas Antarticos y Subantarticos, Punta Arenas, Chile
[3]Jet Propulsion Laboratory, California Institut of Technology, Pasadena, USA
[4]Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Department Geodesy and Remote Sensing, Potsdam, Germany

Repeated GPS observations at 31 sites near the Southern Patagonian Icefield (SPI) captured robust vertical crustal motion. We describe the fieldwork and the data analysis carried out utilizing the Bernese GNSS software. Reference frame issues and accuracy of the observations will be discussed. The resulting uplift rates show a coherent pattern, with maximum rates of up to 40 mm/yr in the north-central part of the SPI.

The observed uplift rates were used to constrain the modelling of the viscoelastic glacial isostatic adjustment in that region. For two reasonable ice-load histories the lithospheric thickness and the mantle viscosity have been determined. Considering the special geodynamic and rheological setting of the region featuring a slab window below the SPI, the changing ice loads provide a unique opportunity to use GPS results for an estimation of these parameters. The two load models represent either a rapid or a slow transition of ice-mass change from regional Little Ice Age maximum to present-day. Both the two end members of the optimum fit between model and observations reveal a lithospheric thickness of 36.5 km. However, these two climatologically distinct models yield quite different mantle viscosity optima: 1.6 ×10^18 Pa s and 8.0 ×10^18 Pa s, respectively. Prospects for future geodetic work and modeling that might incorporate more geophysical and geological data are also discussed.

Joint Inter-Association Symposium

JG01c - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-3534

Post-seismic deformation of East Antarctica following the 1998 great Antarctic Plate earthquake

M. King[1]
[1]*University of Tasmania, School of Land and Food, Hobart, Australia*

Accurate modelling of Antarctica's present-day vertical bedrock motion is required to obtain unbiased estimates of present-day ice mass change from GRACE. This motion is thought to be purely due to solid-earth response to past and present changes in ice-ocean loading, known as glacial isostatic adjustment (GIA). Here we investigate post-seismic deformation following the great 1998 Antarctic intra-plate earthquake and its effect on bedrock vertical motion across East Antarctica. We use continuous Global Positioning System (GPS) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) coordinate time series from the Dumont D'Urville station, hundreds of kilometres from the rupture location, to show co-seismic offsets are followed by sustained post-seismic changes in horizontal and vertical position. We find close agreement with modelled horizontal viscoelastic deformation using a wide range of Earth structures, with a preference for upper mantle viscosities around 1×10^{19} Pa s. This previously unconsidered deformation represents a bias on GPS velocities or other empirical estimates of GIA of up to 2 mm/yr with larger horizontal velocity bias. GIA models tuned to such data will have errors in their ice history, potentially over significant regions of East Antarctica. Applying this modelled solid-earth mass change to GRACE data within East Antarctica would further increase estimates of ice sheet growth.

Joint Inter-Association Symposium

JG01c - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-4607

Winter speed-up signals detected at surge-type glaciers of two distinct settings: implications for the glacier surge mechanisms

M. Furuya[1], *T. Yasuda*[1], *T. Abe*[1]
[1]*Hokkaido University, Department of Earth and Planetary Sciences, Sapporo, Japan*

Surge-type glacier exhibits severalfold to orders-of-magnitude speed-up during the short active phase. The faster speed cannot be explained by the ice deformation and can only be achieved by basal sliding. Faster basal sliding is attributed to higher basal water pressure, which can reduce the effective overburden pressure and lubricate the interface between the ice and the bed. Two distinct theories have been proposed to explain the generation of high water pressure at Alaskan-type temperate and Svalbard type sub-polar settings, respectively. However, the detailed generation mechanisms remain uncertain at both types of surge because of limited observations. On one hand, Alaskan-type glacier surge is known to often initiate in winter, but the mechanisms remain unclear in light of the summer speed-up at normal glaciers; no surface meltwater is supplied in winter. On the other hand, Svalbard-type glacier surge is explained by thermal regulation. Because of little surface meltwater in sub-polar settings, basal meltwater is assumed to be supplied by pressure melting of the ice. Upon the initiation of basal sliding, frictional heat is presumed to further enhance the generation of meltwater. Here we report spatial-temporal velocity changes of surge-type glaciers at St Elias Mountains in Yukon and West Kunlun Shan in NW Tibet, applying the offset-tracking technique to synthetic aperture radar images. At the quiescent surge-type glaciers in Yukon, we detected significant winter speed-up. At the surging glaciers in West Kunlun, we detected seasonal modulations in the velocities, indicating faster speed in winter. These new findings suggest that winter speed-up are never uncommon, and that surface meltwater and its rerouting processes may explain the diversity of glacier surges.

Joint Inter-Association Symposium

JG01c - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

IUGG-4978

Observation of a glacier surge of Bivachny Glacier, Pamir Mountains, by means of repeated high-resolution interferometric digital elevation models

A. Wendt[1], *D. Floricioiu*[2], *C. Mayer*[1]
[1]*Bavarian Academy of Sciences and Humanities,*
Commission for Geodesy and Glaciology, Munich, Germany
[2]*German Aerospace Center, Remote Sensing Technology Institute,*
Oberpfaffenhofen, Germany

Bivachny Glacier in the Pamir Mountains is an approximately 25 km long former tributary of Fedchenko Glacier, the largest glacier in the region. It lost its dynamic connection to the main trunk of Fedchenko glacier and its lowest part is close to stagnant. The glacier is known for its periodically unstable behavior with 3 glacier surges witnessed in the 20th century. These fast advances may be caused by the interplay between several confluent glaciers.

We use TanDEM-X data acquired between 2011 and 2014 to observe the temporal development of the most recent glacier surge. From the bi-static synthetic aperture radar data acquired by the two satellites, digital elevation models (DEMs) with a horizontal resolution of 12 m and a vertical accuracy in the order of 2 m were derived. By inter-comparing these DEMs and the comparison with the Shuttle Radar Topography Mission DEM from 2000 as reference, the evolution of the surge can be described in detail. By September 2014 the up to 100 m thick surge bulge had reached the confluence of Bivachny and Fedchenko Glacier, after having advanced a total distance of 15 km within 3 years. Velocity information based on feature tracking results from consecutive TanDEM-X amplitude images and Landsat scenes complement the analysis of the surge mass transport.

Joint Inter-Association Symposium

JG01p - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

JG01p-393

Bayesian inversion of glacial isostatic adjustment beyond linear viscoelasticity using Burgers rheology

L. Caron[1], *M. Greff-Lefftz*[1], *L. Fleitout*[2], *L. Métivier*[3], *H. Rouby*[2,3,4]
[1]*Institut de Physique du Globe de Paris, Géomagnétisme, Paris, France*
[2]*Ecole Normale Supérieure de Paris, Laboratoire de Géologie, Paris, France*
[3]*Institut national de l'information géographique et forestière, Laboratoire de recherche en géodésie, Paris, France*
[4]*Australian National University, Research School of Earth Sciences, Canberra, Australia*

In Glacial Isostatic Adjustment inverse modeling, the usual assumption for the mantle rheology is the Maxwell model, which exhibits constant viscosity over time. However, mineral physics experiments and post-seismic observations show evidence of a transient component in the deformation of the shallow mantle, with a short-term viscosity lower than the long-term one. In these studies, the resulting rheology is modeled by a Burgers material: such rheology is indeed expected as the mantle is a mixture of materials with different viscosities. We propose to apply this rheology for the whole viscoelastic mantle, and, using a Bayesian Monte-Carlo with Markov Chains inverse formalism for Glacial Isostatic Adjusment during the last glacial cycle, study its impact on estimations of viscosity values, elastic thickness of the lithosphere, and ice distribution. To perform this inversion, we use a global dataset of sea level records, the geological constraints of ice-sheet margins, and present-day GPS data as well as satellite gravimetry. Our ambition is to present not only the best fitting model, but also the range of possible solutions (within the explored space of parameters) with their respective probability of explaining the data. Our results indicate the Burgers model provides a fit to the dataset as good as the Maxwell model, but with a larger lower mantle viscosity and thicker ice over Fennoscandia and Canada, as well as thinner ice over Antarctica and Greenland.

Joint Inter-Association Symposium

JG01p - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

JG01p-394

An investigation of ice flow and retreat of the Baltic Ice Stream from a new rich submarine glacial landform record.

P. Holmlund[1], *C. Clason*[1], *S. Greenwood*[2], *M. Jakobsson*[3]
[1]*Stockholm University, Department of Physical Geography, Stockholm, Sweden*
[2]*Stockholm University, Department of Geological Sciences, Stockholm, Sweden*
[3]*Stockholm University, Department of Geological Scinces, Stockholm, Sweden*

The submarine environments of the Gulf of Bothnia and the Baltic Sea are considered to have been occupied by a glacial timeline which includes periods of ice streaming and margin retreat, the build-up and drainage of the Baltic Ice Lake, and in the north has hosted part of the ice divide of the Scandinavian Ice Sheet. Recent collection of high resolution multibeam swath bathymetry data in large sectors of the Gulf of Bothnia provides a window to the previously unseen record of glacial geomorphology, recording for the first time the flow and deglaciation of the southern-central sector of the ice sheet. Evidences of glaciotectonic activities can be seen both on land and in the bathymetric data. Landforms mapped from these data disclose a story of dynamic ice stream flow and meltwater driven deglaciation. These data offer an unprecedented insight to the advance and the deglaciation of the Scandinavian Ice Sheet through the Baltic and Bothnian basins, and the retreat and flow patterns of the Baltic Ice Stream.

Joint Inter-Association Symposium

JG01p - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

JG01p-395

Glacial Isostatic Adjustment and gravity gradients anomalies over North America

L. Metivier[1], *L. Caron*[2], *M. Greff-Lefftz*[2], *G. Pajot-Métivier*[1], *I. Panet*[1], *H. Rouby*[1,3], *L. Fleitout*[3]
[1]*Institut National de l'Information Géographique et Forestière IGN, LAREG, Paris, France*
[2]*Institut de Physique du Globe de Paris, Laboratoire de Géomagnétisme, Paris, France*
[3]*Ecole Normale Supérieure, Laboratoire de Géologie, Paris, France*

Observed geoid and gravity anomalies over North America are usually attributed to the lithosphere structure or to mantle convection. In the context of the GOCE satellite mission, we show here that gravity gradients observations at satellite altitude present long wavelength anomalies over the Laurentide region, which can only be explained by an incomplete rebound due to Glacial Isostatic Adjustment (GIA).

We investigate a large variety of lithosphere and mantle dynamic models, assuming various mantle viscosity profiles. We find that one may easily find a lithosphere or a mantle model that generates a negative geoid anomaly over North America at very long wavelengths. However, the gravity gradients, due their high sensitivity to small wavelength density anomalies, lead to completely different conclusions. In particular the long wavelength signal that we observe at satellite altitude over the Laurentian region is clearly not consistent with a lithospheric or a mantle signature.

Based on different models of ice history, we show that the geoid, the free air gravity and the gravity gradients anomalies over the Laurentide region can be completely explained by the GIA. Such a change would have a broad impact on GIA general investigations, ice history determinations, or crustal thermo-chemical investigations.

Joint Inter-Association Symposium

JG01p - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

JG01p-396

Detection of local irregular displacements on Greenland ice sheet by double differential interferometric synthetic aperture radar

K. Doi[1,2], *T. Yamanokuchi*[3], *K. Nakamura*[4], *K. Shiramizu*[2]
[1]*National Institute of Polar Research, Geoscience, Tachikawa, Japan*
[2]*Graduate University for Advanced Studies SOKENDAI, Polar Science, Tachikawa, Japan*
[3]*Remote Sensing Technology Center, Research and Development, Tokyo, Japan*
[4]*Nihon University, Computer Science, Koriyama, Japan*

Phases recorded in interferometric synthetic aperture radar (InSAR) image mainly consist of signals induced by surface topography and displacement. Displacement can be extracted by removing the topographic phase which can be simulated from a Digital Elevation Model (DEM). This procedure is called Differential InSAR (DInSAR).

Stable ice flow is a dominant component of surface displacements over ice sheet. Double DInSAR (DDInSAR) means a procedure to take difference between two DInSAR images. Irregular surface displacement such as ice sheet flow rate change can be detected by applying DDInSAR technique, because phase change due to steady surface displacement is canceled out by taking the difference.

Under the situation of ongoing rapid ice sheet melting in Greenland, it is likely that the ice sheet flow velocity is changing there. We applied the DDInSAR technique to ALOS/PALSAR data over northwestern region of Greenland ice sheet to detect irregular displacement. The scene (path-frame: 76-1590) was observed three times in series at August 30, October 15, and November 30 in 2007. One DDInSAR image was derived from two DInSAR images generated from the three pass data. Two displacement maps along radar illumination direction have been obtained from the two DInSAR images and a map of displacement difference has been obtained from the DDInSAR image.

In the displacement difference map, we found several spots of circular or elliptical shape where displacement differences of 10 to 15 cm were observed. Because the positions of the spots are almost coincident with locations of ponds on the ice sheet near coastal region, these differences seem to be induced by surface displacement of the ponds. Further investigations are required to explain the displacement differences.

Joint Inter-Association Symposium

JG01p - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

JG01p-397

Stable ice-surface height above subglacial Lake Vostok, central East Antarctica:Geodetic observations and implications

A. Richter[1], L. Schröder[1], M. Horwath[1], M. Scheinert[1], R. Dietrich[1], L. Eberlein[1], M. Fritsche[2], J. Schwabe[3], S. Popov[4], V. Lukin[5], A. Matveev[6], Y. Brovkov[6], D. Fedorov[6], A. Ekaykin[7], V. Lipenkov[7]
[1]Technische Universität Dresden, Institut für Planetare Geodäsie, Dresden, Germany
[2]Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Department Geodesy and Remote Sensing, Potsdam, Germany
[3]Technische Universität Dresden,
now at Federal Agency of Cartography and Geodesy, Dresden, Germany
[4]Polar Marine Geosurvey Expedition, Antarctic Division, St. Petersburg, Russia
[5]Arctic and Antarctic Research Institute, Russian Antarctic Expedition, St. Petersburg, Russia
[6]OAO Aerogeodeziya, ., St. Petersburg, Russia
[7]Arctic and Antarctic Research Institute, Russian Antarctic Subprogram, St. Petersburg, Russia

We present results of different GNSS observation techniques in the Lake Vostok region spanning more than a decade. Repeated occupations of 56 surface markers 2001-2015 yield 3D firn particle velocities. Continous GNSS observations carried out at Vostok station since early 2008 provide 3D firn particle position time series. Repeated measurements of surface height profiles around Vostok station since 2001 using kinematic GNSS observations on snowmobiles allow the quantification of surface height changes in crossover points. These in-situ observations are complemented by regional, high-resolution geometric models and a repeat-track analysis of ICESat laser altimetry data. Surface height changes above subglacial Lake Vostok reflect the combined effect of the local ice-mass balance of the ice sheet, the lake-water volume balance and water circulation within the largest subglacial lake on earth. The integration and combination of different geodetic observation techniques allows to separate the contributions of individual processes within the lake or the ice sheet to surface and particle height changes. Our results lead to the conclusions that 1) the ice sheet in the Vostok region is close to mass balance, 2) Lake Vostok does not discharge water, 3) no water volume increase in the lake is observed over a decade, 4) Lake Vostok is therefore most likely not an 'active' subglacial lake, 5) spatiotemporal height changes reflecting water

movement in the lake do not exceed 1 cm, and 6) firn densification occurs linearly over a decade. Our results qualify the ice surface above Lake Vostok as calibration site for satellite altimetry. We present ICESat laser operation period biases derived from a crossover adjustment of release 633 of the GLAS 12 data product within the lake area.

Joint Inter-Association Symposium

JG01p - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

JG01p-398

How to reduce the uncertainty of observed Antarctic mass balance?

M. Horwath[1], *M. Scheinert*[1]
[1]*Technische Universität Dresden, Institut für Planetare Geodäsie, Dresden, Germany*

Current uncertainties of observed Antarctic mass trends are unsatisfactory. Particularly for East Antarctica it is even not certain which sign can be allocated to the mass changes. Each of the observational approaches (input-output method, geometric method and gravimetric method) is subject to systematic errors which are locally very small, but tend to be spatially coherent and, therefore, to sum up to substantial uncertainties over the huge area. We give an overview of these systematic errors, their interlinkages and the attempts to mitigate or even to overcome them. In particular, we address the uncertainties caused by glacial isostatic adjustment (GIA), deficiencies in the low-degree harmonics involved in the gravimetry approach, possible biases in the satellite altimetry results induced by sensor properties and signal-firn interaction peculiarities, and reference frame realisation issues with regard to GNSS observations, altimeter orbits and the consistency between GIA modeling and observation. We discuss the potential of geodetic and glaciological fieldwork on the East Antarctic plateau to provide additional constraints on the past and present evolution of the ice sheet and, thereby, to reduce its uncertainty.

Joint Inter-Association Symposium

JG01p - JG1 Dynamics of the Cryosphere from Geometric and Gravimetric Observations (IAG, IACS)

JG01p-399

Contribution of present-day ice reservoir ablations to sea-level rise

C.K. Shum[1], *K. Shang*[2], *X. Su*[2], *J. Wan*[2], *A. Braun*[3], *G. Cogley*[4], *X. Ding*[5], *J. Guo*[2], *I. Howat*[2], *C. Kuo*[6], *H. Lee*[7]
[1]*The Ohio State Uni., Columbus, USA*
[2]*The Ohio State Uni., School of Earth Sciences, Columbus, USA*
[3]*Queen's U., Dept. of Geological Sciences & Geological Engin, Ontario, Canada*
[4]*Trent Univ, Dept. of Geography, Ontario, Canada*
[5]*Hong Kong Polytechnic Univ., Dept. of Land Survey. & Geo-Informatics, Hongkong, China Peoples Republic*
[6]*National Cheng Kung Uni., Dept. of Geomatics, Taiwan, Taiwan Republic of China*
[7]*University of Houston, Dept. Civil & Environmental Engineering, Austin, USA*

Exact quantification of the geophysical sources of the 20th century and present-day sea-level rise requires improved understanding of competing geophysical processes within the Earth system. These geophysical sources include ice-sheet/glacier ablations, steric sea-level, land/seafloor uplift due to glacial isostatic adjustment, geocenter motions, tectonics, sediment loading or anthropogenic causes, hydrologic imbalance, and human processes including water retention in reservoirs and aquifer extraction. The 2013 Intergovernmental Panel for Climate Assessment (IPCC) Fifth Assessment Report (AR5) concluded that the observed and explained geophysical causes of global geocentric sea-level rise, 1993–2010, is much closer towards closure at 3.2 [2.8→3.6] mm yr^{-1} versus 2.8 [2.3→3.4] mm yr^{-1}. However, the discrepancy reveals that circa 1.3→37.5% of the observed sea-level rise remains unexplained, despite contemporary reports on reconciled mass balance estimates of ice-sheet and mountain/peripheral glaciers during the early 21st century. This discrepancy is primarily attributable to the relatively wide range of estimates of respective contributions of ice-sheets and mountain glaciers to sea-level rise, at 0.60 [0.41→0.79] mm yr^{-1} and at 0.76 [0.39→1.13] mm yr^{-1}, respectively. In particular, the Himalayan glacier system, remains a focus of public and scientific debate, as the uncertainty of its mass balance estimates and its future projection have a significant implication of water resource problems potentially affecting 5 billion people. In this contribution, we provide an updated estimate of the world's ice reservoir mass balance and its contribution to global sea-level rise, 2002–2014, primarily using space geodetic data including GRACE and satellite altimetry.

Joint Inter-Association Symposium

JG02a - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-1117

Observation of non-migrating tides in the ionosphere and thermosphere

H. Lühr[1], *C. Xiong*[2]
[1]*GFZ- German Research Centre for Geosciences, Potsdam, Germany*
[2]*GFZ- German Research Centre for Geosciences, Earth's Magnetic Field, Potsdam, Germany*

Recent missions of low-Earth orbit satellites have contributed a lot to our understanding of the tidal activities in the upper atmosphere on global scale. A rather prominent example is the DE3 tidal component at low latitudes that is driven by deep tropical convection in the troposphere. Effects of DE3 can be found in many ionospheric and thermospheric quantities. By using CHAMP and GRACE measurements we have investigated the tidal spectrum on global scale for several upper atmospheric quantities. In particular for the low latitude regions we find two coupling mechanisms for the upward propagation of the tidal signal to F-region altitudes. One is direct propagation, in particular for neutral quantities; and the other is electrodynamic coupling at the E-region and subsequently upward mapping of the E-field to the F-region. These two mechanisms show different diurnal variations and solar cycle dependences. Direct propagation is enhanced during solar minimum.

Distinct tidal features are also observed at middle and high latitudes. A prominent result of them is the Weddell Sea Anomaly in electron density and related counterparts in the northern hemisphere. For these effects the azimuthially symmetric tide D0 and the westward propagating DW2 are found to play a major role. These tidal components are probably generated in situ, and they seem to be caused by an interaction between the diurnal tide DW1 with a stationary planetary wave, SPW1. For a better understanding of the relation between the various tides in the different quantities it needs a proper modelling of the upper atmospheric dynamics.

Joint Inter-Association Symposium

JG02a - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-2158

Satellite observations of gravity waves in the middle atmosphere: seasonal variations and vertical coupling

M. Ern[1]*, P. Preusse*[1]*, S. Kalisch*[1]*, T. Trinh*[1]*, M. Riese*[1]
[1]*Forschungszentrum Juelich GmbH,*
Institut fuer Energie- und Klimaforschung IEK-7, Juelich, Germany

Gravity waves (GWs) play an important role in the driving of the atmospheric circulation. Most GW sources are located in the troposphere. From their sources GWs preferentially propagate upward and dissipate at higher altitudes. Thereby, they couple different atmospheric layers and regions.
Because GWs have small horizontal scales (about 10-1000km), realistic simulation of their effect on the background flow is a challenge for global models. For this reason, global observations of GWs from satellite over a large altitude range are important as a guidance and reference for GWs in models, either parameterized or resolved.
We have derived absolute GW momentum fluxes and potential GW drag in the stratosphere and mesosphere from observations of the satellite instruments HIRDLS and SABER.
Seasonal variations of the observed gravity wave distribution reflect the characteristic patterns of GW source regions, such as orography, wind jets, and regions of deep convection in the summertime subtropics. In addition, seasonal changes in the background winds have strong influence on the observed momentum fluxes.
Vertical gradients of GW momentum fluxes and differences in the global distributions at different altitudes are indicative of GW dissipation. Further, non-vertical propagation of GWs may play an important role in the mesosphere during winter after major stratospheric warmings, and during summer for the wind reversal on top of the summertime mesospheric jet.

Joint Inter-Association Symposium

JG02a - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-3056

Gravity waves and their seasonal variation from high resolution WACCM simulations

H. Liu[1]
[1]*National Center for Atmospheric Research, High Altitude Observatory, Boulder, USA*

Gravity waves play a key role in the vertical coupling of atmosphere regions, because they can impact large-scale flow, induce transport of atmosphere constituents, and cause increasingly large atmospheric perturbations at higher altitudes, including the thermosphere and ionosphere. At the same time they also pose a stiff challenge to the study of vertical coupling, mainly because of the very broad range of spatial and temporal scales of these waves, and the even broader range of scales of the wave impacts, and observations and numerical simulations usually can only cover a limited range of spatial and temporal scales. The gravity waves in the global context are generally poorly quantified, and they are one of the most important causes of bias and uncertainty in middle and upper atmosphere models. However, the recent development of model capability and computing power is expanding the horizon of gravity wave research, and affording the opportunity to explore increasingly broader scales over the whole atmosphere domain. Recently we have performed Whole Atmosphere Community Climate Model (WACCM) simulations at ~0.25 degree horizontal and 0.1 scale-height vertical resolution. In this talk, I will present results from this simulation. Gravity wave quantities will be compared with observational and numerical studies, including wave energy density and their spatial distribution, and wave forcing in the middle and upper atmosphere. The gravity wave momentum flux from the simulation, its longitude, latitude and height dependence, and it seasonal variation are compared with satellite and ground-based observations.

Joint Inter-Association Symposium

JG02a - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-5379

Gravity waves resolved by the high resolution European centre for medium-range weather forecasts analysis data

P. Preuße[1], Q.T. Trinh[1], M. Ern[1], P. Bechtold[2], M. Riese[1]
[1]Forschungszentrum Juelich, IEK-7, Juelich, Germany
[2]ECMWF, Research department - physical aspects section, Reading, United Kingdom

Analysis data of the ECMWF in 2008 gained a sufficient resolution to resolve a large part of the gravity wave (GW) spectrum. We analyze these data for GW momentum flux and compare the results with observations from the HIRDLS infrared limb scanner. High realism is found for winter mid and high latitudes. Main sources of a particular strong event in January 2008 are the south tip of Greenland, a storm approaching the Norwegian coast and orography of southern Norway. For low summer latitudes convection is the main source of GWs both in the ECMWF model and in HIRDLS observation. However, the detailed source mechanism is different, which is expressed by longer horizontal wavelengths and slower phase speeds of the ECMWF resolved waves than found in reality. The large advantage of the global model data is that sources can be identified by backward ray-tracing. This is not possible for current generation limb scanners such as HIRDLS, where sources have to be attributed by spatial collocation. The study demonstrates that this may be seriously missleading. It also demonstrates that this problem may be overcome by future limb imaging instruments.

Joint Inter-Association Symposium

JG02b - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-0922

A proposed approach for correcting the S4 scintillation index from multipath effects

E.M. Souza[1]*, G.O.N. Brassarote*[2]*, J.F.G. Monico*[3]*, D.B.M. Alves*[3]*, B.F. Oliveira*[4]
[1]*Maringa State University - UEM, Department of Statistics, Maringa, Brazil*
[2]*Sao Paulo State University - UNESP, Cartographic Science Graduate Program, Presidente Prudente, Brazil*
[3]*Sao Paulo State University - UNESP, Department of Cartography, Presidente Prudente, Brazil*
[4]*Sao Paulo State University - UNESP, Applyed Mathematics and Computational Graduate Program, Presidente Prudente, Brazil*

Both multipath effect, caused by GNSS signal reflections, and ionospheric scintillation, caused by fluctuations of the phase and amplitude of the signal when it passes through irregularities on ionospheric electron density, have been a challenge for some GNSS applications became fully operational. The S4 index has been largely used in the literature to investigate scintillation effects in amplitude. However, the influence of other effects in this index, such as multipath, deteriorates its quality. In this presentation a correction method will be presented. For such aim, the ionospheric scintillation S4 index was investigated under multiscale/multiresolution analysis from non-decimated wavelets to detect and separate sidereal/multipath from scintillation effects. S4 time series from different satellites and stations in different Brazilian regions were analyzed in periods of both low and high scintillation occurences. Through multiscale decomposition during periods of the year with low scintillation index it was possible to estimate the multipath effect. Once identified and estimated, this effect could be removed from the S4 index series in the strong scintillation period. Therefore, this work took a first step toward separating the effect of scintillation from other effects that may influence its analysis. Furthermore, probability distribution functions of uncorrected and corrected S4 indexes were also investigated. The methodological aspects as well as the results and analysis will be presented in the paper.

Joint Inter-Association Symposium

JG02b - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-2489

Two-dimensional Imaging of Sporadic E with a Dense GNSS Array

K. Heki[1], *J. Maeda*[1]
[1]*Hokkaido University, Dept. Natural History Sci., Sapporo, Japan*

Sporadic-E (Es) is a thin densely ionized plasma patch, and its occurrence is highly unpredictable. It often appears in the E-region of the ionosphere most frequently during the local summer in mid-latitude regions. The two-dimensional (2-D) horizontal structure of Es patches, however, has long remained ambiguous due to the lack of appropriate observation instruments. Radio occultation observations of low earth orbiters has revealed spatial distribution of Es patches in global scale, but its horizontal spatial resolution was not high enough to image individual patches. Here we report morphological characteristics of daytime mid-latitude Es patches studied by two-dimensional total electron content (TEC) maps drawn using the Japanese dense network of Global Navigation Satellite System (GNSS) receivers. By analyzing over 70 cases, we found that their horizontal shapes are characterized by frontal structure typically elongated in east-west by ~100 km with widths of ~30 km. They are observed to migrate mainly northward in the morning and southward in the afternoon with speeds of 30-100 m/s. This may reflect the velocities of neutral winds controlled by the atmospheric tides. Such frontal structures are often found to include smaller-scale quasi-periodic structures.

Joint Inter-Association Symposium

JG02b - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-3595

Neutral atmosphere and geodesy

J. Böhm[1]
[1]*TU Wien, Vienna, Austria*

Delay modeling of microwave signals in the neutral atmosphere is a major error source in the analysis of space geodetic techniques, such as the Global Navigation Satellite Systems (GNSS) or Very Long Baseline Interferometry (VLBI). Typically, we separate hydrostatic and wet zenith delays as well as mapping functions to map the zenith delays down to the elevations of the observations. More rigorously, approaches have been developed in recent years which are based on exact ray-tracing through data of numerical weather models. In this presentation, various strategies of tropospheric delay modeling are discussed and future paths are outlined. On the other hand, variations in the neutral atmosphere deform the solid Earth by loading, change the gravity field of the Earth, and excite Earth rotation variations. The quantification of all those effects by the use of numerical weather models is presented and the interactions between the parameters are discussed.

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JG02b - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-3849

Low-latency global modeling of the total electron content from space observations and localizing B-splines

M. Schmidt[1], D. Dettmering[1], M. Limberger[1], F. Seitz[1], K. Börger[2], S. Brandert[2], B. Görres[3], W. Kersten[3], V. Bothmer[4], J. Hinrichs[4], M. Venzmer[4]
[1]Technische Universität München, DGFI, Munich, Germany
[2]German Space Situational Awareness Centre, GSSAC, Uedem, Germany
[3]Bundeswehr Geoinformation Centre, BGIC, Euskirchen, Germany
[4]University of Goettingen, Institute of Astrophysics IAG, Göttingen, Germany

The latency of the availability of satellite measurements reaches a limit that allows nowadays to run operational services aiming the provision of ionospheric information such as the Total Electron Content (TEC) in near real-time. The project „Operational Tool for Ionospheric Mapping and Prediction“ (OPTIMAP) exploits this opportunity to combine different satellite observation techniques for deriving the global TEC distribution as part of an operational service for the German Space Situational Awareness Centre (GSSAC).

For this purpose, we combine hourly batch observations of GPS, GLONASS and radar altimetry to derive the TEC from dual-frequency signals and apply a sequential processing method based on a Kalman filter to continuously map the global TEC. The implementation of additional techniques is currently under progress. For the spatial parametrization, localizing B-spline functions in latitude and longitude have been selected to constrain the signal information to a finite interval. The B-spline level and the placement of B-spline knot points can be adapted to the measurement distribution and thus allow to control the handling of data gaps.

Furthermore, additional Sun observation processed by our project partner of the Institute of Astrophysics at the University of Göttingen (IAG) will be incorporated to feed the Kalman filter with additional information about incoming, extraordinary events that shall be considered in the update steps.

Joint Inter-Association Symposium

JG02c - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-0972

COST Action ES1206: Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC)

J. Jones[1], G. Guergova[2], J. Dousa[3], S. de Haan[4], E. Pottiaux[5], O. Bock[6], R. Pacione[7]
[1]Met Office, Observations R&D, Exeter, United Kingdom
[2]Sofia University, Department of Meteorology and Geophysics Physics Faculty, Sofia, Bulgaria
[3]Geodetic observatory Pecn, Department of Geodesy and Geodynamics, Pecny, Czech Republic
[4]Royal Netherlands Meteorological Institute KNMI, Research and Development Department, de Bilt, Netherlands
[5]Royal Observatory of Belgium, GNSS Research Group, Brussels, Belgium
[6]l'Institut National de l'information Géographique et Forestière, LAboratoire de Recherche en Géodésie LAREG, Paris, France
[7]e-Geos, Centro di Geodesia Spaziale, Matera, Italy

Global Navigation Satellite Systems (GNSS) have revolutionised positioning, navigation, and timing, becoming a common part of our everyday life. Aside from these well-known civilian and commercial applications, GNSS is now an established atmospheric observing system which can accurately sense water vapour, the most abundant greenhouse gas, accounting for 60-70% of atmospheric warming. Water vapour observations are currently under-sampled and obtaining and exploiting additional high-quality humidity observations is essential to severe weather forecasting and climate monitoring.

COST Action ES1206 addresses new and improved capabilities from developments in both the GNSS and meteorological communities to address these requirements. For the first time, the synergy of multi-GNSS (GPS, GLONASS and Galileo) will be used to develop new, advanced tropospheric products, exploiting the full potential of multi-GNSS water vapour estimates on a wide range of temporal and spatial scales, from real-time monitoring and forecasting of severe weather, to climate research. In addition the Action will promote the use of meteorological data in GNSS positioning, navigation, and timing services and stimulate knowledge and data transfer throughout Europe.

Joint Inter-Association Symposium

JG02c - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-1234

SHAtropw: the new tropospheric delay model over China continent

J. Chen[1], J. Wang[1], B. Wu[1], J. Wang[2]
[1]Shanghai Astronomical Observatory-Chinese Academy of Sciences, Center for Astro-geodynamic Research, Shanghai, China Peoples Republic
[2]Tongji University, College of Surveying and Geo-informatics Engineering, Shanghai, China Peoples Republic

The GNSS network of the Crustal Movement Observation Network of China (CMONOC) is composed of 260 reference stations and more than 2000 campaign stations. The GNSS data analysis center of Shanghai astronomical observatory (SHA) analyzes the CMONOC data routinely on daily basis. Among various products based on the CMONOC data, zenith troposhperic delay (ZTD) products provide valuable information for the development of more precise regional tropospheric model.

In this paper, we develop a regional ZTD model (SHAtropw) over China mainland. SHAtropw is developed based on 4 years' (spanning from 2011 to 2014) ZTD time series generated by SHA. The hydrostatic part of SHAtropw is the same as the GPT (Global Pressure and Temperature) model, and the wet part (ZWD) is modeled by a function of station height and the ZWD at geoidal surface (ZWD-Geiod). Grid-function is used in the modeling of ZWD-Geiod, where ZWD-Geiod at each grid is modeled by the sum of a constant, semi-annual and annual terms.

Based on the ZTD time series of 223 stations, SHAtropw compiles a complete ZWD-Geiod grid file containing all model coefficients at each grid divided by 2°×2.5° in latitude and longitude direction. Huge amount of validations were carried out, results show that the accuracy of the SHAtropw model has improvement of 38%, 33% and 26% over China mainland compared to the EGNOS, UNB3m and GPT2 models.

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JG02c - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-1340

Water vapor tomographic modeling and performance evaluation using multi-sensor data in Hong Kong

Z. Liu[1], *B. Chen*[1], *W.C. Woo*[2], *P.W. Chan*[3], *W.K. Wong*[2]
[1]*The Hong Kong Polytechnic University PolyU, Department of Land Surveying & Geo-Informatics LSGI, Hong Kong, China Peoples Republic*
[2]*Hong Kong Observatory, Forecasting Development Division, Hong Kong, China Peoples Republic*
[3]*Hong Kong Observatory, Aviation Weather Services Branch, Hong Kong, China Peoples Republic*

Acquisition of accurate information on the spatio-temporal distribution of the atmospheric water vapor has long been a crucially important task in the geodesy and meteorology community. However, water vapor is one of the most poorly measured meteorological parameters in terms of both spatial and temporal resolutions. Global Positioning System (GPS) water vapor tomography is a very promising atmospheric remote sensing technique that is able to characterize spatial structure and temporal variation of the atmospheric water vapor.

In this study, a GPS water vapor tomography method with multi-sensor water vapor data has been developed. The water vapor data are retrieved from multiple sources including GPS, radiosonde, MWR (Microwave Radiometer), NWP (Numerical Weather Prediction), and meteorological instruments. Based on 5 month's water vapor data collected during May-September 2013 in Hong Kong, a large number of tomography experiments have been carried out. The tomographic water vapor density (WVD) data are compared with water vapor data measured by MWR located at King's Park, Hong Kong and Hong Kong International Airport (HKIA).

Comparison results show that the correlation coefficients of WVD between tomography and MWR are 0.969 and 0.967 for King's Park and HKIA, respectively. At the King's Park station, the bias and RMS (root mean squares) error of the WVD differences between tomography and MWR are -0.440 g/m^3 and 1.752 g/m^3, respectively. At the HKIA station, the bias and RMS error of the WVD differences are 0.245 g/m^3 and 1.742 g/m^3, respectively. The good agreement demonstrates that tomographic technique can provide accurate and high spatio-

temporal resolution water vapor data for many applications such as GPS precise positioning and weather forecasting.

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JG02c - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

IUGG-2435

Using atmospheric turbulence models for the stochastic model of geodetic VLBI data analysis

S. Halsig[1], *T. Artz*[1], *A. Iddink*[1], *A. Nothnagel*[1]
[1]*Institute of Geodesy and Geoinformation, University of Bonn, Bonn, Germany*

Space-geodetic techniques, such as Very Long Baseline Interferometry (VLBI) and Global Navigation Satellite Systems (GNSS), play a crucial part in the understanding of the Earth's atmosphere. At the same time, dynamic processes, particularly refractivity variations in the neutral atmosphere, contribute considerably to the error budget of these space-geodetic techniques. Micro-scale fluctuations in refractivity lead to elevation-dependent uncertainties and induce physical correlations between the observations. However, up to now such correlations are not considered routinely in the stochastic model of geodetic VLBI analysis which lead to very optimistic formal errors of the derived target parameters.

In this study, the standard stochastic model, which only includes, almost exclusively, the uncertainties from the VLBI correlation process, is now augmented by a variance-covariance matrix derived from an atmospheric turbulence model. For this purpose, the turbulence model for GNSS applications by F. K. Brunner and S. Schön, which is based on the widely accepted Kolmogorov turbulence theory, was adapted and modified for VLBI observations. Thus, atmospheric refractivity fluctuations in space and time can be quantified.

In order to validate the new approach, the turbulence model is applied to several VLBI observation campaigns consisting of different network geometries. This should lead to first approaches for future VLBI campaigns.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-374

Inversion of ionogram data for reconstruction of model based ionospheric electron density

G. GOK[1], O. ARIKAN[1], F. ARIKAN[2], Z. MOSNA[3], P. KOUCKA KNIZOVA[3], D. KOUBA[3], L. REJFEK[3]
[1]BILKENT UNIVERSITY, ELECTRICAL AND ELECTRONICS ENGINEERING, ANKARA, Turkey
[2]HACETTEPE UNIVERSITY, ELECTRICAL AND ELECTRONICS ENGINEERING, ANKARA, Turkey
[3]Institute of Atmospheric Physics, Academy of Sciences, PRAGUE, Czech Republic

Ionosphere plays a key role in HF and satellite based communication and space based positioning systems. The crucial parameter of the ionosphere is electron density. Due to the sparsity of in-situ 'measurements' of electron density, ionosondes are used to gather information on the layer structure and parameters of ionosphere. Since the velocity of the electromagnetic wave is also variable due to inhomogeneous, anisotropic and dispersive nature of the refractive index, the reconstruction of electron density from ionosonde signalsi s a challenging inversion problem. Round trip delays of the received echoes provide information about the virtual vertical profile of the ionization distribution which is called an ionogram. The process of assigment of the reflections to the ionospheric layers is known as the 'ionogram scaling'. To compute electron density profile from the ionogram, various inversion techniques have been developed. The most commonly used ionogram inversion techniques include POLAN and NHPC. In this study, we propose a new model based on a ionogram scaling technique where the electron density construction problem is cast as a non-convex optimization problem in Chapman model parameters that are are determined by PSO. The proposed inversion algorithm is applied to the Digisonde data at Pruhonice and the reconstructed electron density profiles are compared by those from POLAN and NHPC. It is observed that the proposed reconstruction is highly robust and accurate to reflect the nature of the ionosphere during geomagnetically disturbed days. This study is supported by Joint TUBITAK 114E092 and AS CR 14/001 projects.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-375

Status of neutrospheric delay modeling in Brazil and GNSS positioning improvement using Numerical Weather Prediction Models

T. Gouveia[1], *J. Monico*[1], *D. Alves*[1], *L. Sapucci*[2], *J. Magario*[1]
[1]*Unesp, Cartography, Presidente Prudente, Brazil*
[2]*CPTEC/INPE, Data Assimilation, Cachoeira Paulista, Brazil*

The atmospheric layer electronically neutral extends from the surface to 50 km and is named Neutrosphere, also called Troposphere. The neutrospheric refraction generated in the radio frequency signal propagation, due to thermodynamic characteristics of the atmosphere, can be divided in two components: one generated by the dry gases influence, the hydrostatic component, and another by water vapor influence, the wet component. Different techniques are being developed in order to minimize or eliminate this refraction that causes error in GNSS (Global Navigation Satellite System) positioning. Brazil territory has regions with singular climatic characteristics, in which the neutrosphere theoretical models (empirical models) are not totally representative, mainly because they were built based on average values of pressure and temperature. Numerical Weather Prediction (NWP) models are a better alternative to minimize such effect. In Brazil, CPTEC/INPE provides a regional model to generate weather forecasts, with a horizontal resolution of 15 km, called Eta model. This version is currently used to produce zenith neutrospheric delay (ZND) predictions. Furthermore, a new NWP model is being developed to higher resolution and consequently improves ZND prediction quality, called ZTD. The goal of this paper is to present the new model G3DVar, compare it with Eta model and evaluate their impact in GNSS positioning against to Hopfield empirical model, as well as discuss the future of ZND prediction in Brazil.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-376

Effect of Ionospheric Scintillation on GNSS Positioning at low and medium latitude areas

D. Alves[1]*, E. Souza*[2]*, T. Gouveia*[1]*, M. Ortega*[1]*, J. Magario*[1]
[1]*Unesp, Cartography, Presidente Prudente, Brazil*
[2]*UEM, Statistical, Maringa, Brazil*

Ionospheric effects has a great influence on GNSS (Global Navigation Satellite System) signals and its behavior depends on several variables: local time, geographic location, seasons and solar activity. Besides, there are ionospheric irregularities that also affect the GNSS signal propagation, as the ionospheric scintillation. This effect can be described as a fast change in phase and amplitude of GNSS signal, caused by irregularities of electron density. Scintillation can degrade or cause the GNSS signal lost. The Brazilian territory is one of the most affected regions of the Earth, with high scintillation activity in sunset hours. In order to study this effect, there is available in Brazil a scintillation monitoring network from CIGALA (Concept for Ionospheric Scintillation Mitigation for Professional GNSS in Latin America) and CALIBRA (Countering GNSS high Accuracy applications Limitations due to Ionospheric disturbances in BRAzil) projects (http://is-cigala-calibra.fct.unesp.br/is/#). In this paper, experiments regarding the scintillation effect on GNSS positioning have been conducted from two Brazilian reference stations, located in different regions of the country (low and medium geomagnetic latitudes). Three years of scintillation index and GNSS positioning results were evaluated. It was possible to verify different impact for low and medium latitude reference stations. Furthermore it was obtained different behavior in different months of the year, as expected. Additional analyses were also realized considering specific high scintillation days and hours. Theoretical details, results and analyses will be detailed in this paper.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-377

Analysis of Precipitable Water Vapor over South America

. Bianchi[1], . Epeloa[1], . Mendoza[1], . Fernandez[1], . Natali[1], . Meza[1], . Moirano[1]
[1]Facultad de Ciencias Astronómicas y Geofísicas, Astrometría, La Plata, Argentina

The Precipitable Water Vapor (PWV) is one of the key variables needed to model the spatial and temporal behavior of tropospheric phenomena. While regular radio-soundings are poorly distributed over South America a constantly growing network of continuously operating geodetic Global Positioning System (GPS) stations is being deployed over the continent for the last 30 years. We compare PWV estimation from GPS with respect to PWV from radio-soundings and the respective values from ERA Interim for a set of stations in South America during 2008 to 2013. The analysis involves stations in different climate types according the Köppen and Geiger classification. The comparison displays an overall agreement on the millimeter level between PWV coming from radio sounding and from GPS processing. The differences show a normal distribution with a mean values ranging from -0.3 to 0.5 mm. and a correlation higher than 0.9. The discrepancy between PWV from ERA Interim and the respective values from GPS is mainly due to the difference in heights where the values are computed. We can conclude that reliable PWV values can be recovered from a regional continuously operating geodetic GPS network with accurate pressure and temperature surface information available nearby.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-378

First results of the real-time multi-GNSS troposphere parameters demonstration campaign at the Royal Observatory of Belgium

E. Pottiaux[1], J. Dousa[2], P. Vaclavovic[2], C. Bruyninx[1]
[1]Royal Observatory of Belgium,
Reference Systems and Planetology - Space Geodesy, Uccle, Belgium
[2]Geodetic Observatory Pecny- RIGTC- Czech Republic,
Departement of Geodesy and Geodynamics, Geodetic Observatory Pecny, Czech Republic

One of the objectives of the COST Action ES1206 « Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate» (GNSS4SWEC) is to develop new and enhanced GNSS processing methods and products to support nowcasting and forecasting of severe weather. In that context, the Royal Observatory of Belgium (ROB) started a collaboration with the Geodetic Observatory Pecný (GOP), Czech Republic, in order to exploit observations from the Belgium Active Geodetic Network (BAGN) to provide multi-GNSS tropospheric estimates in real-time based on the Gnut/Tefnut software.

After the initial development phase, ROB started in July 2014 a real-time demonstration campaign in order to assess continuously the performance of the tropospheric estimates w.r.t. nowcasting requirements. This demonstration campaign currently includes more than 170 multi-GNSS permanent stations and uses various real-time satellite orbit and clock products currently available (IGS combined as well as individual contributions) to provide real-time Zenith Total Delays (ZTD) and horizontal gradient estimates. To assess their performance, the real-time tropospheric estimates are compared to 1) the final IGS troposphere product (for IGS stations only), and 2) to in-house (final) post-processed products (for all stations). These in-house post-processed products are estimated with the Bernese GNSS software version 5.2. In this presentation, we summarise the results obtained after almost one year of operating continuously the demonstration campaign and assess how this campaign can contribute to the objectives of GNSS4SWEC.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-379

Global Analysis of the Zenith Wet Delay to Precipitable Water Vapour Conversion Methods using Radiosonde Observations and Numer-ical Weather Models

I. Juni[1], *S. Rozsa*[1]
[1]*Budapest University of Technology and Economics,*
Department of Geodesy and Surveying, Budapest, Hungary

Water vapour plays an important role as a basic climate variable in the thermodynamics and dynamics of the storm systems at the atmosphere and in the hydrological cycle on the local, regional and global scales. Moreover, the distribution of atmospheric water vapour is difficult to determine because of its rapid spatial and temporal changes. Recently the precipitable water vapour content (PW) is estimated using the zenith wet delay (ZWD) derived from ground-based GNSS data.

This study investigates the conversion methods used for the estimation of PW from the ZWD. Currently two types of conversion methods are widely used in the literature. Bevis et al. proposed a linear regression model between the surface temperature (Ts) and the mean temperature of atmospheric water vapor (Tm), and the scale factor ZWD/PW is computed as a function of Tm. Emardson-Derks proposed the direct estimation of the scale factor as a polynomial function of Ts.

The newly developed global meteorological parameter model, GPT2W can also be used to model this scale factor.

A global radiosonde database as well as ECMWF numerical weather models are used to assess the global performance of the aforementioned models. Moreover, based on the raytracing of ECMWF numerical weather models, a new global ZWD/PW conversion method is introduced in this paper.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-380

Ray-traced model of the upper atmosphere using GNSS measurements

M. Alizadeh[1], *H. Schuh*[1,2]
[1]*Technical University of Berlin, Institute of Geodesy and Geoinformation Science, Berlin, Germany*
[2]*DeutschesGeoForschungsZentrum GFZ, Dept. 1 'Geodesy and Remote Sensing', Potsdam, Germany*

Due to the fact that ionosphere is a dispersive medium with respect to microwave band, the signals of space geodetic techniques travelling through this medium experience a delay in code measurements and an advance in the phase measurements. This phenomenon allows gaining information about the parameters of the ionosphere in terms of Total Electron Content (TEC) or the electron density along the ray path. The relevant input data for modeling the ionospheric parameters from Global Navigation Satellite Systems (GNSS) is the ionospheric observable (L4) which is formed from the phase-smoothed code pseudorange obtained from dual-frequency measurements.

This study aims at developing a global 3D model for the ionosphere/plasmasphere peak parameters by applying ray-tracing technique to the upper atmosphere using GNSS measurements. In the developed modeling approach the horizontal variations of the electron density is presented with two sets of spherical harmonic expansions of degree and order 15 and the height dependency by a multi-layered Chapman profile function for the bottom-side and topside ionosphere, and a separate profile function for the plasmasphere. The coefficients of two sets of spherical harmonic expansions are obtained through a recursive parameter estimation technique and by applying appropriate constraints. The developed model includes geophysical parameters like maximum electron density, and its corresponding height. High resolution modeling of these parameters allows an improved geophysical interpretation, which is essential in all studies of the upper atmosphere, space weather, and for the solar-terrestrial environment.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-381

Advances in the GNSS based estimation of atmospheric water vapour and its application in numerical weather prediction

S. Rozsa[1], M. Mile[2], T. Horvath[3], A. Kenyeres[3], I. Juni[1], T. Weidinger[4], A.Z. Gyongyosi[4], J. Adam[1], J. Bartholy[4]
[1]Budapest University of Technology and Economics, Department of Geodesy and Surveying, Budapest, Hungary
[2]Hungarian Meteorological Service, Informatics and Methodolody Department, Budapest, Hungary
[3]Institute of Geodesy- Cartography and Remote Sensing, Satellite Geodetic Observatory, Budapest, Hungary
[4]Eotvos Lorand University, Department of Meteorology, Budapest, Hungary

In the last decade a new network of continuously operating GNSS reference stations has been established in Hungary and in the neighbouring countries. The availability of this network enables us to develop and realize a processing facility to estimate the tropospheric zenith delays from the observations in near real time.

In the recent years some new developments have been realized including the update of the processing software to Bernese V5.2. Moreover the estimation of precipitable water vapour from the zenith wet delays was further refined and implemented in the system. As a result of these developments, GNSS based estimates of the zenith total delays and precipitable water vapour are transmitted to the E-GVAP project of the EUMETNET for more than 50 Hungarian stations with the spatial resolution of approximately 60 kilometres.

The Hungarian Meteorological Service conducted the first tests of the assimilation of zenith total delays in their AROME numerical weather prediction model. During these tests data assimilation diagnostics showed that the zenit total delays originated from nearly 70 stations have important contribution to AROME analysis (especially to humidity analysis). The verification results of the first test conducted in January, 2014 show that the assimilation of GNSS based zenith wet delays slightly improved the accuracy of the short-term forecasts of the 2m relative humidity values.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-382

Preconditions to GNSS tomography of the troposphere

G. Möller[1], *J. Maras*[1], *C. Schönberger*[1], *R. Weber*[1]
[1]*Technische Universität Wien, Department für Geodäsie und Geoinformation, Vienna, Austria*

GNSS observation data allows us to estimate parameters which represent the signal delay in the troposphere. The parameter SWD (Slant Wet Delay) represents the signal delay along the ray path caused by the heterogeneous distribution of water and water vapour in the atmosphere. However, since it is an integral value it does not allow to derive any information about the vertical structure of the atmosphere. Therefore a tomography approach has to be applied.

For GNSS tomography we make use of the relation Ax =m where the vector m represents the SWD and x describes the current state of the atmosphere, i.e. the refractivity Nwet,j in each voxel j. The matrix A defines the mapping of the state x on the observations m and is most frequently not squared, ill-posed and ill-conditioned. Hence, to invert the A matrix is rather tricky. Different approaches have been developed to solve this problem like the Singular Value Decomposition or the least squares (LSQ) approach. Independent from the reconstruction technique a large set of GNSS observations and a high station density is required to provide an enhanced resolution (especially in vertical direction).

In this presentation we will highlight the reconstruction process of anisotropic SWD from GNSS observation. Therefore simulated and real GNSS observations were processed to obtain anisotropic SWD for a small network of GNSS receivers. Further the network geometry is analysed to assess its impact on the tomography approach. In order to improve the spatial and temporal resolution of the tomography results we present a selective method for the densification of the existing network with low-cost GNSS receivers.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-383

Contribution of GPS technology to the study of intense tropical weather events

S. Nahmani[1], *O. Bock*[1]
[1]*IGN, LAREG, Paris, France*

A better understanding of tropical weather processes is necessary to improve numerical weather models, which are not fully satisfactory in tropical regions. Water vapor has a key role in these atmospheric processes and precipitable water vapor (PWV) is a widely employed quantity to study these processes and compute water budgets. PWV can generally be retrieved with an accuracy of about 1 $kg.m^{-2}$ from the zenithal wet delays (ZWD) estimated during GPS data processing. In Sahel, 90% of annual rainfalls are produced by Mesoscale Convective Systems (MCSs) and few meteorological instruments can provide precisely PWV during these extreme meteorological conditions.

In this study, we investigated the contribution of GPS estimates to better understand such extrem events. First, we identified 556 MCS events on 6 GPS tropical stations by analysing in situ meteorological data: temperatures fall, GPS PWV estimates reach a local maximum and GPS phase residuals show strong variations that are spatially and temporally correlated. We observed that under certain conditions, GPS phase residuals clearly reveal the passage of MCSs similarly as reflectivity measurements from MIT C-band Doppler radar. At inter-annual time scales, GPS phase residuals are sensitive to the displacement of the Intertropical Convergence Zone. Finally, we carried out sensitivity tests on GPS data processing strategies (network versus PPP) and on the Gauss-Markov process which constrains the temporal variability of the ZWD estimates. We concluded that GPS PWV estimates are clearly subject to caution during these intense events.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-384

Homogeneous tropospheric path delays from GNSS re-processing by Geodetic Observatory Pecny

J. Dousa[1], P. Vaclavovic[1], M. Elias[1]
[1]Geodetic Observatory Pecny- RIGTC, Geodesy and Geodynamics, Zdiby, Czech Republic

EUREF Permanent Network (EPN) was established in 1996, initially for the maintenance of the European Terrestrial Reference System (ETRS). Since that time it has grown up to 250 GNSS continuously operating stations and its utilization became much wider. A contribution to a climate research exploiting the tropospheric products could be one of future applications. However, it requests a long-term homogeneously processed data in order to avoid any interruptions or jumps in the tropospheric parameter time-series.
Recently, the 2nd reprocessing campaign was completed in support of a new realization of ETRS. Using global precise products, the EUREF reprocessing is closely linked to the similar re-processing coordinated by the International GNSS Service (IGS). Geodetic Observatory Pecny (GOP) performed the reprocessing of the whole EPN network and the period of 1996-2014 which was additionally aimed to support a climate research within the COST ES1205 (GNSS4SWEC project). GOP provided several variants with special focus on tropospheric estimates - VMF1 and GMF mapping functions were used together with different elevation cut-off angles and setting of horizontal tropospheric gradients. The processing strategy was enhanced in several aspects: 1) combining tropospheric parameters in midnights, 2) careful handling of the weekly coordinates of all stations when substituted for estimating tropospheric parameters and 3) providing a procedure to filter problematic stations (based on a consistency of combined coordinates). Results of the GOP reprocessing, including all available variants, will be described and evaluated using the powerful GOP-TropDB database system for an intra- and inter-technique tropospheric and meteorological parameter comparisons.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-385

On the assessment of surface pressure and mean temperature data for the conversion of GPS ZTD to IWV

A. Parracho[1]*, O. Bock*[1]*, S. Bastin*[2]
[1]*IGN, LAREG, Paris, France*
[2]*IPSL, LATMOS, Guyancourt, France*

Surface pressure measured by SYNOP stations and weighted mean temperature (Tm) data are used in the conversion of GPS ZTD to IWV. For climate applications, an accuracy of 1hPa in the surface pressure measurements is needed (which corresponds to an accuracy in sensor height of about 10m), and a 3K accuracy is required for Tm.
In this work, an assessment of the station coordinates was performed, using daily coordinate information from the Météo France database, for 2012, over Europe and North Africa. In general, 103 counts of altitude change were found, with magnitudes varying from -71m to +64m. Although these changes are generally updated in the WMO database, this may take several days, or even months, creating uncertainties in the coordinates that can result in large biases when the pressure is extrapolated to the GPS site. Therefore, it is important to detect and correct these errors before using the pressure data. Hence, SYNOP pressure measurements were used to detect possible station height errors, using two approaches. Firstly, the pressure was extrapolated from each SYNOP station to every other station within a 100km radius and 500m vertical distance, and the extrapolated pressure was compared with measured pressure at these stations. Secondly, the pressure for each SYNOP station was compared with the pressure extrapolated using ERA-Interim data, interpolated to the station sites. Both approaches resulted in similar lists of stations with high pressure biases.Finally, Tm was computed using the ERA-Interim temperature profiles at full resolution. The results were compared with other Tm products with lower resolution.

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JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-386

Study on optimal temporal approximation of meteorological and tropospheric parameters

M. Elias[1], *J. Dousa*[1]
[1]*Research Institute of Geodesy- Cartography and Topography, Department of Geodesy and Geodynamics, Zdiby, Czech Republic*

Over the past few years, the attention was paid for an optimal modelling of tropospheric corrections in support of GNSS positioning and navigation. For this purpose, data from numerical weather models are more and more utilized. Because of a large volume of data, several approximations are commonly applied for an effective provision of meteorological and tropospheric parameters for a GNSS signal path delay calculation. First, vertical approximation is useful to significantly reduce the amount of NWM data to a two-dimensional field at a reference level. This approximation is usually based on model algorithms approximating the physics of the atmosphere. Second, the grid spatial approximation is commonly utilized. Although the horizontal resolution is progressively improving, it strongly depends on the available input data from numerical weather field. Third, an approximation in time enables to provide a closed form of the correction model that does not require any additional information about the actual state of the atmosphere. Such temporal approximation usually benefits from results of the individual parameter time-series analysis using an effective data time-span.

Our study focuses on the temporal approximation of selected meteorological and tropospheric parameters in order to develop a blind tropospheric correction model for positioning and navigation. First, an effective length of the time-span of input data is assessed. Second, we studied a spectral analysis of individual parameter time-series and identify those harmonic coefficients applicable for an effective temporal approximation with a partial physical amplitude and their frequency interpretations.

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JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-387

"Effects of integration of pressure sensor data in the Virtual Reference Station technique for Network Real Time Kinematic satellite navigation"

P. Zoccarato[1], *A. Bråthen*[2], *H.G. Duenck-Kerst*[1], *C. Pagels*[1], *P.H. Andersen*[2], *M. Herwig*[1], *G. Grinde*[2]
[1]*Trimble Terrasat GmbH, Infrastructure Division, Hoehenkirchen-Siegertsbrunn, Germany*
[2]*Norwegian Mapping Authority, Geodetic Institute, Hønefoss, Norway*

The Virtual Reference Station (VRS) technique for Network Real Time Kinematic (RTK) navigation takes advantage of several reference stations in a network of Global Navigation Satellite System (GNSS) receivers to generate virtual data simulating a reference station very close to the rover position. The purpose of VRS is reducing the baseline length between the rover and the reference station in order to remove the spatially correlated errors using differential processing at the rover side. Generating the VRS observations requires a really accurate modeling of distance-dependent errors, mainly caused by ionospheric and tropospheric refractions, and satellite orbit errors.

Focusing on computing the part of the VRS observations aiming to remove the tropospheric error, it is interesting to evaluate the contribution of pressure sensors located nearby the network reference stations. Instead of an a priori model for pressure values, measurements from those sensors are used. These pressure values are provided to a zenith delay model which, with the aid of a mapping function, corrects the GNSS observations. A network of GNSS receivers in the south west of Norway and a static rover are used, together with five pressure sensors located at the stations closest to the rover. A tropospheric scaling factor is estimated for each reference station, then a scaling factor is interpolated at the VRS position and it contributes to generate the tropospheric correction for the rover. The a priori models used are the Global Pressure Temperature 2 with Saastamoinen, compared with the Numerical Weather Model values for the south west of Norway. The Vienna Mapping Function 1 is used in all the cases. The results are reported and discussed in terms of accuracy of the rover position determination.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-388

Dense and sparse network solutions of zenith wet delays for real time kinematic precise point positioning

P. OLIVEIRA JR.[1], *F. FUND*[1], *L. MOREL*[2], *R. LEGROS*[1], *J.F.G. MONICO*[3], *S. DURAND*[2], *F. DURAND*[2]
[1]*Geodata Diffusion, Research & Development, Arpajon, France*
[2]*GeF/Cnam, Laboratoire Géomatique et Foncier, Le Mans, France*
[3]*PPGCC/Unesp, Cartography Department, Presidente Prudente, Brazil*

Precise Point Positioning (PPP) is a well-known technique of positioning by GNSS (Global Navigation Satellite System) that provides accurate solutions. With the availability of real-time precise orbit and clock products provided by IGS (International GNSS Service) through the Real Time Project, real-time PPP is also achievable. With those orbit and clock products and using dual frequency receivers, ionospheric effects can be greatly reduced by the iono-free combination. Zenith Wet Delays (ZWD) have to be estimated because they cannot be mitigated by observables combinations. However, adding ZWD estimates in the PPP processing increases the convergence time of positions. To reduce this convergence time, we 1) model the behavior of troposphere over a GNSS reference stations network using ZWD estimates and 2) send the modeling to GNSS users to be introduced as a priori ZWDs in the PPP processing. In this work, results of tropospheric modeling obtained by an adaptive quadric surface algorithm for application in RT-PPP are presented. The French permanent GNSS network Orpheon is used to estimate the tropospheric model. The quality of the modeling is assessed by comparison with tropospheric products calculated by IGN (Institut Géographique National), and the improvements achieved in terms of convergence time of positions at the rover level. Results for dense and sparse network configurations are also discussed, in order to determine a minimal number of stations necessary to accomplish the tropospheric modeling for RT-PPP purposes.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-389

Global validity and behaviour of tropospheric gradients estimated by GPS

L. Morel[1]*, . Pottiaux*[2]*, . Durand*[3]*, . Fund*[4]*, . Follin*[5]*, . Durand*[3]*, . Boniface*[6]*,*
. De Oliveira[7]*, . Van Baelen*[8]
[1]*CNAM - ESGT, Gef, LE MANS, France*
[2]*ROB, -, Bruxelles, Belgium*
[3]*CNAM - ESGT, -, LE MANS, France*
[4]*Geodata, -, Arpajon, France*
[5]*CNAM-ESGT, -, LE MANS, France*
[6]*Universite of Grenoble, ISterre, Grenoble, France*
[7]*Geodata diffusion, -, Arpajon, France*
[8]*Laboratoire de Météorologie Physique, -, Clermont Ferrand, France*

Estimation of tropospheric gradients in GNSS data processing is a well-known technique to improve positioning. Today, they are routinely estimated by several global and regional GNSS analysis centres but they are still not yet used for operational meteorology. We discuss the physical meaning of tropospheric gradients estimated from GPS observations recorded by several permanent stations located all around the world. We estimated Zenith Total Delay (ZTD) and tropospheric gradients using two software: GAMIT/GLOBK (GAMIT version 10.5) and GIPSY-OASIS II version 6.3 in order to analyse the differences in the tropospheric results (ZWD and gradients) coming from the processing strategy (double-differences for GAMIT/Globk versus zero-difference for GIPSY-OASIS). We also observe that gradient directions are stable over the time and pointed toward the relief for most of the stations selected. These results give us a first step for a physical meaning to gradients when stations are closed to high mountains.

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JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-390

Modelling of the global ionosphere by means of a data adaptive technique using observations acquired from various space geodetic systems

M. Schmidt[1], E. Erdogan[1], D. Dettmering[1], M. Limberger[1], F. Seitz[1], K. Börger[2]
[1]Technische Universitaet Muenchen, DGFI, Munich, Germany
[2]German Space Situational Awareness Centre, GSSAC, Uedem, Germany

In this presentation the estimation problem of the ionospheric Vertical Total Electron Content (VTEC) in a global scale is handled by means of data adaptive filtering techniques. The main focus is on the development of a stable filtering framework that can run data adaptive approaches to assimilate ionospheric data in near real-time. Although, various space geodetic observation techniques such as GNSS, satellite altimetry, DORIS and radio occultation from LEO satellites can provide information about the electron content of the ionosphere, the distribution of these observations is not homogeneous both in time and space, even with large data gaps over the oceans. In this respect, temporal and spatial variations of the global VTEC are considered in a proper adaptive data assimilation framework which makes use of appropriate basis functions.

To realize this adaptive framework, data adaptive basis functions (e.g. Multivariate Adaptive Regression B-Splines) combined with recursive filters (e.g. Kalman filtering, unscented Kalman filtering, mixed filtering) have been considered to investigate the further improvements compared to the classical methods in the estimation of global ionosphere. Besides, a special emphasize on numerical stability is considered, since the ionospheric inverse problem is naturally ill-posed. The global VTEC products using this new estimation framework are compared with other products provided, e.g. by CODE, and can be taken into account as an external benchmark for validation.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-391

Assessing Galileo precise point positioning capability for integrated water vapor estimation

M. Mendonca[1], R. White[1], M. Santos[1], R. Langley[1]
[1]University of New Brunswick, Geodesy and Geomatics, Fredericton, Canada

Although conventionally used for positioning, navigation, and timing, GNSS observations constitute a useful tool for atmospheric remote sensing. By quantifying and analyzing the influence of the atmosphere on the propagating electromagnetic signals, we can infer a significant amount of information for further understanding Earth’s atmosphere as well its relationship with satellite positioning activities. For some industrial sectors that require high accuracy and reliability, such as oil exploration, dredging, and aviation, the understanding of how GNSS satellite signals propagate across the atmosphere is crucial information. Among several improvements related to GNSS, the increasing number of in-orbit Galileo satellites opens a new window of opportunities for atmospheric research. Users can achieve improved satellite geometry and take advantage of Galileo signals characteristics, such as the improved signal strength. In this study, the usage of Galileo signals for neutral atmospheric delay (NAD) estimation is assessed along with its integration with signals from the already established GPS constellation. Using the University of New Brunswick’s GPS Analysis and Positioning Software (GAPS) precise point positioning suite, the NAD values are estimated and integrated with in situ measurements of pressure, temperature and humidity, allowing us to estimate the integrated water vapor (IWV) of the atmosphere above a GNSS station. As a reference for the estimation assessment, existing IWV values from radiosondes are used. Preliminary results show that the Galileo+GPS NAD estimations are close to those of GPS and Galileo-only at a 2 centimeters level. The soon-to-be-available multi-GNSS processing online version of GAPS will become a useful tool for future atmospheric research.

Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-392

GNSS PWV estimation during heavy snow storm event in Korea

D. Song[1]
[1]*Kangwon National University, Ocean Construction Engineering, Samcheok, Korea- Republic of Korea*

The Global Navigation Satellite System (GNSS) signal delays in the troposphere are used to retrieve the precipitable water vapor (PWV) along the signal path between a transmitting satellite and GNSS permanent station. The purpose of this study is to evaluate GNSS PWV variations during heavy snowstorm event occurred along the East Coast of the Korean Peninsula. The precipitable water vapors were retrieved from GNSS tropospheric wet delay during the progress of heavy snowfall during winter season on 2014. For this period, the time series analysis between GNSS PWV and fresh snow depth were accomplished. The time series and the comparison with the GNSS precipitable water vapor and the fresh snow depth indicate that the temporal change of two variations is closely related to the progress of the heavy snowfall. Also, the periodicity of GNSS precipitable water vapor using the wavelet transform method was showed a similar cycle of saturated water vapor pressure as the limitation of this study span. The result shows that the decrement of GPS precipitable water vapor was conflicted with the increment of fresh snow depth at two GNSS permanent sites (KANR and WULJ) in Korea. The correlation between the GNSS PWV and the saturated water vapor pressure for the event was showed a positive correlation, compare with the non-heavy snowfall periods.

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Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-393

Development and evaluation of monthly weighted mean temperature models for GNSS precipitable water vapor in Korean peninsula

D. Song[1]
[1]*Kangwon National University, Ocean Construction Engineering, Samcheok, Korea- Republic of Korea*

Since the retrieval accuracy of precipitable water vapor estimates from Global Navigation Satellite System measurements is proportional to the accuracy of water vapor weighted mean temperature, the weighted mean temperature model is a significant formulation in the conversion of PWV from the GNSS zenith wet delay. The purpose of this study is to develop a monthly weighted mean temperature model for the retrieval of highly accurate GNSS precipitable water vapor using the radiosonde measurements from six upper-air observing stations in the region of Korea. The values of 1-hr precipitable water vapor estimated at four GNSS permanent stations during one year are used to evaluate the validity of the monthly weighted mean temperature model. It is compared to the precipitable water vapor obtained from radiosonde data that are located in the vicinity of GNSS stations. Inter-comparison of radiosonde precipitable water vapors and GNSS precipitable water vapors derived using different weighted mean temperature models is performed to assess the quality of MWNT model for Korea. The result in this study indicates that the monthly weighted mean temperature model is an effective model to retrieve the enhanced accurate GNSS precipitable water vapor, compared to other GNSS precipitable water vapor derived by Korean annual or global weighted mean temperature models.

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Joint Inter-Association Symposium

JG02p - JG2 Modelling the Atmosphere and Ionosphere by Space Measurements (IAG, IAGA, IAMAS, IACS)

JG02p-394

Analysis of PM10 observations and GNSS PWV Estimations

D. Song[1], *J. Nam*[2], *S. Sim*[3]
[1]*Kangwon National University, Dept. Ocean Construction Engineering, Samcheok, Korea- Republic of Korea*
[2]*Kangwon National University,*
Dept. of Environmental Disaster Prevention Engineering, Samchok,
Korea- Republic of Korea
[3]*Kangwon National University,*
Dept. of Environmental Disaster Prevention Engineering, Samcheok,
Korea- Republic of Korea

During the dust storm season, as the radio signals propagate from GNSS satellites to the receivers on the ground, they are subject to attenuation and polarization. It can be expected that GNSS signal propagation delays caused by dust particulates will result in poorer accuracy of positioning, navigation and GNSS-based atmospheric sensing. Precipitable water vapor (PWV) is the moisture content within the air represented by the water depth, which is an important information for the analysis of land-atmospheric interaction and local hydro meteorological change. Continuously GNSS networks offer the possibility of estimating the integrated water vapor (IWV) or, equivalently precipitable water vapor. This study tries to find out the correlation between meteorological factors (PM10) and GNSS PWV. This study analyzed the GNSS PWV data estimated at the Korean GNSS Permanent stations in 2007, along with the particulate matter measured at the collocated meteorological stations.

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Joint Inter-Association Symposium

JH03a - JH03/JG03 Assessment of Climate and Anthropogenic Changes Impacts on the Terrestrial Hydrosphere (IAHS, IAMAS) / Variations of the Hydrosphere from Satellite Gravity Missions (IAG, IAHS)

IUGG-0316

Estimating fine-resolution terrestrial water storage changes over Central Congo Basin By Integrating GRACE, PALSAR, and altimetry

H. Lee[1], H.C. Jung[2], T. Yuan[1], E. Beighley[3], D. Alsdorf[4], C.K. Shum[4]
[1]University of Houston, Department of Civil and Environmental Engineering, Houston- TX, USA
[2]NASA Goddard Space Flight Center, Office of Applied Sciences, Greenbelt- MD, USA
[3]Northeastern University, Department of Civil and Environmental Engineering, Boston- MA, USA
[4]Ohio State University, School of Earth Sciences, Columbus- OH, USA

Several studies have been conducted to quantify and characterize terrestrial water storage changes over the Congo's wetlands, especially focusing on the central Congo Basin, or Cuvette Centrale, where vast wetlands can be found. The annual variations of the surface water storage changes over the wetlands were estimated to range between ~20 km^3 to ~30 km^3 by multiplying changes of inundated areas from PALSAR ScanSAR with changes of water level changes from Envisat altimetry. By comparison with total storage changes from GRACE, it was revealed that the coarse-resolution (~300 km) GRACE signal is mostly governed by the surface water storage changes. Based on this finding, we then, for the first time, attempted to generate finer-resolution storage change maps by integrating coarse-resolution GRACE data and fine-resolution (~100 m) ScanSAR data. The downscaled storage change maps were then validated with a few upscaled water depth maps (~100 m) which were generated based on spatial variations of water level changes from altimetry, backscattering coefficients from ScanSAR, and vegetation density from MODIS. The maps were further compared with estimated storage changes from the Hillsope River Routing (HRR) model.

Our finer-scale storage change maps revealed significant annual changes of water storages around the proximal floodplains of the Congo mainstem up to 1 km^3 over a 40 km by 40 km grid, which approximately corresponds to 10^9 Litres of water over the entire city of Prague.

Joint Inter-Association Symposium

JH03a - JH03/JG03 Assessment of Climate and Anthropogenic Changes Impacts on the Terrestrial Hydrosphere (IAHS, IAMAS) / Variations of the Hydrosphere from Satellite Gravity Missions (IAG, IAHS)

IUGG-0333

Future prospects of research on extreme floods & droughts and adaptive management under climate change in East China Monsoon Region

J. Xia[1]
[1] *+8613910922532,*
State Key Laboratory of Water Resources and Hydropower Engineering Science-Wuhan University, Wuhan, China Peoples Republic

China is one of the 13 countries in the world that experience water scarcity, especially in East China Monsoon Region, with the obvious contradiction between water supply and demand and frequent droughts and floods. In the context of global warming over the past 30 years, increased droughts and the deterioration of water environment in northern China, and also increased extreme floods in the southern China, have seriously hampered the sustainable socio-economic development. This paper proposes several revisions and future prospects of research on water resources vulnerability and adaption measures under climate change combing with the project, that is impacts of climate change on water resources security and adaption measures in East China Monsoon Region, which is supported by the National Basic Research Program of China. This presentation will focus on the four parts: (1) the recognition for extreme precipitation and changes from drought and flood of non-stationary sequence. (2) The assessment of vulnerability status quo of water resources and the fact that floods and droughts exacerbate the vulnerability of water resources. (3) The trend of flood and drought disasters in China. (4) Adaptation strategies for flood and drought disasters under climate change. To put forward adaptive measures for reducing the impacts of flood and drought disasters on urban development, ensuring the food security and maintaining sustainable development of socio-economic, it is very important to carry on the interdisciplinary research to explore the trend of them under climate change scenarios. All above is to implement the most strict water resources management institution and achieve strategic goals of ecological civilization construction.

Joint Inter-Association Symposium

JH03a - JH03/JG03 Assessment of Climate and Anthropogenic Changes Impacts on the Terrestrial Hydrosphere (IAHS, IAMAS) / Variations of the Hydrosphere from Satellite Gravity Missions (IAG, IAHS)

IUGG-0738

Minimizing signal loss due to filtering of GRACE observed total water storage change.

B.D. Vishwakarma[1]*, B. Devaraju*[2]*, N. Sneeuw*[1]
[1]*Institute of Geodesy, Faculty of aerospace and geodesy- University of Stuttgart, Stuttgart, Germany*
[2]*Institute of Geodesy ife,*
Faculty of Civil Engineering and Geodetic Science- Leibniz University, Hannover, Germany

Total water storage variations of catchments obtained from the Gravity Recovery and Climate Experiment satellite mission is usable only after filtering due to high frequency noise. Filtering smothers both signal and noise, inevitably decreasing the amplitude of the filtered dataset. Several studies have mainly focused on retrieving the signal amplitude by way of scale factor derived with the aid of geophysical models. In this study, we demonstrate that in addition to amplitude loss there is also significant phase shift. The change in phase and amplitude of a catchment time-series is related to the phase and amplitude of leakage time-series from nearby catchments. The phase change can be around 20 to 30 degrees for catchments with moderate size. We discuss inter-catchment leakage. We quantify leakage signal in one catchment due to a nearby catchment only and come up with a strategy to retrieve the time-series with accurate phase and amplitude. This strategy is independent of any geophysical models, which is first demonstrated in a closed-loop environment for a few selected catchments in South America and southern Africa. We finally discuss the application of this strategy to GRACE observations.

Joint Inter-Association Symposium

JH03a - JH03/JG03 Assessment of Climate and Anthropogenic Changes Impacts on the Terrestrial Hydrosphere (IAHS, IAMAS) / Variations of the Hydrosphere from Satellite Gravity Missions (IAG, IAHS)

IUGG-2778

Can GRACE observe an intensification of the global water cycle?

A. Eicker[1], *J. Kusche*[1], *E. Forootan*[1], *L. Longuevergne*[2], *A. Springer*[1]
[1]*University of Bonn, Institute of Geodesy and Geoinformation, Bonn, Germany*
[2]*University of Rennes, Geosciences Rennes, Rennes, France*

One possible evidence of the water cycle intensifying due to climate change and anthropogenic forcing might be an increase in hydrological fluxes such as precipitation (P), evapotranspiration (E), and river discharge (R). An increase (or decrease) of the net flux deficit (P-E-R) would correspond to an acceleration (or deceleration) of water storage changes and might, on large spatial scales, be detectable by GRACE gravity field observations. In the present study, we therefore compare global accelerations maps obtained from the GRACE time series to trends in the flux deficit provided by two global atmospheric reanalysis models (ERA-Interim, MERRA-LAND) after removing a global ENSO-related signal which is assumed to contain a large part of the inter-annual variability. Furthermore, we specifically investigate flux time series in several hot-spot regions in which significant water storage acceleration can be identified. While on short temporal scales (inter-annual down to sub-seasonal) the modeled fluxes agree surprisingly well with GRACE water storage changes, the reanalyses fail to capture the long-term flux trends corresponding to GRACE accelerations. We conclude that despite the short time span of available gravity field observations, GRACE is able to provide new information for constraining the long-term evolution of water fluxes in future reanalysis models.

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IUGG-5319

Changing water systems and the Tryrrany of small problems: Socio-hydrology

M. Sivapalan[1]
[1]*University of Illinois at Urbana-Champaign,*
Civil and Environmental Engineering, Urbana, USA

We are well and truly in the Anthropocene. Humans can no longer be considered mere external drivers or boundary conditions in the hydrologic systems we study. The interactions and feedbacks between human actions and water cycle dynamics on the planet, exacerbated in many places by climate change and the evolution of human norms in relation to water, are throwing up a range of emergent “big problems”. Understanding these and offering sustainable solutions require a broadening of hydrologic science to embrace the perspectives of both social and natural scientists, including hydrologists and climatologists. The practice of the newly formed discipline of socio-hydrology faces challenges because the knowledge foundations and methodologies of natural and social sciences are vastly different. Yet, the benefits of working together are enormous, including both scientific and practical. Bringing together the perspectives of both social and natural scientists dealing with water is good for hydrologic science, having the salutary effect of revitalizing it as use-inspired basic science. It is good for management too, in that the broader, holistic perspectives provided by socio-hydrology can help recognize potential problems that may otherwise be unforeseen and, equally, identify potential solutions to otherwise intractable problems.

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IUGG-5728

Applications of energy balance and regional gravity modeling approach on improved GRACE estimates of terrestrial water storage changes

C.K. Shum[1], *K. Shang*[1], *C. Dai*[1], *O. Akyilmaz*[2], *A. Bezdek*[3], *E. Forootan*[4], *J. Guo*[1], *F. Hossain*[5], *J. Klokocník3*[3], *J. Sebera*[6], *M. Schmidt*[7]
[1]*The Ohio State Uni., School of Earth Sciences, Columbus, USA*
[2]*Istanbul Teknik Üniversitesi, Istanbul Teknik Üniversitesi, Istanbul, Turkey*
[3]*Astronomical Institute, Astronomical Institute, Prague, Czech Republic*
[4]*Universität Bonn, Institut für Geodäsie und Geoinformation, Bonn, Germany*
[5]*Univ. of Washington, Dept. of Civil & Environmental Engineering, D C, USA*
[6]*Astronomical Institute, Astronomical Institute-, Prague, Czech Republic*
[7]*Deutsches Geodätisches Forschungsinstitut, Deutsches Geodätisches Forschungsinstitut, Munich, Germany*

Improved formulations for the Energy Balance Approach has demonstrated that more than couple orders of magnitude improvement in precision could be achieved for the estimation of in situ geopotential differences directly using GRACE twin-satellite K/Ka-Band inter-satellite range-rate tracking data, and that the technique is efficient for global and regional gravity inversions. Our eventual study goal is to preserve both the low- and high-frequency gravity signals, and to enhance spatio-temporal resolutions via regional gravity inversion methodologies. Here we present selected applications associated with our plausible goals towards quantifying terrestrial water storages at a local and fine temporal scale, combining other measurements including satellite altimetry and other data, in an effort to separate surface and ground water signals over large hydrologic basins, including snow hydrologic regions. The purpose of this contribution includes, but not limited to, the development of water resource management tools, and assessment of the feasibility of improvement of GRACE observations at the appropriate temporal-spatial scales to address or study natural disasters such as floods, droughts and other phenomena.

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IUGG-4545

Assessing long-term impact of urbanization on runoff using a remote sensing supported hydrological model

H. Zhang[1], *Y. Chen*[2]
[1]*Sun Yat-sen University,*
Lab of Water Disaster Management and Hydroinformatics, Guangzhou,
China Peoples Republic
[2]*Sun Yat-sen University, Water Resources and Environment, Guangzhou,*
China Peoples Republic

Urbanization causes rapid land use changes in urban area, particularly increasing the impervious area, the impact to urban hydrological process is to cause rapider hydrological response, the results followed is observed higher peak flow and flooding risk. In this paper, this impact is studied in Dounguan City in the Pearl River Delta Area, which observed the fastest urbanization in China in the past decades. The land use/land cover (LULC) change of Dongguan in the rapid urbanization period between 1979 to 2013 is analyzed first by using the historic remote sensing imagery acquired in 1979, 1989, 2000, 2006, and 2013 respectively, the employed processing method is support vector machine (SVM) , and the results show that urbanized area in Dongguan has increased more than 52% from 1979 to 2013. A long-term hydrologic impact assessment model, the L-THIA model is then developed to estimate the direct surface runoff using the CN method from daily rainfall depth, land use, and hydrologic soil group data. The simulated results show that the percentage of the annual surface runoff depth and annual surface runoff coefficient increased 58% and 5.83% respectively.

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IUGG-4604

Fully coupled atmosphere-hydrology modeling: Approaches and case studies for different climate regions

H. Kunstmann[1], *B. Fersch*[1], *S. Wagner*[1], *T. Rummler*[2], *J. Arnault*[2], *A. Senatore*[3], *D. Gochis*[4]
[1]*Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research, Garmisch-Partenkirchen, Germany*
[2]*University of Augsburg, Institute of Geography, Augsburg, Germany*
[3]*University of Calabria, Department of Environmental and Chemical Engineering, Arcavacata di Rende, Italy*
[4]*National Centre for Atmospheric Research, Research Applications Lab, Boulder, USA*

Limitations in the adequate representation of terrestrial hydrologic processes controlling the land-atmosphere coupling are assumed to be a significant factor currently limiting prediction skills of regional atmospheric models. It is particularly the lateral surface and subsurface water fluxes that are neglected in standard regional atmospheric models. Current developments in enhanced lateral hydrological process descriptions in the WRF model system will be presented. Based on WRF and WRF-Hydro, new modules and concepts for integrating the saturated zone by a 2-dim groundwater scheme and coupling approaches to the unsaturated zone will be presented. The fully coupled model system allows to model the complete regional water cycle, from the top of the atmosphere, via the boundary layer, the land surface, the unsaturated zone and the saturated zone till the flow in the river beds. We will show results of fully coupled simulations for the regions of sempiternal humid Southern Bavaria/Germany (rivers Isar and Ammer) and semiarid to subhumid Westafrica (river Sissilli). In the German region we apply the extended WRF-Hydro modeling system in 3km atmospheric grid resolution and 300m subsurface grid resolution for the terrestrial hydrological processes. For streamflow we achieve Nash-Sutcliff efficiencies of 0.86 in uncoupled mode and of 0.49 in fully coupled mode of WRF-Hydro. In the West African Sissilli catchment we apply WRF-Hydro in 2km atmospheric- and 500m subsurface horizontal resolutions and achieve Nash-Sutcliff efficiencies of 0.4. Further validation of energy balance components obtained from EC-stations is shown and differences of the fully coupled model system to corresponding uncoupled and one-way coupled mode results are discussed.

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IUGG-5465

Glacier hazards evolution during deglaciation: What Cordillera Blanca portends about 21st-22nd century Alaska, the Himalaya, and Patagonia

J. Kargel[1]
[1]*University of Arizona, Hydrology & Water Resources, Tucson- Arizona- USA, USA*

Immense glacier lake outburst floods (GLOFs) took place late in the Pleistocene and early Holocene during retreat of ice sheets. For example, during the retreat of the Cordilleran ice sheet, GLOFs from Glacial Lake Missoula at times exceeded 2000 cubic kilometers and had flood discharges in the millions of cubic meters per second. The Laurentide ice sheet's Glacial Lake Agassiz released floods several times larger. By contrast, slightly glacierized modern ranges such as the Brooks Range (Alaska) and Lewis Range (Montana) are not generating GLOFs. Between these scales, in recent decades the Himalaya, Peruvian Andes, Chugach Mountains, and Southern Patagonia Icefield have generated small GLOFs in the tens of millions of cubic meters, with peak discharges of 1,000-30,000 cubic meters per second. May one conclude that risks from GLOFs become inexorably smaller as deglaciation proceeds? No! Whereas the magnitude of GLOFs should generally become smaller as ice sheets, ice caps, and mountain glaciers lose area and thin, their associated hazards and risks do not diminish accordingly. Aside from the "wild card" of human development patterns and vulnerabilities, hazard processes shift in location and type as ice retreats. As climate change and deglaciation proceed, lakes tend to form closer to mountain peaks, and unstable moraines and hanging glaciers are more closely poised to collapse directly into the lakes, which may more readily unleash GLOFs. Cordillera Blanca—source of the world's most deadly known GLOFs—is an example of how deglaciation can increase glacier hazards, while increasing development in harm's way dramatically increases vulnerabilities. A proposed glacial-hazard cycle is a portent for heavily glacierized regions that are tending toward deglaciation.

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IUGG-5607

Sediment provenance and climate changes of lower Yangtze River during the last 130 years, and potential impacts from human

Y. Zheng[1]*, S. Yang*[2]*, C. Deng*[3]
[1]*Insitute of Vertebrate Paleontology and Paleoanthropology, Beijing, China Peoples Republic*
[2]*Tongji Univerysity, Department of Marine Geology, Shanghai, China Peoples Republic*
[3]*Institute of Geology and Geophysics- Chinese Academy of Sciences, Paleomagnetism and Geochronology Lab, Beijing, China Peoples Republic*

Fluvial sediment is one of the best archives for the investigations of high-resolution natural environmental variability and anthropogenic impacts in catchment over the last hundreds or even thousands years when the documentary data is scarce. In this study, magnetic properties of the profile sediments from the lower Changjiang (Yangtze River) were measured for the investigation of sediment sources and climatic changes over the last 130 years. Dominant magnetic minerals in the profile sediments are magnetite, hematite and goethite. Magnetite is relatively enriched in the upper Changjiang sediment, while low magnetic concentrations and fine magnetic grains characterize the mid-lower river sediments. Both sediment grain and magnetic signals clearly indicate the flood events happened in the large Changjiang drainage basin, consistent with the documentary record over the last 130 years. Anthropoganic impacts on the sediment transpotation as well as properties of suspended matters could be also observed from the data. Our study sheds new light on the application of magnetic property for high-resolution environmental study in the large drainage basin where has complicated sedimentary processes. This detailed comparision between physical parameters and documentary data is a potential new way to study ancient climate changes.

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IUGG-5747

Basin management under the global climate change

S. Liu[1]
[1]*Tongji University, Shanghai, China Peoples Republic*

The impact of global climate change on environment and society causes increasingly concern in different countries around the world. The main climate characteristic values, such as precipitation and temperature, have been changed, which leads to the variation of water resources, especially in large basins. Heilongjiang-Amur Basin and Taihu Basin are two large and important basins in China with large area and population. As global climate change and human activities have an obvious impact on hydrology and water resources in two basins, the analysis of climate change are of much significance. In this study,in Heilongjiang-Amur Basin, precipitation and temperature are investigated and their variation are predicted. And in Taihu Basin, precipitation including plum rain and typhoon, are studied and the variation trend of precipitation is predicted. Hence, the impacts of global climate change are assessed. From the result, it shows that globally the average temperature will continue to increase and the precipitation will reduce first and then turn to increase in these two basins.It demonstrates that the water resources have been affected a lot by climate change as well as human activities.Meanwhile, according to basin's individual characters, the suggestions to water resources management in these two basins are given.More scientific, comprehensive and sustained managements should be adopted. Especially, in Heilongjiang-Amur River, which is aboundary river between China and Russia, it is very essential and important to make cooperation with two countries.Consequently, these suggestions can support policy makers and basin authorities in water resources management and natural hazards mitigation.

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IUGG-1832

Simulating the spatiotemporal impacts of large-scale reservoir operation on the 2011 Thai flood inundation through a combined modeling framework

C.M. Mateo[1], N. Hanasaki[2], D. Yamazaki[3], D. Komori[4], M. Kiguchi[1], A. Champathong[5], K. Tanaka[6], T. Sukhapunnaphan[5], T. Oki[1]
[1]The University of Tokyo, Institute of Industrial Sciences, Tokyo, Japan
[2]National Institute for Environmental Studies, Tsukuba- Japan, Tsukuba, Japan
[3]Japan Agency for Marine-Earth Science and Technology, Department of Integrated Climate Change Projection Research, Kanagawa, Japan
[4]Tohoku University, Urban Environment and Environmental Geography, Tohoku, Japan
[5]Royal Irrigation Department, Office of Water Management & Hydrology, Bangkok, Thailand
[6]Kyoto University, Water Resources Research Center- D.P.R.I., Kyoto, Japan

Large-scale reservoir operation critically affects the spatiotemporal distribution of floods. Mitigation of impending floods in human-impacted hydrological systems will greatly benefit from improved modelling of reservoir operation and understanding its impacts to flood dynamics. In this study, global hydrologic and hydrodynamic models were combined to explicitly simulate the impacts of reservoir operation on flood inundation and its propagation. H08, an integrated water resources model with a reservoir operation module, was combined with CaMa-Flood, a river routing model with representation of flood dynamics. The study was applied in Chao Phraya River Basin, Thailand, where a catastrophic flood event with global economic impacts occurred in 2011. A new reservoir operation algorithm was developed to represent the seasonal and inter-annual variability in the actual operation of the two largest reservoirs in the basin, the Bhumibol and Sirikit Reservoirs. The modelling system simulated the 2011 Thai flood well: regulated flows at a major gauging station yielded high daily NSE-coefficient of 92% as compared with observed discharge; spatiotemporal extent of simulated percent flooded area also match well with those of satellite observations. Simulation results show that the operation of reservoirs in 2011 effectively reduced the flood volume by about 8.6 billion m^3 and both the mean flood depth and flood area by 40%. Nonetheless, simulation of simple modifications in reservoir operation resulted to further reduction of 2.4 million m^3 in flood volume and 20% in flood depth and flood area. The modelling framework which combined global

models proved to be relevant in assessing reservoir operation rules for practical and operational local application.

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IUGG-2448

A detailed assessment of hydrological processes acting on anthropogenic surfaces in urban areas.

T. Redfern[1]
[1]*NERC Centre for Ecology & Hydrology, Wallingford, United Kingdom*

Understanding of urban hydrology is typically based on the assumption that roads, roofs and other urban surfaces block the infiltration of rainfall. By exploring in detail the hydrological processes acting upon different types of urban surface, this study challenges the assumption, arguing that anthropogenic surfaces are often pervious to some degree.

A review of empirical data from peer reviewed literature indicates that the hydrological performance of urban surfaces is governed by material properties, condition and connectivity. Roofs typically convert a larger proportion of rainfall into runoff than roads, whilst non-continuous surfaces convert less. Runoff may be directed to surface water drains, the soil or adjacent surfaces increasing antecedent wetness. Infiltration occurs through 'impervious surfaces' via small scale features such as cracks, joins and fractures. Experimental studies indicate that infiltration losses can be considerable even where there is a direct connection to the storm sewer (up to 7 l/min/m of kerbing) and can account for 20% of an urban areas annual rainfall volume.

Changes in condition and the physical properties of surfaces over time can alter their hydrological performance. Runoff generation and infiltration is therefore dynamic in both space and time. Whilst large volumes of rainfall are converted to runoff, this review demonstrates that the current 'impervious surface' model of understanding over simplifies the hydrological behaviour of urban surfaces; potentially leading to an over estimation of runoff and under estimation of recharge in urban areas.

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IUGG-2504

A synoptic-typing bias correction method for considering the impacts of climate change on IDF relationships

J. Li[1]*, F. Johnson*[1]*, J. Evans*[2]*, A. Sharma*[1]
[1]*UNSW Australia, School of Civil and Environmental Engineering, Sydney, Australia*
[2]*UNSW Australia,*
Climate Change Research Centre and ARC Centre of Excellence for Climate System Science, Sydney, Australia

One of the challenging questions for engineering design into the future is how key inputs to hydrological modelling may change. One area where there is significant uncertainty is the impact of climate change on Intensity-Duration-Frequency (IDF) curves.

Regional climate models (RCMs) are important tools in assessing these changes because the fine resolution of the simulations means that the models can represent orographic effects and if the resolution is fine enough they can resolve convective systems. Despite these advances, the precipitation simulations from RCMs tend to have significant biases in them. This presentation focuses on methods that can be used to provide improved estimates of design rainfalls from RCM simulations.

The main feature of our approach is that biases are likely to be different depending on the causative mechanism of the rainfall event. Therefore the bias correction should be applied differently for each event type. The key innovation of our approach is in the combination of the different events, accounting for both the frequency and the bias in the frequencies that result from the RCM. The approach is demonstrated with synthetic data as well as 2 km resolution WRF model simulations over south eastern Australia.

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IUGG-3446

Evaluations of anthropogenic impacts on groundwater temperature

M. Taniguchi[1], . *RIHN project R08-Init members*[2]
[1]*Research Institute for Humanity and Nature, Kyoto, Japan*
[2]*Research Institute for Humanity and Nature, Research Division, Kyoto, Japan*

Groundwater temperature is affected by climate change and anthropogenic impacts including land cover changes due to urbanization. Evaluations of subsurface warming due to urbanization in Asian mega cities show that the stage of city development during the urbanization is remained in the terrestrial hydrosphere, groundwater, as subsurface warming. In this study, we assessed several case studies with different type of climate and anthropogenic impacts on groundwater temperature in Japan. The cases include the impacts of changes in groundwater recharge rate, the different of heat island effects among the cities and within the cities, transient impacts of land cover changes and others.

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IUGG-4292

Recent climate change and its possible impacts on water resources in the Northwest China

Y. Chen[1]
[1]*Xinjiang Institute of Ecology and Geography- Chinese Academy of Sciences, State Key Laboratory of Desert and Oasis Ecology, Urumqi, China Peoples Republic*

The arid region of Northwest China, with a unique landscape characterized by mountain-oasis-desert ecosystems, responds sensitively to global change. This report discusses various aspects of climate change and its impacts on water resources, which includes: 1) Recent observational air temperature analyses showed that the temperature experienced a 'sharply' increase in 1997, since then has been in a high volatility; there was a significant turning point in the change of pan evaporation in 1993, in which a decline reversed to a significant upward trend. 2) Changes in snowfall and snowmelt regimes significantly impact the water resources. The ratio of snowfall to precipitation (S/P) in the Northwest China experienced a downward trend under the precipitation increase as well as temperature increases, precipitation shift from snow towards rain. 3) The characteristics of water formation, distribution and the water supply in the northwest arid region are very distinct. Under the impact of global warming, the vulnerability of water systems and uncertainty of water resources are increasing. 4) The high volatility of temperature and increase of pan evaporation may bring some adverse ecological effects. Recent research results show that the vegetation coverage and NDVI in the arid region of Northwest China exhibit an increased trend before 2000; however, the trends reversed to decrease since 2000. Moreover, even shrub encroachment in grasslands.

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IUGG-4579

Improving models and methods for assessing climate change-forced impacts to water resources in the United States

J.R. Arnold[1]*, M. Clark*[2]*, E. Gutmann*[2]*, A. Wood*[2]*, A. Newman*[2]*, P. Mendoza*[2]*,*
N. Mizukami[2]*, L. Brekke*[3]
[1]*US Army Corps of Engineers, Climate and Global Change Programs, Seattle, USA*
[2]*National Center for Atmospheric Research, Research Applications Laboratory, Boulder- CO, USA*
[3]*US Department of Interior - Bureau of Reclamation,*
Research and Development Office, Denver- CO, USA

Assessments of projected climate-change impacts to water resources typically chain together multiple numerical models to evaluate the projected effects from the various emissions scenarios and different climate models used to drive the hydrologic models configured for the domain. However, these assessments most often include only one or a very few different climate and hydrologic models, and inter-model differences are often not constrained to define uncertainties in the simulations consistently. Moreover, when they appear in assessments, uncertainty characterizations are mostly for the climatology projections made using many climate models and emission scenarios; less work has been done to understand the regional-scale climate and hydrologic uncertainties and their important interactions for local-to-regional scale water resources decision-making under changed future climates.

This talk will describe both the approach and several new data and model products from the on-going collaboration between the two chief United States federal water management agencies, US Army Corps of Engineers and the Bureau of Reclamation, and the Research Applications Laboratory of the National Center for Atmospheric Research. The collaboration has two high-level objectives: 1- systematically uncovering and understanding some of the hitherto unrevealed process-level uncertainties and errors produced when using chains of these model components, and 2- designing and testing potential improvements in the models and methods commonly chained together for use in water resource assessments. This work is especially significant now because United States federal agencies are

beginning seriously to consider large-scale decisions about climate-forced changes to their authorized programs and operations.

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JH03p-334

Effect of climate change on the contribution of groundwater to the root zone for winter wheat in Huaibei Plain,China

Y. Zhu[1], *L. Ren*[1], *H. Lü*[1], *Y. Chen*[2], *Z. Wang*[3]
[1]*State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing, China Peoples Republic*
[2]*State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography- Chinese Academy of Sciences, Urumqi, China Peoples Republic*
[3]*Water Resources Research Institute, Anhui Province and Huai River Conservancy, Bengbu, China Peoples Republic*

On the Huaibei Plain of Anhui Province, China, winter wheat is the most prominent crop. The study area is the traditional zone between warm temperate zone and suptropical zone, with shallow water table. The original climate change is complex, in addition, global warming make the climate change more complex. The winter wheaat growth period is from October to May during the non-flood season, the winter wheat growth always depends on part of irrigation water. Under such complex climate change, the rainfall varies during the growing seasons, and water table elevations also vary. Therefore, water tables supply variable contributions of groundwater to the root-zone of winter wheat, which impact plant growth and yield. In Huaibei plain, the environmental pollusion is very serious because of agricultural use of chemical fertilizer, pestcides, herbicide and etc. In order to protect river water and groundwater from pollusion, the irrigation water should be estimated accurately. Therefore, estimating the contributions of groundwater to the root-zone for winter wheat in climate change is important for determining irrigation volumes and times and construction of water conservancy works for winter wheat growth management decision-making. Based on field observations and local weather data of 2004-2005 and 2005-2006, the numerical model HYDRUS-1D was validated and calibrated by comparing simulated and measured root-zone soil water contents. The validated model was used to estimate the daily CGWR in 2010-2030 under the scenarios described by HadCM3, with winter wheat growh in a optimum state indicated by growth height and LAI.

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JH03p-335

Temporal characteristics of various land mass changes and their comparisons to land water storage changes with a land-surface hydrological model

T. Nakaegawa[1], *Y. Fukuda*[2], *K. Yamamoto*[3]
[1]*Meteorological Research Institute, Climate Research Department, Tsukuba, Japan*
[2]*Kyoto University, Graduate School of Science, Kyoto, Japan*
[3]*Japan Aerospace Exploration Agency,*
Institute of Space and Astronautical Science, Sagamihara, Japan

We investigates the land mass changes on the Earth's surface based on the numerical model simulations and various statistics. First, we estimated the principal components of terrestrial water storage (TWS) and their contribution at different time-scales on a global-scale, using a land-surface hydrological model (LSHM), and determine the climatological mean mass changes. The TWS is composed of four water storages: soil wetness, snow water equivalence, river channel water storage, and shallow groundwater storage estimated with LSHM. Lake water storage is also investigated from satellite altimetry and some lake statistics. We identify the largest annual amplitude among the four components and present the amplitude ratio of the largest one to TWS. At the monthly time-scale, soil wetness covers most areas of the globe as the largest annual amplitude. At the interannual time-scale, snow water equivalence disappears in high latitudinal regions and switches with soil wetness, although the unique geographical distributions of the four components as the largest annual amplitude resemble that of the monthly time-scale. In addition, we estimated both natural and anthropogenic land mass changes from various statistics. Natural mass changes considered in this study are mineral dust and sediment transports, while anthropogenic mass changes are crude oil, coal, and natural gas, iron, and bauxite mining. We demonstrated that both the land mass changes is smaller than the interannual variability of TWS. Based on the current observational accuracy of a satellite gravity mission, the land mass decreases due to mineral dust and sediment transports and mining are detectable in specific regions with large signals within 20 years under ideal conditions.

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JH03p-336

Towards the assimilation of GRACE data into a high-resolution hydrological model over Europe

A. Springer[1,2]*, J. Kusche*[1]*, L. Longuevergne*[3]*, J. Keune*[2,4,5]*, S. Kollet*[2,6]*, W. Kurtz*[2,6]
[1]*Institute of Geodesy and Geoinformation IGG, Bonn University, Bonn, Germany*
[2]*Centre for High-Performance Scientific Computing in Terrestrial Systems, Geoverbund ABC/J, Juelich, Germany*
[3]*CNRS- UMR 6118, Geosciences Rennes, Rennes, France*
[4]*Hans-Ertel-Centre for Weather Research, Climate Monitoring Branch, Bonn, Germany*
[5]*Meteorological Institute, Bonn University, Bonn, Germany*
[6]*Institute for Bio- and Geosciences- Agrosphere IBG-3, Research Centre Juelich, Juelich, Germany*

Hydrological models are indispensable for water resources management, disaster prevention, and the assessment of long-term climate variability. However, models are built on a simplified representation of reality, and therefore are subject to large uncertainties leading to limited predicting skills. One approach for reducing these errors is the assimilation of observational data. Since 2002, the Gravity Recovery and Climate Experiment (GRACE) mission enables the direct observation of total water storage (TWS) variations from space, and thus, is a valuable tool for improving modeled water storage of soils, groundwater, and surface water bodies.

In this study, the Community Land Model CLM3.5 over the European CORDEX domain is used in conjunction with the Parallel Data Assimilation Framework (PDAF) in order to investigate the benefit from the assimilation of GRACE TWS observations on the European scale. CLM3.5 has a spatial resolution of 0.11° (12.5km) and is one component of the Terrestrial Systems Modeling Platform, TerrSysMP, which also includes coupling with the groundwater model ParFlow and the numerical weather prediction model COSMO.

Here, the representation of the initial ensemble, the uncertainty of the forcing data, and the representation of the GRACE error covariance matrix are discussed. Special emphasis is also placed on the challenges arising from the different resolution of model data and GRACE observations. Finally, water storage simulated by CLM3.5 is validated with real GRACE data.

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JH03p-337

Predicting the variation of water storage by river discharge with aid of climate indices

J. Zhang[1], *N. Sneeuw*[1]
[1]*Institute of Geodesy, University of Stuttgart, Stuttgart, Germany*

The discharge over ungauged basins can be predicted to a large extent by observations from gauged basins over the world by least-squares prediction. Climate change has a strong impact on hydrologic variables, globally and regionally, on interannual and decadal time scales. To investigate the impact of climate change on the variation of water storage change, we introduce different types of climate indices (e.g., ENSO, AMO, PDO, etc.) in this research. Using least-squares prediction and a Kalman filter, the water storage are statistically predicted by a set of climate indices, and compared with the prediction from discharge. To better identify the spatial influence, both regional and global examples are given. The teleconnections among different catchments are also investigated at different time periods. From the contribution of proxy indices to different catchments, the impact of climate change in different regions (e.g., North America, South America, Western Europe, East Asia, etc.) is investigated and discussed. We then validate the predictions against observations from GRACE and from gauged catchments.

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JH03p-338

Impacts of climatic and anthropogenic changes on runoff of the Ying River catchment, China

G. Wang[1], *J. Zhang*[1]
[1]*Nanjing Hydraulic Research Institute, State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Nanjing, China Peoples Republic*

The Ying River catchment located in the upper reaches of the Huai River basin of China. Over the past decades, the recorded runoff at the Zhoukou station on the Ying River presented significant declining trend with linear decreasing rate of 1.4mm/a. The impacts of climatic and anthropogenic changes on runoff were investigated using hydrological simulation approach. Mann-Kendall test was used to detect the natural and impacted epochs through identifying the abrupt change of runoff series. A water balance model was employed to naturalize runoff in the impacted epoch. Results show that runoff series exhibited an abrupt change in 1965. The water balance model performs well for discharge simulation of natural epoch (1951—1965) with Nash-Sutcliffe coefficients for calibration and verification periods exceeding 70% and the relative errors being less than 5%. Runoff depth over the 1966~2010 reduced by 77.8mm as comparing to that in previous period. Anthropogenic Changes and climatic change contribute 79.1% and 20.9% of the total reduction respectively. Human activities play a principle role of change in water resources of the Ying River catchment.

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JH03p-339

Analysis on runoff and sediment trend and influence factors in Jinghe River Basin

Q. Huang[1], *J. Zhao*[1]
[1]*State Key Laboratory cultivation Base of Eco-Hydraulic Engineering in Arid Area, Xi'an University of Technology, Xi'an, China Peoples Republic*

Jinghe River is a tributary of the Wei River Basin. In recent years, the problems of water resources in Jinghe River Basin has caused ecological environment more serious. The monitored runoff and sediment data from 1060 to 2010, collected from Zhangjiashan station, were used to analyze the time trend of runoff and sediment by the Mann-Kendall and R/S method, and the effect of climate change and human activities on runoff and sediment in Jinghe River Basin was also calculated. It was found that the runoff and sediment have decreased significantly, while in the beginning year of 2000 the runoff presented a rising trend. Hurst index was found to be 0.6, showing a weak variation, future runoff and sediment variation being insignificant. Affected by human activities, it showed that the abrupt changes on runoff and sediment both happened around 1996. The impact of climate change and human activities on runoff and sediment were assessed, and the result showed that the human activities was the dominating factor that caused the runoff and sediment reduction. The main reason is the soil and water conservation, which caused the reduction of runoff while reducing the erosion. The second reason is the increase in industrial and agricultural water consumption which makes the direct result of the reduction in runoff.

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JH03p-340

Impacts of intensive irrigation and armed conflict on a semi-arid Mediterranean catchment: The Orontes River basin (Lebanon and Syria)

M. Saadé-Sbeih[1]*, A. Haj Asaad*[2]*, R. Gonzalez*[3]*, R. Jaubert*[1]*, F. Zwahlen*[4]
[1]*Graduate Institute of International and Development Studies, Development studies, Geneva, Switzerland*
[2]*University of Lausanne, Faculty of Geosciences and Environment, Lausanne, Switzerland*
[3]*UNITAR, UNOSAT, Geneva, Switzerland*
[4]*University of Neuchatel, Centre for Hydrogeology and Geothermics, Neuchâtel, Switzerland*

The Orontes River basin – shared between Lebanon, Syria and Turkey – is representative of the global changes in water use that impacted hydrosystems during the last century in the southern and eastern parts of the Mediterranean basin. Since the 1950s large-scale surface water development has been a major piece of the agricultural policy. From the 1980s on and especially in the 1990s, the area witnessed the development of individual pumping systems and a huge increase in groundwater extraction, mostly for agricultural purposes. Intensive surface and ground water developments led to a sharp decrease of the Orontes river discharge in its middle course; the drying up of several springs and groundwater overexploitation in several areas. After 2011, the study area became a key region in the Syrian conflict. The sudden decrease in water consumption in Syria lead to a rapid and unplanned increase in water flow, causing flood management problems in the downstream Turkish part of the basin. The purpose of this contribution is to assess the impact of the successive intensive surface and groundwater developments and of the ongoing conflict in Syria on the Orontes River hydrosystem dynamics (Lebanon and Syria). The approach adopted calculates historical water balances for representative periods of anthropic influences: the 1930s; 1970s; 2000s and post-2011 (respectively before and after the extension of irrigation from surface water, after the development of irrigation from groundwater and during the Syrian conflict). It aims at providing bases for the planning of emergency relief as well as post-conflict interventions and policies.

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JH03p-341

Assessing vegetation response to meteorological drought in the Laohahe catchment, North China

J. Xu[1]
[1]*Nanjing University, Nanjing, China Peoples Republic*

Drought as a natural disaster is a world's urgent problem threating the human society and economic development. Based on the Laohahe River basin information and data, the correlation analysis between the AVHRR-NDVI index and SPI with different time scales was implemented and a quantitative relationship was established to analyze the response of different vegetation type NDVI to drought. The results showed that the impact of drought on vegetation was less in the beginning and end of the vegetation growing stage. The impact of drought on vegetation was greater in growing season and June and July is the moisture sensitive period in the Laohahe river watershed instead of August which is the most lush vegetation growth stage. The impact of drought on vegetation is different with time scale. The impact of drought on shrub and grassland was greater than that on farmland and woodland. The dummy variable regression model can reasonably consider seasonal effects.

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JH03p-342

A hybrid approach for extending hydrologic series

D. Wang[1], D. Hao[1], V. Singh[2], X. Shang[1], D. Liu[1], Y. Wang[1], J. Wu[1], L. Wang[3]
[1]Nanjing University,
Department of Hydrosciences- School of Earth Sciences and Engineering, Nanjing, China Peoples Republic
[2]Texas A & M University,
Department of Biological and Agricultural Engineering- Zachry Department of Civil Engineering, College Station, USA
[3]Nanjing University, School of Geographic and Oceanographic sciences, Nanjing, China Peoples Republic

For scientific and sustainable management of water resources, hydrologic series often need to be extended. This paper proposes a hybrid approach for series extension. Wavelet analysis has time-frequency localization features, known as 'mathematics microscope,' that can decompose and reconstruct the hydrologic and meteorologic series by wavelet transform. The cloud model is a mathematical representation of fuzziness and randomness, and has strong robustness for uncertain data. The hybrid approach first employs the wavelet transform to decompose the measured non-stationary series and then uses the cloud model to develop an extension model for each decomposition layer series. The final extension is obtained by summing the results of extension of each layer. Two kinds of hydrologic data sets from 4 (2 pairs) representative stations are used to illustrate this hybrid approach. The approach is also compared with the conventional Correlation Extension (CE) method and single CM (Cloud Model) method. Results show that the hybrid approach is effective, feasible and accurate, and is found to be better than the conventional CE method and single CM method. The theory employed and the approach developed here can be applied to other areas as well.

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JH03p-343

Hydrological and meteorological stochastic simulation based on minimum relative entropy

D. Wang[1], *D. Liu*[1], *J. Wu*[2]
[1]*Nanjing University,*
Department of Hydrosciences- School of Earth Sciences and Engineering, Nanjing, China Peoples Republic
[2]*Nanjing University,*
Department of Hydrosciences- School of Earth Sciences and Engineering, Nanjing, China Peoples Republic

Past few decades have witnessed change in hydrological and meteorological processes, which is evidently acknowledged as the response of increasing human activities. The main contribution of this research is to propose a stochastic simulating approach based on the minimum relative entropy (MRE), a non-parametric statistical inference framework, especially considering variation in hydrological and meteorological systems. The Mann-Kendall test is firstly introduced to analyze the significance of trends, before probable recognition of abrupt points of changes from the perspective of the Kendall correlations. After dividing subsections, if necessary, in accordance with abrupt points, the MRE is employed to obtain different probabilistic models, given the changing information from each subsection. This technique has been applied to detect probabilistic patterns of various hydrological and meteorological measured data from representative basins in China, thus to simulate their statistical properties (mean, standard deviation, skewness, kurtosis) separately. Results indicate that the proposed MRE-based approach not only corresponds with overall statistical properties of hydrological and meteorological processes, but also simulates their changing patterns well.

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JH03p-344

Study of subsurface hydrological impacts of agricultural irrigation and precipitation variabilityin Chikugo-Saga plain, Japan based on groundwater flow modelling

Y. Cai[1], *S. Liu*[1]
[1]*Tongji University, Department of Hydraulic Engineering, Shanghai, China Peoples Republic*

Chikugo-Saga plain, a well-known rice-growing domain in Japan, has been suffering land subsidence since 1970s due to excessive groundwater withdrawals . In view of a close relation between groundwater level and ground settlement, a numerical model was established to simulate groundwater flow and consequently to figure out groundwater head variation, which is helpful for effective control of land subsidence. At first, a conceptual model was built based on geological formations of the plain and their hydrogeological characteristics. Then, ModFlow was employed to establish a numerical model and various input data such as elevation, withdrawal & recharge, initial groundwater head and model parameters were prepared by using GIS. Recorded pumping data are incomplete in the plain and as a result, groundwater withdrawals were estimated at monthly time and 1-km space scales with combination of meteorological data, agriculture survey and administrative statistics. Moreover, groundwater recharge was assessed at 1-month & 1-km scales based on surface water balance and geological formation distribution. Finally, daily-time-series of groundwater level at given observation wells were used to calibrate the model. It is shown that the proposed model by using GIS and ModFlow provides a quantitative method for understanding the long-term variation of groundwater level in the plain; the simulated groundwater head basically corresponding to the observed takes on the season-dependent fluctuation due to seasonally varying groundwater withdrawals for agricultural irrigation; the model can represent the behavior of the aquifer system in response to meteorologic disturbance, especially reproduce the significant depression of groundwater level in the drought year of 1994.

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JH03p-345

Influence of clime change on sediment transportation in the Yangtze river estuary

S. Lou[1], *C. Han*[1], *G. Zhong*[1]
[1]*Tongji University, Department of Hydraulic Engineering, Shanghai, China Peoples Republic*

Sediment transportation is an complicated process and it has great impacts on riverbed characteristics, morphology, and ecosystem. In the Yangtze River Estuary, sediment transportation is under the combined effects of runoff, tide, and wave. In the mean time, the mechanism of sediment transportation has been changed as the recent globe clime change. The typhoon, storm surge and other clime extremes could affect the re-suspension and transportation of sediment, especially for fine sand, which should be paid more attention. Therefore, in this paper, sediment transportation was studied in the Yangtze River Estuary through numerical simulation. Several hydrological conditions were combined considering the clime change. And the sediment distribution and transportation were analyzed under different hydrological conditions. Based on the results, climate changes impacts on the sediment transportation in the Yangtze River Estuary were assessed. It could reveal the spatial and temporal distribution of sediment, and provide technological information for the Yangtze Estuary Deepwater Channel Regulation Project.

Joint Inter-Association Symposium

JH01a - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0022

The extreme 2014 flood in South-Western Amazon basin

J.C. Espinoza[1], J. Marengo[2], J. Ronchail[3], J. Molina[4], L. Noriega[5], J.L. Guyot[6]
[1]Instituto Geofisico del Peru, Lima, Peru
[2]CEMADEM, CEMADEM, Sao Paulo, Brazil
[3]Univ. Paris Diderot- Sorbonne Paris Cite,
UMR Locean Sorbonne Universites- UPMC-, CNRS, IRD, MNHN., LOCEAN, Paris, France
[4]Universidad Mayor de San Andres, Instituto de Hidrologia e Hidraulica, La Paz, Bolivia- Plurinational State of
[5]Servicio Nacional de Meteorologia e Hidrologia, SENAMHI, La Paz, Bolivia- Plurinational State of
[6]Institute de Recherche Pour le Developpement, GET, Lima, Peru

Unprecedented wet conditions are reported in the 2014 summer in Southwestern Amazon, with rainfall about 100% above normal. Discharge in the Madeira River (the main southern Amazon tributary) has been 74% higher than normal (58000 m3/s) at Porto Velho and 380% (25000 m3/s) at Rurrenabaque, at the exit of the Andes in summer, while levels of the Rio Negro at Manaus were 29.47 mm in June 2014, corresponding to the fifth highest record during the 113 years record of the Rio Negro. While previous floods in Amazonia have been related to La Niña and/or warmer than normal tropical South Atlantic, the 2014 rainfall and flood anomalies are characterized by warm condition in the western Pacific-Indian Ocean, via atmospheric large-scale teleconnections, and with an exceptionally warm Subtropical South Atlantic. Our results suggest that the tropical and subtropical South Atlantic SST gradient is a main driver for moisture transport from the Atlantic toward south-western Amazon, and this became exceptionally intense during summer of 2014.

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JH01a - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0089

Modern and historical floods in Prague: comparison of causes and characteristics of 2002 and 2013 floods to historical extreme events

J. Danhelka[1], *L. Elleder*[1]
[1]*Czech Hydrometeorological Institute, Hydrology, Prague, Czech Republic*

Two significant flood events have occurred at Vltava River in Prague in recent years. August 2002 flood reached the 500 years return period while June 2013 flood return period has been evaluated to be 50 years. The main aim of this work is to describe different types of floods and flood producing mechanisms affecting Prague with some implication to the flood protection of Prague. Four major flood types have been identified from the historical evidence: i) large scale regional summer flood, ii) large scale flash flood, iii) spring snow melting flood, iv) spring snow melting flood with massive ice breaks. In addition small scale flash floods outbreaks are mentioned.

In this contribution we further present the comparison of 2002 flood with 1432 floods representing a large scale summer floods type. This analysis is based on historical chronical description of flood and analysis of change in Prague urban area. Floods in 2013, 1872 and 1714 are described in order to illustrate a large scale flash flood type with emphasis on the real time flood management implications. We also shortly introduce remaining flood types using examples of 1784, 1845 and 1862 floods.

At the end we discuss a known long term changes in flood types occurrence connected with climate variability and anthropogenic modifications of the basin to estimate their current relevance. In conclusion although the recent flood experience contributed significantly to flood protection enhancement some specific flood types (spring melting, large scale flash floods) are not well understood and addressed.

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JH01a - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0105

Trends in European droughts

L. Gudmundsson[1], *S.I. Seneviratne*[1]
[1]*ETH Zürich, Institute for Atmospheric and Climate Science, Zürich, Switzerland*

Recent climate change projections suggest pronounced changes in European drought frequency. In the north, increased precipitation volumes are likely to reduce drought occurrence, whereas an increase in drought frequency is expected for southern Europe. To assess whether this pattern of changes in drought frequency can already be identified for the recent past, we analyse trends in recently developed pan-European drought climatologies, comprising both the Standardized Precipitation Index (SPI) and the Standardized Precipitation and Evapotranspiration Index (SPEI). Both indices are derived on multiple time scales, ranging from 1 to 36 months, which allows the assessment of trends in both short term and multi-year droughts. Trends are quantified using the Theil-Sen trend estimator combined with an extension of the Mann-Kendal test that accounts for serial correlation. The trend analysis reveals that there has been a tendency for decreased drought frequency in northern Europe in the past decades, whereas droughts have likely become more frequent in the south.

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IUGG-0118

Trends of glacier retreats induced by climate change and Its impacts on water resource in Mongolia

A. Orkhonselenge[1]
[1]*National University of Mongolia, Department of Geography, Ulaanbaatar, Mongolia*

This study presents the significance of the temperature rising induced glacier retreats and its impacts on surface water in Mongolia. Today, the only three mountain ranges, namely Altai, Khangai and Khuvsgul, in Mongolia have been still remained with the glaciers. For instance, although numerous studies provide evidence for restricted Pleistocene glaciations in Altai Mountains, others suggest that an extensive ice sheet once covered. Preliminary record from the reconstruction of the glacial landforms indicates that the Altai Mountains experienced mainly alpine glaciations, with some ice caps and ice fields located around the higher mountain areas. By tracing the outer limits of present-day glaciers in Munkh Saridag Mountains, we estimate past glacier coverage of 51.6 ha (57.3 % of the total glaciated area) has melted due to temperature rising of 2.16^{0}? between 1970 and 2007. It shows its present glacier will disappear by 2040 if the temperature rising continues. It implies the continuous glacier retreating or melting of the ice masses in the mountains lead to a relatively rapid rise in level of surface waters and change in water balance. For an understanding and predicting of how the glacier advanced in the past periods of global cooling, of how the current global warming forces the glacier retreats and/or melting to surface water and of how it continues in the future, it is needed more detail temporal information from the age of past ice expansions/advances in Mongolia.

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IUGG-0147

Hidden behind Magdalena: flood extremes in 1342 and 1343 in Europe

A. Kiss[1]
[1]*Vienna Universitx of Technology,*
Institute of Hydraulic Engineering and Water Resources Management, Vienna, Austria

The most famous 'Magdalena' flood in July 1342 is known as the millennial flood event in large parts of Central Europe. This particular flood, caused by excessive rainfall, attracted great attention: causes and consequences (e.g. atmospheric blocking as a cause, mass soil erosion as a consequence, short-term impacts on society) have been discussed in a number of studies. Due to the overwhelming importance of 'Magdalena', however, the other extraordinary floods of 1342 and 1343 and their consequences received less attention.

Based on a systematic collection, critical evaluation and analysis of contemporary evidence covering the presently available documentary (and epigraphic) evidence in Europe, we provide a concise overview of the events (with detectable causes) and their social-environmental consequences, with special emphasis on evaluating the magnitude of extremes and discussing short-term and multiannual social consequences of the series of extraordinary events, occurred during these two exceptional years. Results, presented on series of maps - including discussion of causes and consequences - show that during these extraordinary wet years, in 1342 and 1343, at least three major flood waves affected Central Europe. Moreover, beyond the unusually strong sea-storm activity along the Atlantic coast and in the Mediterranean, great or devastating river floods were also recorded in the Carpathian Basin, the Balkan Peninsula, North-Italy and France.

Apart from the direct social/environmental consequences (e.g. food shortage, famine with moderate disease), long-term social perception such as the local and regional memory of the great floods, and long-term problems (e.g. transportation, water-cover, health issues) are also discussed.

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IUGG-0154

Comparative assessment of climate extreme variability and human activities on regional hydrological droughts in the Weihe River basin, North China

H. Shen[1], *L. Ren*[2], *F. Yuan*[2], *X. Yang*[2]
[1]*Hohai University, State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering- College of Hydrology and Water Resources, Nanjing, China Peoples Republic*
[2]*Hohai University, State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Nanjing, China Peoples Republic*

Drought is a comprehensive phenomenon not only resulting from precipitation deficits and climatic factors, but also being related to terrestrial hydrological conditions and human activities. This paper investigates the relationships among regional hydrological droughts, climate extremes and human activities. Based on 20 meteorological stations, 63 rain gauge stations and two hydrological stations in the Weihe River basin, North China, a typical drought-prone area, an analysis was performed to compare the droughts identified by the standardized runoff index (SRI) and eight extreme climate indices that are derived from daily temperature and precipitation data during 1961-2012. First, trend tests were employed to analyze the change points in precipitation and discharge series. Accordingly, baseline and variation periods were divided. Subsequently, the variable infiltration capacity (VIC) macroscale distributed hydrological model was applied to the Weihe River basin for model calibration and validation at a 0.25-degree resolution in the baseline period. Furthermore, the effects of climate change and human impacts on runoff were separated by reproducing the natural discharge in variation period from the VIC model with calibrated parameters. Finally, SRIs, extreme indices were reconstructed to quantatively assess the relationships among hydrological droughts, climate extremes and human activity impacts. The results indicate that human activity impacts are a remarkable source of runoff reduction and represent a in-phase pattern among SRI-based drought severity and duration with the warm nights and warm days but an out-phase with cold nights and cold days. It also shows that the SRI-based floods and droughts characteristics are in good correlation with extreme precipitation.

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JH01b - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0046

Precipitation delivery trajectories associated with extreme river flow for the Waitaki River, New Zealand

D. Kingston[1]
[1]*University of Otago, Department of Geography, Dunedin, New Zealand*

Analysis of large-scale climate conditions associated with extreme river flow is an important first step in the development of predictive relationships for such events. The potential of this approach is demonstrated here for one of the most important rivers in New Zealand, the Waitaki River. Previous research has shown that a series of circulation indices that describe the meridional and zonal components of atmospheric circulation over New Zealand perform very well as descriptors of the large-scale climate conditions associated with variation in lake inflow. However, there remains the possibility that such monthly-scale relationships may mask atmospheric variation associated with extremes of discharge, thus limiting their usefulness as the basis for understanding the causes (and so predictability) of such events. Here, precipitation delivery mechanisms for specific extreme flow events are investigated using back-trajectory analysis. The situation of these trajectories within the circulation anomalies identified previously enables substantial further understanding of the cascade of processes linking atmospheric to surface hydrological variation. Results show trajectories associated with high Waitaki river flow follow a small number of different pathways, but all occur under a similar pattern of monthly pressure anomalies. As such, the results indicate that different precipitation generation mechanisms are captured by a single monthly climate anomaly pattern, pointing the direction for future process-informed research on sources of predictability for Waitaki river flow.

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JH01b - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0051

An assessment of danger during spring floods and ice jams in the north of European Russi

N. Frolova[1], *S. Agafonova*[1], *I. Krylenko*[1], *A. Zavadski*[1]
[1]*Lomonosov Moscow State University, Geography, Moscow, Russia*

Heavy ice jams during spring floods are usual on the rivers in the north of the European part of Russia. For example, the probability of a disastrous flood followed by the inundation of settlements in the middle course of the Northern Dvina river is about 35%. Research suggests that climatic changes of the last decades have led to significant changes of water and ice regimes of the rivers. Continuous freezing periods followed by sludge ice jams and late freezing at high water levels are occurring with increasing frequency. Winter break-ups have become more frequent. The last catastrophic flood in the area of study took place in the spring of 2013.

An assessment of the probability of floods and formation of ice jams, calculations of duration and depth of flooding at various water levels, with an assessment of the corresponding economic losses in the north of Russia are considered in the current research. The modeling of the formation of maximum water levels and flooding in the period of a high water and formation of ice jams was carried out using a Russian program complex called “Flood” on the basis of numerical solution of the two-dimensional Saint-Venant equations. The reach of the channel and valley of the Northern Dvina river with a total length of about 90 km is considered as the case study for the development of the hydrodynamic model. Basic data for calibration and verification of the model were: field works results (measurements of depth and water discharge, morphometric characteristics of river valleys), monitoring observations in the period from 1966 to 2012, and satellite data for high and low water periods. The results of the calculations were used in the development of recommendations for flood protection of the territory of research.

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IUGG-0106

The effect on river discharge estimation by considering an interaction between land surface process and river routing process

K. Yorozu[1], *Y. Tachikawa*[1]
[1]*Kyoto University, Civil and Earth Resources Engineering, Kyoto, Japan*

There are so many assessment researches about climate change impact on hydrologic cycle. However, it is often focusing on the specific hydrologic process without considering an interaction among hydrologic processes. In this study, a distributed hydrologic model considering interaction between flow routing process and land surface process was developed and its effect on river discharge estimation was investigated. This model can consider flow routing, irrigation withdrawal from river at paddy field, crop growth depending on water and energy status, and evapotranspiration based on the meteorological, soil water and vegetation status. To exam the effect of considering hydrologic interaction in a numerical model on river discharge estimation, our model was applied to Chao Phraya river basin using near surface meteorological data calculated by GCM with TL959 spatial resolution as forcing data. And also, flow routing model, which is a part of our model, was carried out independently using surface and subsurface runoff by same GCM. As a result, annual maximum daily discharge by our model was 24% larger than that by flow routing model. It is assumed that surface runoff by our model was larger than that by flow routing model because soil water content maintained high level by irrigation withdrawal. As for drought discharge, which is defined as 355th largest daily discharge, our model shows 2.7 times discharge as large as flow routing model does. It seems that subsurface runoff by our model was larger than that by flow routing model. The result of this study suggested that considering hydrologic interaction in a numerical model could have effect on both flood and drought estimation.

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IUGG-0114

Diagnosing possible anthropogenic contributions to heavy Colorado rainfall in September 2013

M. Wehner[1]*, P. Pall*[2]*, D. Stone*[2]*, W. Collins*[3]
[1]*Lawrrence Berkeley National Laboratory, Berkeley, USA*
[2]*Lawrence Berkeley National Laboratory, Computational Research Division, Berkeley, USA*
[3]*Lawrence Berkeley National Laboratory, Earth Science Division, Berkeley, USA*

Unusually heavy rainfall occurred over the Colorado Front Range during early September 2013, with record or near-record totals recorded in several locations. It was associated with a stationary large-scale weather pattern that drove a strong plume of deep moisture inland from the Gulf of Mexico against the Front Range foothills. The resulting floods across the South Platte River basin impacted several thousands of people and many homes, roads, and businesses. To diagnose possible anthropogenic contributions to the odds of such heavy rainfall, we adapt an existing event attribution paradigm of modeling a 'world that was' for September 2013 and comparing it to a modeled 'world that might have been' for that same time but for the absence of historical anthropogenic drivers of climate. We performed 'event that was' simulations with the regional Weather Research and Forecasting (WRF) model at 12km resolution over North America, driven by NCEP2 reanalysis. We then resimulate, having adjusted the re-analysis to 'event that might have been conditions' by modifying atmospheric greenhouse gas and other pollutant concentrations, temperature, humidity, and winds, as well as sea ice coverage, and sea-surface temperatures – all according to estimates from global climate model simulations. Our findings are highly conditional on the driving reanalysis and adjustments, but the setup allows us to elucidate possible mechanisms responsible for heavy Colorado rainfall in September 2013. Our model results suggests that, given an insignificant change in the pattern of large-scale driving weather, there is an increase in atmospheric water vapor under anthropogenic climate warming leading to a substantial increase in the probability of heavy rainfall occurring over the South Platte River basin.

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JH01b - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0115

Spatiotemporal characteristics of extreme precipitation and temperature:A case study in Yunnan Province, China

Z.X. Xu[1], *X.J. Yang*[1], *D.P. Zuo*[1], *Q. Chu*[1], *L.F. Liu*[1]
[1]*Beijing Normal University, College of Water Sciences, Beijing, China Peoples Republic*

Droughts are usually triggered by long-term deficit of precipitation and extreme high temperature, which has resulted in huge losses of economics in southwestern China since 2008, especially in Yunnan Province. Unfortunately, few investigations were made on the extreme precipitation and temperature in Yunnan Province. In this study, spatiotemporal characteristics of extreme precipitation and temperature in Yunnan Province were analyzed by using observed daily data at 28 meteorological stations from 1959-2013. Nine extreme precipitation indices and six extreme temperature indices were used, and the tendency of those indices was investigated by using Mann-Kendall trend test. In order to distinguish the spatial characteristics, the study area was divided into 5 regions according to features of climate and topography, then the characteristics of each region was compared each other. The results indicate that changes of extreme temperature were more sensitive and significant than those of precipitation. The contribution of extreme precipitation to total precipitation showed a significant upward tendency, but the tendency of average annual precipitation did not show significant changes. Both maximum and minimum temperature showed significant increasing tendency, while there was no obvious changes for annual mean temperature. The spatial features of extreme precipitation and temperature are similar. It should be noted that extreme precipitation and temperature events occurred more frequently in central region, where the risk of occurrence for extreme climate events may be higher than other regions.

Joint Inter-Association Symposium

JH01c - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0027

Interdisciplinary approach to hydrological hazard mitigation and effects of climate change on the occurrence of flood severity in central Alaska

Y. Kontar[1]
[1]*University of Alaska Fairbanks, International Arctic Research Center, Fairbanks, USA*

In May 2013, a massive ice jam on the Yukon River caused flooding that destroyed much of the community's infrastructure and forced the long-term evacuation of nearly 70 percent of the residents. A major disaster declaration was issued and a range of federal and nonprofit agencies rushed to Galena, Alaska to assist state, local, and tribal agencies in disaster response and recovery operations. Logistical and cultural features of the Far North, as well as bureaucracy, significantly challenged and delayed the rebuilding of the village. A set of local factors, e.g., river channel morphology, ice cover thickness and strength, and weather patterns determine the timing and severity of river ice jams (Beltaos, 2008). Effects of climate change are more noticeable in high latitudes and consequently, ice jams on the Yukon River are very sensitive to changes in climatic conditions. The extensive floods on the Yukon in Spring 2013 were attributed to abnormal weather patterns. As a result, the winter snowpack in the Yukon River basin remained in place weeks later than normal, and river ice remained solid. Then, rapid temperature warming led to the development of several massive ice jams along the Yukon River. This case study is used to examine changing climate and flood severity, and analyze and critique hydrological extreme events and disaster response and recovery in rural communities of the Far North.

Joint Inter-Association Symposium

JH01c - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0049

Mixture distribution for modelling extreme precipitation in United Arab Emirates

J.Y. Shin[1], *T. Ouarda*[1], *T. Lee*[2]
[1]*Masdar Institute,*
Institute Center for Water Advanced Technology and Environmental Research iWA TER, Abu Dhabi, United Arab Emirates
[2]*Gyeongsang National Univeristy, Department of Civil Engineering, Jinju, Korea- Republic of Korea*

Heavy precipitation events in the United Arab Emirates (UAE) consist of two types of storms: frontal and local convective storms. Since heavy precipitation events of the UAE have multiple generating phenomena, their probability distribution may show mixture distributional characteristics. In order to improve our understanding of heavy precipitation events in the UAE, mixture distributions need to be used in the frequency analysis of these events.

The current study aims to model heavy precipitation events in the UAE using mixture distributions. Annual maximum precipitation (AMP) are obtained from daily precipitation observations from 4 stations. Six mixture distributions are employed and fitted by the expectation maximization algorithm and the meta-heuristic maximum likelihood method. The goodness-of-fit of employed mixture distributions is computed and compared with generalized extreme value (GEV) distribution. Additionally, storm types of the AMP events are identified and these results are used to check the suitability of the mixture distributions. The spatial distribution of the AMP event, mean sea level pressure, and wind vector are used to identify the storm types of the AMP events.

Results indicate that the employed mixture distributions lead to a good fit to model the AMP data in the UAE. In general the application of mixture distributions provides lower RMSEs than those of the GEV distribution. The Weibull-Extreme Value type-1 mixture distribution is considered as the distribution leading to the best fit to model the AMP data in the UAE. Furthermore, the results indicate that fitted mixture distributions successfully model the two types of storms.

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JH01c - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0101

Combining morphological observations, chemical analyses of surface waters and hydrological model to improve knowledge on flash karst floods genesis.

F. Raynaud[1], V. Borrell Estupina[1], S. Pistre[1], S. Van-Exter[2], N. Bourgeois[3], A. Dezetter[4], E. Servat[4]
[1]HydroSciences Montpellier, University of Montpellier, Montpellier, France
[2]HydroSciences Montpellier, CNRS, Montpellier, France
[3]MAYANE, private company, Montferrier sur Lez, France
[4]HydroSciences Montpellier, IRD, Montpellier, France

During a flood event over a karst watershed, the connections between surface and ground waters appear to be complex ones. The karst may attenuate surface floods by absorbing water or contribute to the surface flood by direct contribution of karst waters in the rivers (perennial and overflowing springs) and by diffuse resurgence along the hillslopes.

If it is possible to monitor each known outlet of a karst system, the diffuse contribution is yet difficult to assess. Furthermore, all these connections vary over time according to several factors such as the water content of the soil and underground, the rainfall characteristics, the runoff pathways. Therefore, the contribution of each compartment is generally difficult to assess, and then flood dynamics are not fully understood.

To face these misunderstandings and difficulties, we analysed surface waters during three recent flood events in the Lirou watershed (a karst tributary of the Lez, in South of France). Analyses consisted on chemical ones, because of the specific chemical signature of karst waters, and on hydrogeomorphological and hydraulic ones, to supply information about water pathways and flood dynamics. Then, we used the dilution law to combine chemical results, flow data and field observations to assess the dynamics of the karst component of the flood. We confronted this estimation with flood simulations from a distributed event-based model. The validation on eleven historic events allowed us to ensure the model reliability and to investigate about the karst impact on floods genesis. To end, we discussed the surface or karst origin of the waters responsible for the apparent runoff coefficient rise during flash karst flood. This study was funded by the French Flood Forecasting Service (SPC Med-Ouest).

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JH01c - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0107

How are estimations of design floods influenced by one wet hydrological year: large floods in 2014 in Slovenia.

N. Bezak[1], *M. Brilly*[1], *M. Miko*[1], *M. raj*[1]
[1]*University of Ljubljana, FGG, Ljubljana, Slovenia*

In 2014, several heavy floods have occurred in Slovenia (Europe), and this year will definitely be considered as a hydrological wet year in many parts of Slovenia. The aim of the study was to analyse how the consideration of the significantly wet year 2014 with several subsequent floods influences the results of the flood frequency analysis; i.e. to which extent can one hydrological wet year change estimations of design floods used for flood protection measures (e.g. 100-year or 300-year flood) and what is the uncertainty in the design flood due to the limitations in the sample length.

The daily discharge data from three torrential streams in Slovenia, namely the Gradašcica, Selška Sora and Poljanska Sora rivers, respectively (W and NW to the City of Ljubljana), have been used for the analysis. The Gradašcica River causes floods in the City of Ljubljana (e.g. extensive floods in SW of Ljubljana in 2010 and 2014 with around 1000 flooded houses), while Selška Sora caused large flooding's in September 2007 (several casualties) and the neighbouring Poljanska Sora caused comparably large flooding's in October 2014.

The annual maximum series and peaks over threshold series methods were used for the flood frequency analysis (Gradašcica: gauging station Dvor 78.67 km2; Selška Sora: gauging station Vešter 212.39 km2; Poljanska Sora: gauging station Zminec 305.51 km2, Sora: gauging station Suha 566.34 km2). Furthermore, multivariate flood frequency analysis was also carried out using copula functions. Based on the (multivariate) flood frequency analysis results we have evaluated the differences in the estimated design floods of different return periods using before mentioned different approaches.

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IUGG-0112

The role of seasonal and occasional floods in origin of extreme hydrological events

M. Kireeva[1]*, N. Frolova*[1]*, E. Rets*[2]*, N. Ezerova*[1]
[1]*Lomonosov Moscow State University, Department of Hydrology, Moscow, Russia*
[2]*Water Problems Institute- Russian Academy of Science,*
Laboratory of Hydrogeology and Environmental Engineering, Moscow, Russia

Extreme hydrological events on the rivers of European part of Russia are closely related to hydrological regime transformation responding to recent climate changes. For the last twenty years the role of occasional floods is constantly increasing. Frequency of winter floods, connected with thaws is rising dramatically. Consequently the most part of the snow pack and related water recourses that used to form the spring seasonal flood are drained during winter season. Statistical analysis of data from 300 gauging stations reveals strong reduction in seasonal flood volume, especially in the west part of European Russia (>40% and 15-30% for the Don River and Volga River basins, correspondingly). Seasonal flood reduction is widely accompanied by increase in low flow by 20–60%. Hence, natural runoff regulation is found out to increase dramatically.

At that a rise in variability and frequency of extreme events is widely detected. More often extreme low flow periods are observed. For instance, in 2010 and 2014 widely-spread hydrological draught resulted in limitation of water consumption for residents and industry. During the last years several extreme flood events, caused by enormous precipitation, occurred in Northern Caucasus.

In the study frequency and duration of extreme low flow and high flow events is analyzed, as well as deficits during hydrological years. The results show that the increase in natural runoff regulation does not reduce frequency of extreme events*.

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Joint Inter-Association Symposium

JH01d - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0021

Modelling the interaction between flooding events and economic growth

J. Grames[1], D. Grass[2], A. Prskawetz[3], G. Blöschl[4]
[1]Vienna University of Technology, Centre for Water Resource Systems, Vienna, Austria
[2]Vienna University of Technology, Institute of Mathematical Methods in Economics- Unit Operations Research and Control Systems, Vienna, Austria
[3]Vienna University of Technology, Institute of Mathematical Methods in Economics- Unit Economics, Vienna, Austria
[4]Vienna University of Technology, Institute of Hydraulic Engineering and Water Resources Management, Vienna, Austria

Socio-hydrology describes the interaction between the socio-economy, water and population dynamics. Recent models analyze the interplay of community risk-coping culture, flooding damage and economic growth (Di Baldassarre (2013), Viglione (2014)). These models descriptively explain the feedbacks between socio-economic development and natural disasters like floods. Contrary to these descriptive models, our approach develops an optimization model, where the intertemporal decision of an economic agent interacts with the hydrological system. This is the first economic growth model describing the influence of the consumption and investment decisions of an economic agent on the appearance of flooding events: Investments in defense capital can avoid floods even when the water level is high. But when floods occur, the flood damage depends on the existing defense capital. The aim is to find a long-term stable solution of consumption and investment decisions. Due to a non-autonomous exogenous periodic rainfall function the long-term equilibrium is periodic.

In our model we answer questions such as which mechanisms allow consumption smoothing in the long term, and how to optimally invest in flood defense to maximize economic output. How do the economic and the defense capital stocks aggregate to maximize the utility of the society? Do people build more defense capital if their time preference rate is lower? What are necessary policies to prevent economies from flood damage in the long term?

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JH01d - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

IUGG-0100

Climate noise effect on uncertainty of hydrological extremes: numerical experiments with hydrological and climate models

A. Gelfan[1], *Y. Motovilov*[1], *V. Semenov*[2]
[1]*Water Problems Institute, Russian Academy of Sciences, Moscow, Russia*
[2]*A.M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow, Russia*

An approach has been proposed to analyze hydrological extreme simulation uncertainty originating from the internal variability of the atmosphere ("climate noise"), which is inherent to the climate system and considered as the lowest level of uncertainty achievable in climate impact studies. Importantly, the role of the climate noise is dominating over spatial-temporal scales of water management in large river basins. To assess the climate noise effect, numerical experiments were made with climate model ECHAM5 and hydrological model ECOMAG. The case study was carried out to Northern Dvina River basin (catchment area is 360,000 km^2), whose hydrological regime is characterised by extreme freshets during spring-summer snowmelt period. The climate noise was reproduced by repeating ECHAM5-runs, when only initial conditions are changed by small perturbations; external forcing parameters were corresponded to the modern climate conditions and did not vary. Totally, 45 model runs were made under the different initial conditions. An ensemble of the ECHAM5-outputs for the period of 1979-2012 was used (after bias correction post-processing) as the hydrological model inputs, and the corresponding ensemble of 45 multi-year hydrographs was simulated. Mean values of flood volume and peak discharge, as well as inter-annual variance of these characteristics, were derived from the simulated ensemble of hydrographs. Uncertainty of the derived statistics was estimated, and these statistics were compared with the corresponding ones obtained from the observed streamflow series. We found that uncertainties of the extreme flood statistics are sensitive to the climate noise, with the uncertainty of the flood characteristic variance is much higher than the uncertainties of the mean value.

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IUGG-0158

Exploring the relationship between flood occurrence and the change of polar motion

S. Liu[1], S. Deng[1,2], Y. Wang[1], X. Mo[1]
[1]Institute of Geographic Sciences and Natural Resources Research- Chinese Acad em, Key Laboratory of Water Cycle and Related Land Surface Processes, Beijing, China Peoples Republic
[2]University of Chinese Academy of Sciences, 100049, Beijing, China Peoples Republic

Floods, as one of the extreme hydrological events develops at the Earth's surface much often than before. The drivers can be meteorological, oceanographic, seismological as well as anthropologic. Identifying possible signals from related variables best with some already existing long-term data will be help for early warning. Relationship between earth polar motion, which has data records from 1864 up to the present and floods occurrence is explored with visual observation and detail analysis. The prominent shift in the historical record of polar motion is found matching with the year with greatest occurrence of documented floods over the world. The year of floods with the peak flow greater than 50000 m3/s matches well with the turning point of polar motion features. Besides the ordinary index such as X and Y coordinates and the amplitude, other innovative indexes such as angle and radius are proposed for identifying the change of polar motion. Comparison between the primitive rivers and rivers with strong human activities is made for separating the contributions from natural and human. Prediction of such indexes is studied in order to make possible warning of floods.

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IUGG-0178

Climate change track in river floods in Europe

Z. Kundzewicz[1]
[1]*Inst. of Agric. and Forest Env.- Polish Academy of Sciences, Climate and Water Resources, Poznan, Poland*

A holistic perspective on changing rainfall-driven flood risk in Europe is provided. Economic losses from floods have greatly increased, principally driven by the expanding exposure of assets at risk. Climate change (i.e. observed increase in precipitation intensity, decrease of snowpack and other observed climate changes) might already have had an impact on floods. However, no gauge-based evidence had been found for a climate-driven, widespread change in the magnitude/frequency of floods during the last decades. There are strong regional and sub-regional variations in the trends. Moreover, it has not been possible to attribute rain-generated peak streamflow trends to anthropogenic climate change.

Physical reasoning suggests that projected increases in the frequency and intensity of heavy rainfall, or the proportion of total rainfall from heavy falls, for the 21st century, would contribute to increases in rain-generated local floods. Also less snowmelt flooding and earlier spring peak flows in snowmelt- and glacier-fed rivers are expected. However, there is low confidence in future changes in flood magnitude and frequency resulting from climate change. The impacts of climate change on flood characteristics are highly sensitive to the detailed nature of those changes that is presently uncertain.

Discussion of flood projections in Europe is offered. Attention is drawn that over the last decade or so, projections of flood hazard in Europe have largely changed. Interpretation of such changes is sought, related to both different scenarios and different modeling approaches.

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IUGG-4555

Bayesian spatial modeling of extreme flood recurrence interval

H. Moradkhani[1], H. Yan[1]
[1]Portland State University, Civil and Environmental Engineering, Portland, USA

The standard at-site flood frequency analysis is generally limited by the few available data. As an alternative, index-flood based regional frequency analysis (RFA) borrows information from the neighboring gages, with the concept "trading space for time". However, RFA suffers several unverified assumptions, like the constant scale over the homogeneous region. Instead, the Bayesian method can overcome the implicit RFA assumptions and provide an attractive way to estimate the extreme flood posterior distributions.

In this study, we propose a spatial Bayesian hierarchical model for flood frequency analysis. Instead of relying on the delineation of implicit homogeneous regions, the Bayesian hierarchical method describes the spatial dependence in its inner structure. This structure is well suited for combining other pieces of information, especially when historical flood and paleofloods data are available. A total of three layers are included in this model, the likelihood, the process, and the prior layers. The performance of this Bayesian hierarchical model is demonstrated over a heterogeneous watershed (which doesn't meet the RFA assumption), the Willamette River Basin (WRB) in the Pacific Northwest (PNW), U.S. Our results indicate that the spatial hierarchical Bayesian model can reduce uncertainties for flood quantile estimators for the majority of the gages. The effect of considering the historical flood in frequency analysis is also explored, and the Bayesian model is much less affected by combining the historical extreme observations.

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JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-195

Estimation of flood-adaptation indices for varying climatic conditions

J. Doroszkiewicz[1]*, R. Romanowicz*[2]
[1]*Institute of Geophysics- Polish Academy of Sciences, Hydrology and Hydrodynamics, Warsaw, Poland*
[2]*Institute of Geophysics- Polish Academy of Sciences, Hydrology and Hydrodynamics, Warsaw, Poland*

Changing Climate is a factor that must be taken into account in evaluating adaptation to the natural hazards (IPCC 2014). Adaptation to future climatic extremes requires the formulation of a management strategy based on adaptation indices. Considering flood as one of the most common natural hazards, we focused our effort on estimation of adaptation indices for flood protection. These include the length of time water levels exceed a critical value along the river, probability of inundation of risk-prone areas and flood recurrence interval. An analysis was performed using a chosen Polish catchment (Biala Tarnowska) as a case study. This catchment has nearly natural conditions which allows for the separation climatic and anthropogenic influence. We applied rainfall-runoff modelling and flow routing using the SOBEK 3 software. The research has been done within the project Climate Change Impact on Hydrological Extremes (CHIHE) supported by Norway Grants.

Joint Inter-Association Symposium

JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-196

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

C. Cudennec[1], *A. de Lavenne*[2]
[1]*IAHS, at Agrocampus Ouest, Rennes, France*
[2]*Agrocampus Ouest, UMR SAS, Rennes, France*

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.

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JH01p-197

Downscaling medium-range ensemble forecasts using a neural network approach

M. Ohba[1], *D. Nohara*[1], *S. Kadokura*[1], *Y. Toyoda*[1], *Y. Yoshida*[1]
[1]*Central Research Institute of Electric Power Industry CRIEPI, Environmental Science Research Laboratory, Abiko, Japan*

In this study, we present an application of self-organizing maps (SOMs) to downscaling weekly ensemble forecasts and probabilistic prediction of local precipitation in Japan. The SOM is an automatic data-mining clustering technique, which allows us to summarize a high-dimensional data space in terms of a set of reference vectors. The SOM is applied to analyze both atmospheric patterns over Japan and local high-resolution precipitation data. SOM is simultaneously employed on four elemental variables derived from the JRA55 reanalysis over area of study (Southwestern Japan and Northeastern Japan), whereby a two-dimensional lattice of weather patterns (WPs) dominated during the 1958–2011 period is obtained. This SOM lattice is also used to represent the local precipitation regime. Downscaling weekly ensemble forecasts to local precipitation are conducted by using the SOM lattice. The downscaled precipitation is derived by the SOM lattice based on the WPs of the global model ensemble forecast for a particular day. Thus, a probabilistic local precipitation is easily obtained from the ensemble forecast. This downscaling of weekly ensembles provides comparable or better results (i.e., capture the relatively detailed precipitation distribution over Japan) to that in 20km GSM. The predictability skill of the weekly ensemble forecast for the precipitation is significantly improved under the downscaling technique and then also brings a much better skill score than traditional analog method. This method effectively takes care of the stochastic uncertainties from the very large number of ensembles and provides better guidance to the user community. It is expected that the results of this study contribute to future development of dam-management (and flood prediction) model.

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JH01p-198

A Tri-National program for estimating the link between snow resources and hydrological droughts

T. Vitvar[1], A. Ruecker[2], G. Melikadze[3], L. Bernhard[2], V. David[1], N. Zhukova[3], M. Sanda[1], M. Zappa[2]
[1]Czech Technical University in Prague, Faculty of Civil Engineering- Prague, Prague, Czech Republic
[2]Swiss Federal Research Institute WSL, Mountain Hydrology and Torrents, Birmensdorf, Switzerland
[3]Tbilisi State University, Institute of Geophysics, Tbilisi, Georgia

A Tri-National research effort will evaluate how summer low flows and droughts are affected by winter snowpack in three catchments Alpbach (Prealps, central Switzerland), Kamenice (Jizera Mountains, northern Czech Republic), and Gudjaretis-Tskali (Little Caucasus, central Georgia). Two GIS-based rainfall-runoff models will simulate more than 10 years of runoff in streams by means of measured rain- and snowfall, other meteorological variables. We also use information on the geographical settings (features) of the catchments and knowledge of the main hydrological processes involved that transform rainfall into streamflow. These processes in the selected mountainous catchments include snow accumulation and melt, evapotranspiration, recharge and subsurface storage until the summer outflow, and will be studied by means of environmental isotopes ^{18}O and ^{2}H. This knowledge will result in parameters such as contribution of snowmelt water in the streamflow and time the water spends in the underground between snowmelt recharge and outflow. The obtained parameters will be employed for improvement of the models and therefore for a better simulation of runoff in snowmelt-dominated catchments. This approach will be tested in all three countries in nested-basins (small catchment 1-2 km^2 and larger catchment 100-200 km^2) in all three countries. The results will improve the performance of the GIS-based rainfall-runoff models, examine their potential of further development through comparison in different catchments, and allow better early prediction of low-flow periods in various mountain zones across Europe. This contribution will present the scopes of the project and first results of field data analysis and modelling experiments.

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JH01p-199

Confrontation between neural network modelling and geochemical waters analyses to understand and forecast flash karst floods (Lez river example).

T. Darras[1], F. Raynaud[2], V. Borrell Estupina[2], L. Kong-A-Siou[3], S. Van-Exter[4], B. Vayssade[1], A. Johannet[1], S. Pistre[2]
[1]LGEI, Ecole des Mines d'Alès, Alès, France
[2]HydroSciences Montpellier, University of Montpellier, Montpellier, France
[3]Mayane, private company, Montferrier sur Lez, France
[4]HydroSciences Montpellier, CNRS, Montpellier, France

Flash floods forecasting in the Mediterranean area is a major economic and social issue. The consequences of such events during the past 20 years in southern France are over 100 fatalities and several billions of euros of material damages. Considering karst basin, heterogeneous structure and nonlinear behaviour make the flash flood forecasting more difficult. One of the main reasons is the misunderstanding about flood genesis on karst. In particular, the contribution of karst waters and direct runoff, leading to different flood intensities and dynamics, is unknown. In that framework, this work proposes to assess the contribution from karst and non karst components by neural network model fed by spatialized rainfalls.

The present work is funded by the French National Flood Warning and Forecasting Services (SCHAPI, SPC Méd-Ouest). It focuses on the Lez basin, upstream the city of Montpellier with 400 000 inhabitants. With a watershed of 114 km^2 and more than 300 km^2 for the karst aquifer, the contribution of the different topographic and geological structures of the basin is heterogeneous in space and various in time. The neural network ability to identify a priori unknown functions and to quantify spatialized contributions thanks to the KnoX method [Kong-A-Siou, et al., 2013] is explored for these floods. It supplies information about flood genesis from the karst and non karst parts.

Then, we use the assessment of the contribution of superficial (direct runoff) and underground waters (springs, diffuse resurgences) to the discharge based on geochemical and hydrodynamics analyses of surface waters during recent floods [Raynaud et al., 2015], to discuss the neural network model performances and its ability to prevent people from consequences of future floods.

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JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-200

The effect of climate change and air pollution on extreme precipitation events

J. Sillmann[1]
[1]*Center for International Climate and Environmental Research - Oslo CICERO, Oslo, Norway*

Global anthropogenic greenhouse-gas emissions as well as regional air pollution (e.g., sulphate aerosols or black carbon) can lead to significant changes in precipitation extremes, such as droughts and heavy precipitation events, which often are associated with substantial economic and human losses. Multi-model studies with state-of-the-art global climate models (i.e., from CMIP5) indicate that extreme precipitation increases about three times as much as mean precipitation under different greenhouse gas emission scenarios. The effect of inhomogeneous aerosol burdens in the atmosphere can further lead to regionally diversified patterns of changes in precipitation extremes. With the newly established Precipitation Driver Response Model Intercomparison Project (PDRMIP), we are able to investigate the effects of different external and internal drivers on global and regional changes in precipitation extremes and assess uncertainties related to differences in the representation of external forcing mechanisms among participating models.

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JH01p-201

Xinanjiang model based drought assessment using a multivariate drought index in the Huaihe River basin, China

Q. Li[1], *M. Yu*[2], *K. Wang*[1]
[1]*Hohai University,*
College of Hydrology and Water Resources- Center for International River Resear ch, Nanjing, China Peoples Republic
[2]*Hohai University, College of Hydrology and Water Resources, Nanjing, China Peoples Republic*

The Huaihe River Basin having China's highest population density (662 persons per km^2) lies in the warm temperature semi-humid monsoon region, which is a transition zone between the climates of North and South China, and is thus prone to flooding and drought. With climate change and the rapid increase in water demand, droughts, whose magnitude and duration have shown an increasing trend in the basin over the past decades, are increasingly becoming a critical constraint to its sustainable socio-economic development. Therefore, the paper aims to develop an appropriate drought assessment approach for drought assessment in the Huaihe River basin, China. Based on the Principal Component Analysis of precipitation, evapotranspiration, soil moisture and runoff, the three latter variables of which were obtained by use of the Xinanjiang model, a new multivariate drought index (MDI) was formulated, and its thresholds were determined by use of cumulative distribution function. To test the applicability of the newly developed index, the MDI, the Standardized Precipitation Evapotranspiration Index (SPEI) and the self-calibrating Palmer Drought Severity Index (sc-PDSI) time series on a monthly scale were computed and their temporal variations were compared during 1994–1995 and 2000 drought events. The results show that the MDI exhibited certain advantages over the sc-PDSI and the SPEI, i.e. better assessing drought severity and better reflecting drought evolution. The MDI formulated by this paper could provide a scientific basis for drought mitigation and management, and references for drought assessment elsewhere in China.

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JH01p-202

Projecting future climate change effects on the extreme hydrological drought events in the Weihe River basin, China

F. Yuan[1], *Y. Li*[2], *L. Ren*[2]
[1]*Hohai University, State Key Laboratory of Hydrology–Water Resources and Hydraulic Engineering &College of Hydrology and Water Resources, Nanjing, China Peoples Republic*
[2]*Hohai University, State Key Laboratory of Hydrology–Water Resources and Hydraulic Engineering & College of Hydrology and Water Resources, Nanjing, China Peoples Republic*

Global climate change deteriorates drought situation in the Yellow River basin of China, which is becoming a serious constraint to the sustainable development of local economic society. Projecting climate change impacts on hydrological droughts is potential to provide scientific guidelines for drought early-warning and monitoring as well as sustainable water resources management under the changing climate. In this study, The VIC (Variable Infiltration Capacity) hydrological model, the PRECIS (Providing Regional Climate for Impact Studies) RCM (regional climate model), and the Copula function were adopted to project future situation of extreme hydrological drought events in the Weihe River basin, a sub-basin of the Yellow River basin. First, the VIC model was used to simulate the daily streamflow process at the Huaxian streamflow station for the baseline period (1961-1990) and future period (2011-2040), driven by the precipitation and air temperature data projected by the PRECIS RCM. Based on the simulated streamflow for baseline and future periods, the Copula function was applied to analyze the probability distribution of extreme hydrological drought events for both periods. It projects that air temperature in the Weihe River basin would increase significantly and precipitation would not change obviously. Due to this trend in air temperature and precipitation, summer runoff is likely to drop considerably. This would deteriorate the hydrological drought situation. In the future the Weihe River basin would experience more severe drought events than the baseline situation, with a much higher occurrence frequency of extreme hydrological drought events.

Joint Inter-Association Symposium

JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-203

Evolution of low flows in Czechia revisited

O. Ledvinka[1]
[1]*Czech Hydrometeorological Institute, Hydrological Database & Water Balance, Prague 412, Czech Republic*

Although a nationwide study focusing on the evolution of low flows in Czechia was conducted in the past, a need for the revision of the results have arisen. By means of the trend analysis, which specifically consider the presence of significant serial correlation at the first lag, the study highlighted areas where 7-day low flows increase or decrease. However, taking into account only the lag-one autoregressive process might still have led to the detection of so-called pseudo-trends. Moreover, besides short-term persistence, also long-term persistence may adversely influence the variance of the test statistic. Therefore, one should carefully investigate the presence of persistence in time series. Before the trend analysis itself, here, the discrimination between short memory processes and long memory processes was done employing jointly the Phillips-Perron test and the Kwiatkowski-Phillips-Schmidt-Shin test. This analysis was accompanied by the Hurst exponent estimation (originally as the factional differencing parameter, to which the value of 0.5 was added). It was found, for example, that in the southwest and northwest parts of Czechia the long memory processes are more likely as regards 7-day low flows and many other characteristics related to drought. Finally, the identification of trends was carried out using three modifications of the Mann-Kendall test that allow different kinds of persistence. These included the Bayley-Hammersley-Matalas-Langbein-Lettenmaier equivalent sample size approach, the trend-free pre-whitening approach and a block-bootstrap with automatic selection of the block length.

Joint Inter-Association Symposium

JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-204

Analysis of 1582 and 1890 flash floods in Carslbad, Czech Republic

J. Danhelka[1]
[1]*Czech Hydrometeorological Institute, Hydrology, Prague, Czech Republic*

Carslbad (Karlovy Vary) is a famous spa city in Western Bohemia. The city is located in a narrow valley of Tepla River (basin area app. 400 km2). Carlsbad has experienced two documented disastrous flash floods since its establishing in 1358. The flood from May 1582 has been described by Clements Stephani. Based on contemporary sources we reconstruct the flood extent and estimate the flood depth in the city center. The flood from November 1890 was an extreme and extraordinary flash flood. Especially its occurrence in late November is unique for Central European area. Description of flood and some hydrometeorological data are used in flood reconstruction. Based on the comparison we conclude that 1890 flood has been most likely more extreme than flood in 1582.

We also discuss the implications for flood protection of the city of Carlsbad, especially a flood transformation effect of Brezova Reservoir on one hand and the limited discharge capacity of a colonnade building in the city center.

Joint Inter-Association Symposium

JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-205

Trends of extreme precipitation during 1979-2012 in Beijing, China

Z.X. Xu[1], *Q. Chu*[1]
[1]*Beijing Normal University, College of Water Sciences, Beijing, China Peoples Republic*

In this study, the time series of 3-hour precipitation with 0.1° × 0.1° spatial resolution were used to analyze the tendency of extreme precipitation during the period of 1979-2012 in Beijing, China. The results show that: (1) average annual precipitation, with a range from 500 mm to 800 mm, increases from northwest to southeast. Around the downtown area as a center, the inter-annual precipitation in Beijing area showed a outward decreasing tendency at the maximum rate of 40 mm/10a; (2) extreme precipitation amount, which accounts for 40% - 50% of the total annul precipitation amount, showed a same spatial distribution to the average annual precipitation; (3) the days and threshold estimated as the upper 95 percentile of extreme precipitation show significant differences with the extreme precipitation amount; with the maximum value concentrating on the downtown and eastern mountain area, and the minimum value in the northwestern area; (4) days of extreme precipitation show the opposite distribution to the thresholds of extreme precipitation, this means that the area with greater precipitation threshold may has smaller precipitation days and vice versa. This results in obvious spatial variances of extreme precipitation intensity, with the maximum value in downtown area, Yanqing and Tongzhou districts; (5) apparent spatiotemporal decreasing trends are detected in extreme precipitation amount. The downward tendencies are also found for threshold and days of extreme precipitation, which are more pronounced in Miyun and Mentougou districts; (6) the tendency of extreme precipitation amount and average annual precipitation are significantly different, and the reducing amplitude in northeastern area is greater than that in southwestern area.

Joint Inter-Association Symposium

JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-206

Short-term/long-term composited drought index development and application in the upper Huaihe River basin, China

M. Yu[1], *Q. Li*[1], *X. Liu*[2]
[1]*Hohai University,*
College of Hydrology and Water Resources- Center for International River Resear ch, Nanjing, China Peoples Republic
[2]*Nanjing Hydranlic Research Institute,*
Hydrology and Water Resources Department, Nanjing, China Peoples Republic

Accurate and reliable drought monitoring is of primary importance for drought mitigation and reduction of social-ecological vulnerability. The aim of the paper was to propose a short-term/long-term composited drought index (CDI) which could be widely used for drought monitoring and early warning in China. In the study, the upper Huaihe River basin above the Xixian gauge station, which has been hit by severe droughts frequently in recent decades, was selected as the case study site. The short-term CDI was developed by the Principle Component Analysis of the self-calibrating Palmer Drought Severity Index (sc-PDSI), the 1- and 3-month Standardized Precipitation Evapotranspiration Index (SPEI), Z Index (ZIND), the Soil Moisture Index (SMI) with the long-term CDI being formulated by use of the self-calibrating Palmer Hydrology Drought Index (sc-PHDI), the 6-, 12-, 18- and 24-month SPEI, the Standardized Streamflow Index (SSI), the SMI. The sc-PDSI, the PHDI, the ZIND, the SPEI on a monthly time scale were calculated based on the monthly air temperature and precipitation, and the monthly SMI and SSI were computed based on the simulated soil moisture and runoff by the distributed Xinanjiang model. The thresholds of the short-term/long-term CDI were determined according to frequency statistics of different drought indices. Finally, the feasibility of the two CDIs was investigated against the SPEI and the historical drought records. The results revealed that the short-term/long-term CDI could capture the onset, severity, persistence of drought events very well with the former being better at identifying the dynamic evolution of drought condition while the latter better at judging the changing trend of drought over a long time period.

Joint Inter-Association Symposium

JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-207

Ensemble long-term forecast of extreme unregulated water inflow into a large reservoir

A. Gelfan[1], *Y. Motovilov*[1], *V. Moreido*[1]
[1]*Water Problems Institute, Russian Academy of Sciences, Moscow, Russia*

A long-term streamflow forecast is crucial for large-scale water reservoirs operation, as water management plans are designed for several months ahead in order to distribute the available resources between stakeholders. Water regime in the European Russia is characterized by high snowmelt-driven spring freshet followed by long summer low-flow periods hence adequate tools to assess the available water resources during these periods are required. An approach to seasonal ensemble forecast of unregulated water inflow into a large reservoir has been developed involving a physically-based semi-distributed hydrological model ECOMAG driven by ensembles of future weather scenarios for a specified lead-time of the forecast. Case study was carried out for the Cheboksary reservoir (cathment area is 374 000 km^2) on the middle Volga River. Initial watershed conditions on the date of the forecast (1st of March for spring period and 1st of June for summer) were simulated by the hydrological model forced by daily meteorological observations several months prior to the forecast date. To assign ensemble of weather scenarios for the lead-time of the forecast (3 months ahead in this study), two approaches were applied: (1) the historical, observed daily weather patterns, which assumed to be representative of possible future weather conditions; and (2) the artificial daily weather patterns simulated by a stochastic weather generator. Hindcasts were produced for spring/summer seasons beginning from the filling of the reservoir in 1982. Statistics of the hydrological extreme indicators (volume, duration, and severity of floods and droughts) were derived from the forecasted hydrograph ensembles and evaluated against the corresponding indicators obtained from observations.

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JH01p-208

Understanding extreme events in a social-ecological perspective

A.C. Souza da Silva[1], *C.D.O. Galvão*[2], *G. Souza da Silva*[3]
[1]*UFCG, Civil Engineering, Joao Pessoa, Brazil*
[2]*UFCG, Civil Engineering, Campina Grande, Brazil*
[3]*UFPE, Civil Engineering, João Pessoa, Brazil*

Extreme events are part of climate variability. Dealing with variability is still a challenge that might be increased due to climate change. However, impacts of extreme events are not only dependent on variability, but also on management and governance. In Brazil, its semiarid region is vulnerable to extreme events, especially droughts, since decades. Actually, other Brazilian regions that have been mostly concerned with floods are currently also experiencing droughts. This article aims to evaluate how a combination between climate variability and water governance might affect water scarcity and increase the impacts of extreme events in some regions. For this evaluation, Ostrom´s framework for analyzing Social-Ecological Systems was applied. Ostrom´s framework is useful for understanding interactions between resource systems, governance systems and resource users. This study focuses on two Social-Ecological Systems located in a drought-prone region of Brazil. Two different extreme events were selected, one in 1999, when Brazil´s new water policy was very young, and the other one in 2012-2014. Although Brazilian water policy considers concepts of integration, decentralization and participation, the analysis showed that the region is still very vulnerable and water users are not aware about the risk. The reasons are more related to water management and governance problems than to drought event magnitude or climate change. This is a problem that holdup advances in dealing with extreme events.

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JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-209

Regional versus geostatistical approaches for the estimation of extreme daily precipitation

R. Deidda[1], M. Hellies[1], A. Langousis[2]
[1]University of Cagliari,
Dipartimento di Ingegneria Civile- Ambientale ed Architettura DICAAR, Cagliari, Italy
[2]University of Patras, Department of Civil Engineering, Patras, Greece

We compare the relative performance of regional and geostatistical approaches for the estimation of extreme daily precipitation. The analysis is conducted using 229 daily timeseries with more than 50 years in record, collected by the Hydrological Survey of the Sardinia Region (Italy). In both approaches, we use a GEV distribution model with parameters estimated using the method of Probability Weighted Moments (PWM). For all stations, the L-Skewness-L-Kurtosis diagrams show that the GEV theoretical distribution performs best for extreme daily precipitation.
For the geostatistical approach we apply kriging for uncertain data, which accounts for the error variance in local parameter estimation, whereas for the regional approach we define homogeneous regions. The latter are obtained by applying cluster analysis techniques with metrics based on L-moments ratios (L-CV and L-Skewness). The analysis results in four contiguous regions, which satisfy the homogeneity tests suggested by Hosking and Wallis (1997). For the latter we use a Monte-Carlo approach based on a 4-parameter Kappa distribution, fitted to each station cluster. Note that the 4-parameter Kappa model includes the General Extreme Value (GEV) distribution as a sub-case.
For the regional approach, the shape and dimensionless scale parameters are constant but display an abrupt change along the boundaries of the homogeneous regions, while the geostatistical approach allows for smooth variations over the whole study area. Comparisons based on different error metrics, show better performance of the geostatistical approach relative to the regional one.

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JH01p-210

Downscaling approach to develop future sub daily IDF relations for major cities in Australia

<u>R. Sarukkalige</u>[1], S. Herath[2], V.T.V. Nguyen[3]
[1]Curtin University, Department of Civil Engineering, Perth- Western Australia, Australia
[2]Curtin University, Department of Civil Engineering, Perth, Australia
[3]McGill University, Department of Civil Engineering, Quebec, Canada

Downscaling of climate projections is the most adapted method to assess the impacts of climate change at regional and local scale. In the last decade, downscaling techniques which provide reasonable approach in improving resolution of General Circulation Models' (GCMs) output are developed in notable manner. Most of these techniques are limited to spatial downscaling of GCMs' output and still there is a high demand to develop temporal downscaling approaches. As the main objective of this study, combined approach of spatial and temporal downscaling is developed to improve the resolution of rainfall predicted by GCMs. Proposed approach is based on the Statistical Downscaling Model (SDSM) and scaling invariant concept. Seven major cities in Australia; Canberra, Sydney, Melbourne, Brisbane, Perth, Adelaide and Darwin are subjected to this study. National Centre of Environmental Prediction (NCEP) data is used in SDSM model calibration and validation of periods between 1961-2000 and HadCM3- A2 and B2 predictors are used to downscale future rainfalls in study areas. Regression based bias correction functions are used to improve the accuracy of downscaled annual maximum rainfalls. By analysing the non- central moments of observed rainfalls, different time regimes identified which exist scaling behaviour and they are used to estimate the sub daily extreme rainfall depths from daily downscaled rainfalls.. Accuracy of estimated sub daily extreme rainfalls are checked and it showed a good agreement with observed rainfalls. Finally, the major output of this study, Intensity Duration Frequency (IDF) relations are developed for the future periods of 2020s, 2050s and 2080s in the context of climate change.

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JH01p-211

Extreme values of snow-related variables in Mediterranean regions: trends and long-term forecasting in Sierra Nevada (Spain)

M.J. Pérez-Palazón[1], *R. Pimentel*[1], *J. Herrero*[2], *C. Aguilar*[2], *J.M. Perales*[1], *M.J. Polo*[1]
[1]*University of Cordoba,*
Fluvial Dynamics and Hydrology- Andalusian Institute of Earth System Research, Cordoba, Spain
[2]*University of Granada,*
Fluvial Dynamics and Hydrology- Andalusian Institute of Earth System Research, Granada, Spain

Mountain areas in Mediterranean regions constitute key monitoring points for climate variability and its impacts, but long time datasets are not always available due to the difficult access to high areas, relevant for capturing temperature and precipitation regimes, and the predominance of cloudy remote sensing images during the snow season. Sierra Nevada National Park (South Spain), with altitudes higher than 3500 m.a.s.l., is part of the world climate change observatories network. Snow occurrence just 40 km from the seaside determines a wide range of biodiversity, a snowmelt fluvial regime, and the associated ecosystem services. This work presents the local trend analysis of weather variables at this area together with aditional snow-related variables. For this, long term point and distributed observations from weather stations and remote sensing sources were studied and used as input and calibration datasets of a physically based snow model to derive long term series of spatially averaged daily snow water equivalent, daily snow cover area, annual number of days with snow exceeding a given area/water equivalent, annual number of days without snow, and annual snowmelt and evaporation volumes. The joint analysis of weather and snow variables showed a decrease trend in the persistence and extent of the snow cover area, but lower significance in the snow water equivalent regime, and the snowmelt/evaporation fractions. The precipitation regime, rather than the temperature trend, seems to be the most relevant driver on the snow regime forcing in Mediterranean areas. This poses a constraint for rigorous scenario analysis in these regions, since the precipitation pattern is poorly aproximated by climatic models in these regions.

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JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-213

Hydro-bio-geo-chemical severe events in the land-sea interface – Symptoms of an agro-environmental crisis in Britanny, France

C. Cudennec[1], *A. de Lavenne*[1]
[1]*Agrocampus Ouest, UMR SAS, Rennes, France*

The French peninsula of Britanny is the place for an agricultural intensification since the Mid-XXth Century, which led to a severe increase of water pollution from agricultural exceeding nutrients. The multi-decadal trends in water quality show a strong environmental crisis with chronicle pollution. Levels of nutrient concentrations, especially nitrates, in river freshwater flowing towards coastal bays lead to more and more frequent, intense and generalized algal blooms in the interface waters. These blooms precisely depend on the conjunction of nutrient concentrations, coastal currents, light availability. Such a nesting in time of hydro-bio-geo-chemical events within a multi-decadal critical trend, and such a regional synoptic generalization, with numerous side effects on society, lead to reframe the notion of extreme events as symptoms of a chronicle crisis which itself emerged from negative socio-hydrodrological trajectories.

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JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-214

Retrospective forensics of the extreme 1969 flood events in pre-dams semiarid and arid Tunisia

C. Cudennec[1], *H. Boudhraa*[2]
[1]*Agrocampus Ouest, UMR SAS, Rennes, France*
[2]*ESIER, Génie Rural, Medjez el Bab, Tunisia*

Tunisia experienced extreme rainfall-flood events in September and October 1969 across most of the country. These events have been gauged and reconstituted in such a detailed manner that they are now the best known extreme events in Maghreb, both because they represent the most important events ever quantified and because many land uses and hydraulic facilities have changed and been set up since then, thus changing regimes. The retrospective forensics of these events are much valuable not only in terms of hydrological and geomorphological knowledge, but also in terms of actual and future water and infrastructure management as many dams, overexploited groundwater, human settlement and security stakes are now depending and vulnerable to such possible events in the future.

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JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-215

Evolution des pluies extremes dans le bassin du chellif (Algerie) au cours des 40 dernieres annees 1971-2010

S. TAIBI[1]*, M. MEDDI*[2]*, G. MAHE*[3]
[1]*ENSH, Blida, Algeria*
[2]*ENSH, GEE, Blida, Algeria*
[3]*IRD, HSM, Montpellier, France*

Une analyse des pluies journalières extrêmes du bassin du Chélif (plus grand bassin du Nord de l'Algérie) a été établie sur la période 1971-2010. Pour cela 13 stations pluviométriques ont été sélectionnées et recueilli auprès de l'Agence Nationale des Ressources Hydrauliques (ANRH). Une classification par percentile a été utilisée pour déterminer le nombre des évènements extrêmes de chaque année. Nous avons évalué dans le cadre de ce travail les percentiles 90%, 95%, 99% et 99,5%. La pente de sen et la régression linéaire montrent une tendance générale à la baisse des extrêmes mais qui n'est pas significative excepté pour trois stations où l'amplitude de la baisse est de 1 à 2 jours par 10 ans pour le 90ème percentile. L'intensité des précipitations montre aussi une tendance générale à la baisse pour les différents percentiles. L'analyse de la variabilité des totaux annuels indique une baisse significative des précipitations du bassin du Chellif.

La recherche de relation entre la fréquence des évènements extrêmes de chaque station et les indices climatiques ENSO, NAO, MO et WeMO a été effectuée en utilisant le coefficient de corrélation de Kendall. Les résultats obtenus ne mettent pas en évidence des coefficients de corrélations significatives. Alors qu'à l'échelle annuelle la majorité des séries pluviométriques est significativement corrélée avec ENSO et la variabilité du cycle saisonnier est plutôt influencée par l'oscillation méditerranéenne (MO) et l'oscillation Nord Atlantique (NAO) particulièrement en hiver.

Une autre méthode est en cours d'exploration pour mettre en évidence la cohérence entre les indices climatiques et les pluies extrêmes qui est dite « la méthode des ondelettes ».

Joint Inter-Association Symposium

JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-216

Extreme hydrological events and security

Z. Kundzewicz[1], *P. Matczak*[2]
[1]*Inst.of Agr. and Forest Env.- Polish Acad. Sci., Climate and Water Resources, Poznan, Poland*
[2]*Adam Mickiewicz University, Institute of Sociology, Poznan, Poland*

Economic losses caused by hydrological extremes – floods and droughts – have been on the rise, worldwide. They cause serious threats to human life and welfare and societal livelihood. Floods and droughts can undermine security, understood as freedom from threat and the ability of societies to maintain their independent identity and their functional integrity against forces of change.
Several dimensions of security are reviewed in the context of hydrological extremes. The traditional interpretation of security, focused on the state military capabilities, has been replaced by a wider understanding, including economic, societal and environmental aspects that get increasing attention. Floods and droughts pose a burden to the state, responsible to sustain economic development, societal and environmental security. The last one can be regarded as the maintenance of ecosystem services, on which a society depends.
Security concerns arise, because over large areas, floods and droughts get more frequent and more severe. Changes in population size and development and protection level drive exposure to hydrological hazards. Exposed population and assets have increased more rapidly than overall population or economic growth. Increasing vulnerability, exposure, severity and frequency of climate events increase disaster risk.
Climate change may have impact on water resources and extreme hydrological events and can jeopardize security. However, projections of climate change impacts on freshwater resources are uncertain, being not only scenario specific, but also largely model specific. In terms of dealing with water related risks, climate change can increase uncertainties, which makes the state's task to deliver security more difficult and more expensive.

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JH01p - JH1 Extreme Hydrological Events (IAHS, IACS, IAG)

JH01p-217

Flood risk governance arrangements in Europe in the light of the STAR-FLOOD Project

P. Matczak[1], *J. Lewandowski*[2], *A. Chorynski*[3], *Z.W. Kundzewicz*[4]
[1]*Institute for Agricultural and Forest Environment- Polish Academy of Sciences, Department fo Climate and Water Resources, Poznan, Poland*
[2]*Institute of Agricultural and Forest Environment- Polish Academy of Sciences, Climate and Water Resources, Poznan, Poland*
[3]*Institute of Agricultural and Forest Environment- Polish Academy of Sciences, Climate and Water Resources, Poznan, Poland*
[4]*Institute of Agricultural and Forest Environment- Polish Academy of Sciences, Climate and Water Resources, Poznan, Poland*

The STAR-FLOOD (Strengthening and Redesigning European Flood Risk Practices Towards Appropriate and Resilient Flood Risk Governance Arrangements) project investigates strategies for dealing with flood risk in six European countries: Belgium, the UK, France, The Netherlands, Poland and Sweden and in 18 vulnerable urban regions in these countries. The project assesses the institutional embedding of these strategies from a combined public administration and legal perspective, with the aim to make European regions more resilient to flood risks. The project overviews and compares national flood risk governance arrangements between the six countries represented in the consortium of the STAR-FLOOD project.
The project aims to describe, analyze, explain, and evaluate the main similarities and differences between the selected EU Member States in terms of development and performance of flood risk governance arrangements. It also discusses the scientific and societal importance of these similarities and differences.
Attention is paid to identification and characterization of shifts in flood risk governance arrangements and in flood risk management strategies and to determination of triggering factors and restraining factors. An assessment of a change of resilience and appropriateness (legitimacy, effectiveness, efficiency) of flood risk governance arrangements in Poland presented and comparison with other European countries is offered.

Joint Inter-Association Symposium

JM02a - JM02/JM01 Climate Variability and Earth Systems Modelling (IAMAS, IAPSO, IACS) / Earth Systems Dynamics, Predictability and Probabilistic Forecasting (IAMAS, IAG, IAGA, IAPSO, IASPEI)

IUGG-1530

Investigation of the atmospheric mechanisms related to the autumn sea ice and winter circulation link in the Northern Hemisphere.

M.P. King[1,2], *M.C. Hell*[3], *N. Keenlyside*[2,4]
[1]*Uni Research, Uni Research, Bergen, Norway*
[2]*Bjerknes Centre for Climate Research, Bjerknes Centre for Climate Research, Bergen, Norway*
[3]*ETH Zuerich, Geological Institute, Zuerich, Switzerland*
[4]*University of Bergen and Bjerknes Centre for Climate Research, Geophysical Institute, Bergen, Norway*

The relationship of Barents-Kara sea ice concentration in October and November with atmospheric circulation in the subsequent winter is examined using reanalysis and observational data. The analyses are performed on data with the 5-year running means removed to reduce the potential effects of slowly-varying external driving factors, such as global warming, on the variables independently. The month-to-month variations in the lag relationships of the atmospheric anomalies related to October and November sea ice concentration are presented. It is found that positive (negative) Barents-Kara sea ice concentration anomaly in autumn is associated with a positive (negative) North Atlantic Oscillation-like (NAO) pattern with lags of up to three months. Evidence of the role of the stratosphere in providing the memory in the system by downward propagation are presented. Positive (negative) sea ice concentration anomaly in November is associated with a strengthened (weakened) stratospheric polar vortex and these anomalies propagate downward leading to the positive (negative) NAO-like pattern in the late December to early January. In addition, results from an idealized model study show in detail a potential mechanism of this vertical link over a period of one and a half months.

Joint Inter-Association Symposium

JM02a - JM02/JM01 Climate Variability and Earth Systems Modelling (IAMAS, IAPSO, IACS) / Earth Systems Dynamics, Predictability and Probabilistic Forecasting (IAMAS, IAG, IAGA, IAPSO, IASPEI)

IUGG-1638

Robust Arctic sea-ice influence on the frequent Eurasian cold winters in past decades

M. Mori[1], *M. Watanabe*[1], *H. Shiogama*[2], *J. Inoue*[3], *M. Kimoto*[1]
[1]*The University of Tokyo, Atmosphere and Ocean Research Institute, Kashiwa, Japan*
[2]*National Institute for Environmental Studies,*
Center for Global Environmental Research, Ibaraki, Japan
[3]*National Institute of Polar Research,*
Research Organization of Information and Systems, Tokyo, Japan

During the last decade, severe winters occurred frequently in mid-latitude Eurasia, despite increasing global- and annual-mean surface air temperature. Statistical analyses of observation have suggested that these cold Eurasian winters were excited by Arctic sea-ice decline. However, it was not yet clear whether the cooling anomalies are a dynamical response to the sea-ice reduction or natural fluctuation of the atmosphere, because a robust response was yet to be obtained in the numerical model simulations perhaps owing to energetic internal fluctuations in the atmospheric circulation. In this research, we successfully detected the signature of Eurasian cold winters excited by sea-ice decline in the Barents-Kara Sea, by generating a 100-member ensemble of state-of-the-art atmospheric general circulation model simulations driven with realistic sea-ice concentration anomalies. We conclude that the observed cold Eurasian winters in the last decade are attributable to a combination of the natural fluctuation and the response to sea-ice loss.

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JM02a - JM02/JM01 Climate Variability and Earth Systems Modelling (IAMAS, IAPSO, IACS) / Earth Systems Dynamics, Predictability and Probabilistic Forecasting (IAMAS, IAG, IAGA, IAPSO, IASPEI)

IUGG-4003

Impact of the springtime Himalayan-Tibetan Plateau on the onset on the Indian summer monsoon in coupled forecasts

Y. Orsolini[1], R. Senan[2], G. Balsamo[3], A. Weisheimer[3], F. Vitart[3], F. Doblas-Reyes[4], T. Stockdale[3]
[1]NILU, Atmosphere and Climate, Kjeller, Norway
[2]University of Oslo, Department of Geosciences, Oslo, Norway
[3]ECMWF, ECMWF, Reading, United Kingdom
[4]ICREA, ICREA, Barcelona, Spain

The springtime snowpack over the Himalayan-Tibetan Plateau (HTP) region and Eurasia has long been suggested to be an influential factor on the onset of Indian summer monsoon.
Here, we examine a suite of coupled ocean-atmosphere forecasts using the Ensemble Prediction System of the European Centre for Medium-Range Weather Forecasts (ECMWF), to assess the impact of realistic initialization of springtime snow over HTP on the onset of the Indian summer monsoon. Twin sets of 4-month ensemble simulations were initialized on 1 April every year for the period 1981-2010. The “realistic” set comprises of the System 4 seasonal hindcasts routinely performed at ECMWF, where the snow is initialized with ERA-Interim/Land Re-analyses. The “unrealistic” set is identical in all aspects except that that initial conditions for snow-related land surface variables over the HTP region are scrambled. We show that high snow depth over HTP influences the meridional tropospheric temperature gradient reversal that marks the monsoon onset. Composites difference based on a normalized HTP snow index reveal that, in high snow years, the onset is delayed by about 7 days with clear signatures on surface temperature, precipitation and moisture fluxes. We further demonstrate that high April snow depths over HTP does not uniquely relate to any climate patterns prevailing over the previous winter, such as ENSO, the Indian Ocean dipole or the North Atlantic Oscillation. Accurate initialisation of spring snow depth over the HTP region could hence have strong implication for dynamical prediction of the Indian sumer monsoon onset.

Joint Inter-Association Symposium

JM02a - JM02/JM01 Climate Variability and Earth Systems Modelling (IAMAS, IAPSO, IACS) / Earth Systems Dynamics, Predictability and Probabilistic Forecasting (IAMAS, IAG, IAGA, IAPSO, IASPEI)

IUGG-4125

Atmospheric response to anomalous sea ice in the Sea of Okhotsk

K. Nishii[1], *H. Nakamura*[1], *T. Nakamura*[2]
[1]*The University of Tokyo, Research Center for Advanced Science and Technology, Tokyo, Japan*
[2]*Hokkaido University, Faculty of Environmental Earth Science, Sapporo, Japan*

Arctic sea ice has been rapidly declining in the current century in association with the global warming. Some studies attribute recent increase of extreme weather events to this sea ice reduction. Sea ice in the Sea of Okhotsk has also been declining. Honda et al. (1999) imposed sea ice anomalies in the Sea of Okhotsk on an atmospheric general circulation model (AGCM). They obtained atmospheric circulation anomalies that form a Rossby wave train extending from the Sea of Okhotsk to Alaska via the Bering Sea in winter. However, the horizontal resolution of their AGCM is only about 550 km. In this study, we used an AGCM that has higher horizontal resolution of about 150 km. Our results are partly consistent with the previous study. The atmospheric response to the sea ice reduction in our AGCM in winter (DJF) is characterized by a cyclonic SLP anomaly just over the Sea of Okhotsk, while the response in spring (MAM) shows an anticyclonic SLP anomaly over the Bering Sea. These cyclonic and anticyclonic SLP anomalies vertically extend to cyclonic and anticyclonic anomalies in the mid-troposphere, respectively, with their phases tilting westward with height. The enhancement of upward sensible and latent heat fluxes from the surface is much larger in winter than spring, and positive diabatic heating anomaly in mid and upper troposphere is only observed in association with positive precipitation anomalies over the Sea of Okhotsk. We will perform thermal budget to discuss formation mechanism of the atmospheric response.

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IUGG-4184

Summer-to-winter sea-ice linkage between the Arctic Ocean and the Okhotsk Sea through atmospheric circulation

M. Ogi[1], B. Taguchi[2], M. Honda[3], D.G. Barber[1], S. Rysgaard[1]
[1]University of Manitoba, Centre for Earth Observation Science, Winnipeg, Canada
[2]Japan Agency for Marine-Earth Science and Technology, Application Laboratory, Yokohama, Japan
[3]Niigata University, Faculty of Science, Niigata, Japan

Contemporary climate science seeks to understand the rate and magnitude of a warming global climate and how it impacts regional variability and teleconnections. One of the key drivers of regional climate is the observed reduction in end of summer sea ice extent over the Arctic. Here we show that interannual variations between the September Arctic sea ice concentration, especially in the East Siberian Sea, and the maximum Okhotsk sea ice extent in the following winter are positively correlated, which is not explained by the recent warming trend only. An increase of sea ice both in the East Siberian Sea and the Okhotsk Sea and corresponding atmospheric patterns, showing a seesaw between positive anomalies of sea level pressures over the Arctic Ocean and negative anomalies over the mid-latitudes, are related to cold anomalies over the high-latitude Eurasian continent. The patterns of atmospheric circulation and air temperatures are similar to those of the annually integrated Arctic Oscillation (AO). The negative annual AO forms colder anomalies in autumn sea surface temperatures both over the East Siberian Sea and the Okhotsk Sea, which causes heavy sea-ice conditions in both seas through season-to-season persistence.

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IUGG-5699

Towards understanding and modeling the atmosphere-ocean-ice sheet system of Glacial-Interglacial cycles

A. Abe-Ouchi[1]
[1]*University of Tokyo, Tokyo, Japan*

The waxing and waning of Northern Hemisphere ice sheets over the past one million years is dominated by an approximately 100-kyr periodicity with a sawtooth pattern. Milankovitch theory proposes that summer insolation at high northern latitudes drives the glacial cycles. However, insolation alone cannot explain the strong 100 kyr cycle which presumably arises through internal climatic feedbacks. Combining climate model experiments and ice sheet models, we show that the ~100-kyr periodicity can be explained by insolation and internal feedback amongst the climate, ice sheet and lithosphere/asthenosphere system. We found that equilibrium states of ice sheets exhibit hysteresis responses to summer insolation, and that the shape and position of the hysteresis loop play a key role in determining the periodicities of glacial cycles. Deep Ocean circulation indicated by geochemical tracers also varied during the ice age cycle with climate and the Milankovitch cycle. Especially at the last Glacial Maximum, multiple line of evidences shows that the water originated from the North Atlantic (NADW) was shallower than the present day ocean, which means the Northern sourced water is reduced compared to the Southern source, not captured well in most of the climate models. We find from our MIROC AOGCM sensitivity experiments and multi-model analysis of CMIP5/PMIP3 LGM experiments that the key processes for the strengthening/weakening of AMOC under glacial condition (other than fresh water forcing) are at first the cooling and brine rejection in the Southern ocean and second the interaction between atmosphere, seaice and ocean in the North Atlantic region with the existence of large ice sheets.

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IUGG-1794

Factors influencing atmospheric circulation anomalies in middle latitudes

R. Greatbatch[1]*, G. Gollan*[1]*, T. Jung*[2]
[1]*GEOMAR Helmholtz Centre for Ocean Research Kiel,*
Ocean Circulation and Climate Dynamics, Kiel, Germany
[2]*Alfred Wegner Institute, Climate Sciences - Climate Dynamics, Bremerhaven, Germany*

Results obtained from applying a relaxation technique to a recent version of the ECMWF model are described. The relaxation technique draws the model atmosphere towards reanalysis (e.g. ERA-40 or ERA-Interim) in specified regions of the model domain, e.g. the tropics or the stratosphere, and enables the impact of these regions on the rest of the model atmosphere to be assessed and compared with observations. Of particular interest is the influence from the tropics which can sometimes be important over the Euro-Atlantic sector and also plays a role in the variability and trend of the austral summer Southern Annular Mode. The latter contrasts (although is not necessarily inconsistent with) the commonly accepted view that anthropogenic forcing (ozone and greenhouse gases) is important for explaining the variability and trend of the austral summer SAM.

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IUGG-2718

Latest developments of the met office global and regional ensemble prediction system

R. Swinbank[1], *A. McCabe*[1], *S. Hagelin*[1]
[1]*Met Office, Weather Science, Exeter, United Kingdom*

The Met Office Global and Regional Ensemble Prediction System (MOGREPS) consists of a 2.2km convective-scale ensemble to produce short-range for the UK, which is nested in a 33km global ensemble. Both ensembles are currently run four times a day with 12 members.
During 2014/15 both the global and UK ensemble have been upgraded to use a new dynamical core, known as ENDGame. Currently MOGREPS-UK is run as a downscaler, entirely driven by the global ensemble. During the next year, the UK ensemble will be upgraded to use the UKV analysis and an initial implementation of stochastic physics that is designed to better capture the uncertainties in forecasts of fog and low cloud. The talk will include results showing the impact of these changes.
With the installation of new high-performance computing capacity, further enhancements are being considered, which are likely to include higher resolution model and running a small ensemble every hour – with products taken from a lagged ensemble.

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IUGG-4790

Predictability of atmospheric ciculation regimes at extended range

L. Ferranti[1]
[1]*ECMWF, Forecast Department, Reading, United Kingdom*

The predictability of Euro-Atlantic regimes is studied by looking at 20 years of re-forecast data set from the European Centre for Medium-range Weather Forecast (ECMWF) ensemble system. The analysis covers the medium and sub-seasonal ranges. Potential drivers for the maintenance of a regime circulation and for transitions between regimes will be studied by analysing the time evolution of each individual model realization. The analysis is then extended to other models by using the S2S dataset.

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IUGG-4933

An investigation of the dynamics of forecast uncertainty in global atmospheric model forecasts

I. Szunyogh[1], *M. Herrera*[1], *G. Gyarmati*[1], *C. Loeser*[1], *J. Tribbia*[2]
[1]*Texas A&M University, Atmospheric Sciences, College Station, USA*
[2]*National Center for Atmospheric Research, NCAR, Boulder- CO, USA*

We investigate the dynamics of the forecast uncertainty in global atmospheric model forecasts. In particular, we study the process by which uncertainties due to initial condition and model errors propagate toward the synoptic scales.

We analyze ensemble forecast data from the THORPEX Interactive Grand Global Ensemble (TIGGE) data set and carry out numerical experiments with Community Atmospheric Model (CAM). The results suggest that there are important differences, especially at the shorter than 3-day forecast times, in the behavior of the different ensemble forecast systems included in TIGGE. The different operational global ensemble systems are clearly tuned to satisfy different optimality conditions. While the systems that employ stochastic schemes for the representation of the effect of model uncertainty perform better in the medium-range, they also have an elevated level of bias in the long-range.

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IUGG-5295

Understanding the non-Gaussian probability distributions of large-scale atmospheric and oceanic variables and their implications for predictability

P. Sardeshmukh[1], *C. Penland*[2]
[1]*University of Colorado and NOAA, CIRES/CU and PSD/ESRL/NOAA, Boulder, USA*
[2]*NOAA, PSD/ESRL/NOAA, Boulder, USA*

The probability distributions of large-scale atmospheric and oceanic variables are distinctively skewed and heavy-tailed. We show that this is fundamentally due to the fact that in a quadratically nonlinear system with a quadratic invariant, the coupling coefficients between system components are not constant but depend linearly on the system state in a distinctive way. In particular, the skewness arises from a tendency of the system trajectories to linger near states of weak coupling. We show that the salient features of the observed non-Gaussianity can be captured in the simplest such nonlinear 2-component system. If the system is stochastically forced and linearly damped, with one component damped much more strongly than the other, then the strongly damped fast component becomes effectively decoupled from the weakly damped slow component, and its impact on the slow component can be approximated as a stochastic noise forcing plus an augmented nonlinear damping. In the limit of large time-scale separation, the nonlinear augmentation of the damping becomes small, and the noise forcing can be approximated as an additive noise plus a correlated additive and multiplicative noise (CAM noise) forcing. The probability distribution of the slow component converges to the well-known Stochastically Generated Skewed (SGS) distribution in this limit. We argue that much of the diversity of observed large-scale atmospheric and oceanic probability distributions can be interpreted in this minimal framework. Our analysis provides a fundamental basis for the ubiquity of SGS distributions encountered in the climate system. It also has important implications for the asymmetric persistence and predictability of extreme positive and negative anomalies.

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IUGG-3026

Extratropical air-sea interaction: Kuroshio front/eddies, Pacific storm track and climate variability

P. Chang[1]*, X. Ma*[1]*, R. Saravanan*[2]*, R. Montuoro*[2]*, H. NAKAMURA*[3]
[1]*Texas A&M University, Oceanography, College Station- TX, USA*
[2]*Texas A&M University, Atmospheric Sciences, College Station- TX, USA*
[3]*University of Tokyo, Research Center for Advanced Science and Technology, Tokyo, Japan*

Eddy-rich western boundary current regimes, such as the Kuroshio and Gulf Stream Extension regions, have been identified as key locations in the extratropics where SST variability may provide an important source of energy for driving atmospheric variability. In this talk, we present high-resolution regional climate modeling results, supported by observational analyses, that the rectified effects of meso-scale SST variability, largely confined in the Kuroshio-Oyashio confluence region (KOCR), can exert a significant remote influence on Pacific storm track and winter rainfall variability along the U. S. Northern Pacific coast. We further show that the ocean mesoscale eddy-atmosphere (OME-A) feedback plays an important role in maintaining the sharp SST gradient along the Kuroshio Extension. These findings point to the need to improve the representation of ocean mesoscale eddies and their interactions with the atmosphere in climate models.

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IUGG-3539

Separated imprints of the Kuroshio Extension and Oyashio fronts on the wintertime atmospheric boundary layer

R. Masunaga[1], H. Nakamura[1], T. Miyasaka[1], K. Nishii[1], Y. Tanimoto[2], B. Qiu[3]
[1]Research Center for Advanced Science and Technology- The university of Tokyo, Climate Science Research Laboratory, Tokyo, Japan
[2]Hokkaido University, Environmental Earth Science, Sapporo, Japan
[3]University of Hawaii, Department of Oceanography, Honolulu, USA

Mesoscale structures of the wintertime marine atmospheric boundary layer (MABL) as imprints of the Oyashio and Kuroshio Extension (KE) fronts east of Japan are investigated. The resolution of SST data prescribed for the ERA-Interim global atmospheric reanalysis has been substantially improved in 2002 with grid intervals changed from 1.0 deg. to 0.5 deg. Only the higher-resolution SST data can clearly represent the KE and Oyashio fronts, separately. To identify the imprints of these oceanic fronts on the MABL, wintertime ERA-Interim climatology constructed for the high-resolution SST period is compared with that for the low-resolution SST period. Climatologically, satellite observations capture dual local maxima in each of upward turbulent heat fluxes at the surface, surface wind convergence, cloudiness and precipitation on the warmer flanks of the KE and the Oyashio fronts. These dual-peak atmospheric features are reproduced in the ERA-Interim in its high-resolution SST period. Correspondingly, dual maxima/minima are evident also in meridionally high-pass-filtered fields of potential temperature and upward motions both in MABL and also in SLP. However, these dual-peak features are totally missing in the ERA-Interim during its low-resolution SST period. These results indicate that not only the KE front but also the Oyashio front can climatologically leave mesoscale imprints on the overlying MABL. Furthermore, both the satellite data and the ERA-Interim reveal that these mesoscale atmospheric distributions in the KOE region are modulated substantially with SST variations associated with the decadal-scale variability of the KE system. Specifically, the dual-peak features in MABL are more distinct in the stable regime of the KE than in its unstable regime.

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IUGG-3817

Impact of warm ocean currents on the three-dimensional cloud structure from space

A. Yamauchi[1], *K. Kawamoto*[1], *A. Manda*[1]
[1]*Nagasaki University,*
Graduate School of Fisheries Science and Environmental Studies, Nagasaki, Japan

This study examines changes in the three-dimensional structure and cloud particle growth processes of clouds induced by strong upward wind flow over the Kuroshio Current. Recent studies have shown that strong updrafts over warm ocean currents such as the Gulf Stream and Kuroshio have an impact on large-scale atmospheric circulation. Such strong upward air flow has the potential to affect the growth processes of cloud particles. This study explored how the warm ocean current affects the frequency of occurrence and the vertical structure of clouds by analyzing state-of-the-art, satellite-based cloud radar data around the Kuroshio, one of the world’s strongest warm ocean currents. Our results showed that the occurrence frequency of geometrically thick and strongly precipitating clouds increased over the Kuroshio. Rainfall intensity in the lower and middle troposphere (1–6 km in height) over the Kuroshio was greater than that of surrounding areas. Additionally, the cloud particle size near the cloud top increased over the Kuroshio compared with surrounding areas. These results can contribute to cloud parameterization of climate models by clarifying the behavior inside the clouds that has yet to be addressed in detail.

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IUGG-4129

Wintertime atmospheric response to decadal SST anomalies in the North Pacific frontal zone and its relationship to atmospheric internal variability

S. Okajima[1], *H. Nakamura*[1,2], *K. Nishii*[1], *T. Miyasaka*[1], *A. Kuwano-Yoshida*[2], *B. Taguchi*[2]
[1]*Research Center for Advanced Science and Technology, The University of Tokyo, Tokyo, Japan*
[2]*Application Laboratory, JAMSTEC, Yokohama, Japan*

Decadal-scale warm SST anomaly observed in the North Pacific subarctic frontal zone (SAFZ) tends to accompany a basin-scale anticyclonic anomaly that peaks in January. This equivalent barotropic anomaly is reproduced in our ensemble AGCM experiments as a response to prescribed warm SST anomaly as observed in SAFZ. The experiment also reproduce the weakening of the observed anticyclonic anomaly in February to some extent. As observed, the simulated anticyclonic anomaly is maintained mainly through energy conversion from the ensemble mean circulation realized under the climatological SST, suggesting that the anomaly may have a characteristic of a dynamical mode. Conversion of both available potential energy (APE) and kinetic energy (KE) from the mean flow is important for the observed anomaly, while only the former is important for the model response. This is because the model response is located closer to the jet core region whereas the observed anomaly is in the jet exit region, which appears to be in correspondence to the zonal displacement of the center of the dominant atmospheric internal variability between the model and observation. Transient eddy feedback forcing also acts to maintain the observed anomaly rather efficiently, while its efficiency is much lower for the simulated response. A multi-decadal integration of our coupled GCM also suggests that atmospheric internal variability may be important for determining atmospheric response to the decadal SST variability of the SAFZ.

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IUGG-4644

The atmospheric response to a realistic shift in the Oyashio sea surface temperature front

M. Newman[1], *D. Smirnov*[2], *M. Alexander*[3], *Y.O. Kwon*[4], *C. Frankignoul*[5]
[1]*CIRES/University of Colorado and NOAA/ESRL/PSD, boulder, USA*
[2]*Dewberry Consultants, n/a, denver, USA*
[3]*NOAA/ESRL, PSD, boulder, USA*
[4]*Woods Hole Oceanographic Institution, Physical Oceanography, woods hole, USA*
[5]*Université Pierre et Marie Curie, LOCEAN/IPSL, paris, France*

The atmospheric response to a realistic shift of the Oyashio Extension SST front in the western North Pacific is analyzed using a high-resolution (0.25°, HR) version of the global Community Atmosphere Model version 5 (CAM5). A northward shift in the SST front causes an atmospheric response consisting of a weak surface wind anomaly but a strong vertical circulation extending throughout the troposphere. In the lower troposphere, most of the SST anomaly induced diabatic heating is balanced by poleward transient eddy heat and moisture fluxes. This response can be seen in the development of individual extratropical cyclones. Collectively, this response differs from the circulation suggested by linear dynamics, where extratropical SST forcing produces shallow anomalous heating balanced by strong equatorward cold air advection driven by an anomalous, stationary mean surface low forming to the east. This latter response, however, is obtained, by repeating the same experiment except using a relatively low-resolution (1°, LR) version of CAM5. Comparison to observations suggests that the HR response is closer to nature than the LR response. Strikingly, HR and LR experiments have almost identical vertical profiles of diabatic heating ?. The results herein suggest that changes in transient eddy heat and moisture fluxes are critical to the overall local atmospheric response to Oyashio front anomalies, which consequently yield a stronger downstream response, with a northward shift in the storm track as it enters North America. These changes may require high resolution to be fully reproduced, warranting further experiments of this type with other high resolution atmosphere-only and fully coupled GCMs.

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IUGG-5307

The response of the lower troposphere to ocean sea surface temperature fronts and eddies

N. Schneider[1], *K. Kikuchi*[2], *H. Nakamura*[3], *M. Nonaka*[4], *J. Small*[5], *K. Takatama*[2], *B. Taguchi*[4]
[1]*University of Hawaii at Manoa, Oceanography and International Pacific Research Center, Honolulu, USA*
[2]*University of Hawaii at Manoa, International Pacific Research Center, Honolulu, USA*
[3]*Research Center for Advanced Science and Technology, The University of Tokyo, Tokyo, Japan*
[4]*Japan Agency for Marine-Earth Science and Technology, Application Lab, Yokohama, Japan*
[5]*National Center for Atmospheric Research, Climate&Global Dynamics- NCAR Earth System Laboratory, Boulder, USA*

The near-surface atmospheric response to the sea-surface temperature fluctuations associated with ocean fronts and eddies is described by a linear model that includes the classical vertical mixing and baroclinic pressure effects, advection by a background Ekman spiral, and pressure fluctuations induced outside of the boundary layer. Tests of this model using satellite observations and output of general circulation models forced by high-resolution sea-surface temperature are encouraging and show that frontal air- sea interactions are governed by wave-number dependent response functions, and that the baroclinic pressure effect dominates for weak, and the vertical mixing effect for strong background winds. The model predicts coupling coefficients traditionally used to characterize the atmospheric response to sea surface temperature fronts and will be used to discuss their variability.

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IUGG-1524

Variability of the Amundsen Sea Low and the Associated Regional Sea Ice Trends in the AO-UMUKCA Model

A. Jrrar[1], *N.L. Abraham*[2,3], *D. Holland*[1,4], *J. Pyle*[2,3]
[1]*Center for Global Sea Level Change, NYU Abu Dhabi, Abu Dhabi, United Arab Emirates*
[2]*Centre for Atmospheric Science, Department of Chemistry, Cambridge, United Kingdom*
[3]*NCAS - Climate, University of Cambridge, Cambridge, United Kingdom*
[4]*EFDL, New York University, New York, USA*

Significant sea ice loss in the Amundsen and Bellingshausen Seas and regional warming in West Antarctica and the Antarctica Peninsula have been observed over the last few decades. These changes are influenced by the presence of the Amundsen Sea Low (ASL), a quasi-stationary area of climatological low pressure that exists over the South Pacific sector of the Southern Ocean between the Antarctic Peninsula and the Ross Sea.

Previous studies have shown that the circulation in the ASL sector region is strongly influenced by large-scale patterns of atmospheric variability, such as the southern annular mode (SAM) and El Nino Southern Oscillation (ENSO).

Studies have also demonstrated a deepening of the ASL, in austral spring and to a lesser extent autumn, the former related to decreases in the underlying cyclone central pressures and the latter previously suggested as due to stratospheric ozone depletion. However, two recent studies have shown that surface warming related to the Atlantic Multidecadal Oscillation (AMO) reduces the surface pressure in the Amundsen Sea and contributes to the observed dipole-like sea-ice redistribution between the Ross and Amundsen–Bellingshausen seas and to the Antarctic Peninsula warming.
We use the recently developed atmosphere-ocean chemistry-climate model AO-UMUKCA to investigate factors affecting the variability of the ASL and subsequently sea ice trends in the Amundsen-Bellingshausen seas. We use output from two simulations, a pre-industrial control integration forced with 1850s climate, and a time slice integration forced with 2000s climate. We investigate whether changes in the ASL are linked to variability in tropical sea surface

temperatures. The different combinations of SAM-ENSO phase are also studied and linked to changes in the ASL.

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IUGG-2336

Seasonality of the subtropical high and storm-track over the South Indian Ocean and its influence on low-level clouds

A. Miyamoto[1], H. Nakamura[1,2], T. Miyasaka[1]
[1]The University of Tokyo, Research Center for Advanced Science and Technology, Tokyo, Japan
[2]JAMSTEC, Research Institute for Global Change, Yokohama, Japan

Over the South Indian Ocean, there is notable seasonality in the subtropical high and storm-track activity. In summer the subtropical high resides over the eastern portion of the basin, while the high strengthens in winter, shifting westward toward the seasonally-enhanced Agulhas storm-track core. The present study investigates how the seasonality of the high and storm-track can influence the formation of low-level clouds, which are important for the Earth’s radiation budget. The MODIS satellite data reveal that stratocumulus clouds are dominant in summer off the west coast of Australia, where near-surface cold advection and descending motion are enhanced with the summertime subtropical high. In midlatitudes, in addition to stratocumulus clouds, fog and stratus clouds can also form under anomalous near-surface warm advection. Daily lag composite analysis shows the importance of anomalous warm advection induced by quasi-stationary Rossby waves in the formation of low-level clouds. In winter, low-level clouds form more extensively over the subtropical ocean than in summer. To the north of the subtropical SST frontal zone, however, cumulus clouds rather than stratocumulus clouds are prevalent, owing to enhanced latent heat flux from the ocean under the Trades, which is likely to induce 'decoupling'. In midlatitudes, more enhanced eddy activity than in summer contributes to the formation of stratocumulus and stratus clouds. Our analysis highlights the importance of the combined effect among the subtropical high, stationary and transient atmospheric eddies, SST and its gradient in determining the local properties of low-level clouds and their seasonality.

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IUGG-2945

Role of the mid-latitude oceanic front in the ozone-induced climate change in southern hemisphere as revealed in aqua planet experiments

F. Ogawa[1,2], N.E. Omrani[1,2], K. Nishii[3], H. Nakamura[3,4], N. Keenlyside[1,2]
[1]University of Bergen, Geophysical Institute, Bergen, Norway
[2]Bjerknes Centre for Climate Research, -, Bergen, Norway
[3]University of Tokyo, Research Center for Advanced Science and Technology, Tokyo, Japan
[4]Japan Agency for Marine-Earth Science and Technology, -, Yokohama, Japan

The Southern Hemisphere Annular Mode (SAM) is the dominant mode of low-frequency atmospheric variability in the extratropical Southern Hemisphere, exerting substantial climatic impacts on extensive regions. A decadal trend of SAM observed in the troposphere during the late 20th century is considered to be related to the intensification of the stratospheric polar vortex induced by the ozone depletion. Known as a manifestation of meridional displacements of the eddy-driven polar-front jet (PFJ) and associated storm-track, the tropospheric SAM and its trend may be sensitive to the near-surface baroclinicity associated with the midlatitude oceanic frontal zone. In the present study, aqua-planet experiments with an atmospheric general circulation model are conducted by prescribing two different latitudinal profiles of zonally symmetric sea-surface temperature (SST) with and without frontal gradient in midlatitudes. A comparison of the tropospheric response to the assigned stratospheric ozone depletion between the two SST profiles reveals critical importance of the frontal SST gradient for translating the direct response of the stratospheric polar vortex to the ozone depletion down to the surface by enhancing the SAM variability and allowing the SAM its deep structure into the stratosphere in late spring through early summer.

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IUGG-3289

Potential importance of midlatitude ocean fronts for the annular-mode variability: Inter-basin differences in the southern annular-mode signature

H. Nakamura[1], *F. Ogawa*[2]
[1]*University of Tokyo, RCAST, Tokyo, Japan*
[2]*University of Bergen, Geophysical Institute, Bergen, Norway*

Annular-mode variability in the extratropical atmosphere is manifested as latitudinal shifts of an eddy-driven polar front jet (PFJ) and associated stormtrack. Climatologically, they are both observed slightly poleward of a midlatitude oceanic front, a confluent region of warm and cool ocean currents, which maintains a surface baroclinic zone against poleward eddy heat transport. A set of “aqua-planet” AGCM experiments with zonally-uniform SST, which mimics the Southern Hemisphere, reveals certain sensitivity of the nodal latitude of anomalous westerlies associated with the annular mode to the latitude of frontal SST gradient. The sensitivity is evident for its positive phase, where PFJ is situated systematically poleward of the SST front wherever it is located. Insensitively to the frontal latitude, by contrast, PFJ for the negative phase resides near 40° latitude, which nearly corresponds to the climatological PFJ axis that is realized without frontal SST gradient. The annular mode can therefore be interpreted as wobble of the atmospheric circulation system between a regime dominated by thermodynamic influence of frontal SST gradient and that by atmospheric internal dynamics. This notion is found useful for understanding inter-basin differences observed in the wintertime signature of the Southern Annular Mode (SAM) that are superimposed on the dominant zonally uniform signature. Compared to its negative phase, the axis of the surface westerlies observed in the positive phase of SAM exhibits stronger latitudinal excursions, which appears to reflect the inter-basin differences in the latitude of the oceanic frontal zone.

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IUGG-4169

A 20-year climatology simulated by non-hydrostatic icosahedral atmospheric model NICAM

C. Kodama[1], Y. Yamada[1], A. T. Noda[2], K. Kikuchi[3], Y. Kajikawa[4], T. Nasuno[1], T. Tomita[5], T. Yamaura[4], H. Takahashi[6,7], M. Hara[8], Y. Kawatani[9], M. Satoh[2,10], M. Sugi[11]
[1]Japan Agency for Marine-Earth Science and Technology, Dept. Seamless Environmental Prediction Research, Yokohama, Japan
[2]Japan Agency for Marine-Earth Science and Technology, Project Team for Risk Information on Climate Change, Yokohama, Japan
[3]University of Hawaii, International Pacific Research Center, Honolulu, USA
[4]RIKEN, Advanced Institute for Computational Science, Kobe, Japan
[5]Kumamoto University, Faculty of Science, Kumamoto, Japan
[6]Tokyo Metropolitan University, Graduate School of Urban Environmental Sciences, Hachioji, Japan
[7]Japan Agency for Marine-Earth Science and Technology, Dept. Integrated Climate Change Projection Research, Yokohama, Japan
[8]Center for Environmental Science in Saitama, none, Kazo, Japan
[9]Japan Agency for Marine-Earth Science and Technology, Dept. Integrated Climate Change Projection, Yokohama, Japan
[10]The University of Tokyo, Atmosphere and Ocean Research Institute, Kashiwa, Japan
[11]Meteorological Research Institute, Climate Research Department, Tsukuba, Japan

A 20-year integration by Non-hydrostatic Icosahedral Atmospheric Model (NICAM) with a 14-km mesh was conducted for the first time to obtain a climatological mean and diurnal-to-interannual variability of a simulated atmosphere. Clouds were explicitly calculated using a cloud microphysics scheme without cumulus convection scheme. The simulation was performed under the Atmospheric Model Intercomparison Project (AMIP)-type conditions except that sea surface temperature was nudged toward observed historical values using a slab-ocean model. NICAM reasonably simulates many aspects of atmospheric climatological mean state and variability. Geographical distributions of precipitation, including interannual, seasonal and diurnal variations are well reproduced. Zonal mean basic states, clouds and top-of-atmosphere radiation are

comparable to observed values. TCs and MJO are the major focus of the simulation. In the simulation, TCs are detected with objective thresholds of maximum wind speed, owing to the realistic intensity of simulated TCs. Seasonal march of TC genesis in each ocean basin is well simulated. Statistical property of the MJO and tropical waves is well reproduced in the space-time power spectra, consistent with previous NICAM studies. This implies that the stratospheric variability is also reproduced, as partly revealed in this study. Asian monsoon analysis shows that climatological western North Pacific monsoon onset occurs near the observed onset, and that the Baiu front is reproduced to some extent. Some significant model biases still exist, which indicates a need for further model improvements. The results of this study indicate that a high-resolution global non-hydrostatic model has the potential to reveal multi-scale phenomena in the climate system.

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IUGG-5669

An atmospheric origin of the multi-decadal bipolar seesaw

Z. Wang[1], X. Zhang[2], Z. Guan[1], B. Sun[3], X. Yang[4], C. Liu[1]
*[1]Nanjing University of Information Science and Technology,
Polar Climate System and Global Change Laboratory, Nanjing,
China Peoples Republic*
*[2]University of Alaska Fairbanks,
International Arctic Research Center and Department of Atmospheric Sciences,
Fairbanks, USA*
*[3]Polar Research Institute of China, Glaciology Division, Shanghai,
China Peoples Republic*
[4]British Antarctic Survey, Climate Program, Cambridge, United Kingdom

A prominent feature of recent climatic change is the strong Arctic surface warming that is contemporaneous with broad cooling over much of Antarctica and the Southern Ocean. Longer global surface temperature observations suggest that this contrasting pole-to-pole change could be a manifestation of a multi-decadal interhemispheric or bipolar seesaw pattern, which is well correlated with the North Atlantic sea surface temperature variability, and thus generally hypothesized to originate from Atlantic meridional overturning circulation oscillations. We found that there is an atmospheric origin for this seesaw pattern. The analysis of long-term instrumental data indicates that the Southern Ocean surface cooling (warming) associated with the seesaw pattern is attributable to the strengthening (weakening) of the Southern Hemisphere westerlies, which can be traced to Northern Hemisphere and tropical tropospheric warming (cooling). Antarctic ozone depletion has been suggested to be an important driving force behind the recently observed increase in the Southern Hemisphere’s summer westerly winds; our results imply that Northern Hemisphere and tropical warming may have played a triggering role at an stage earlier than the first detectable Antarctic ozone depletion, and enhanced Antarctic ozone depletion through decreasing the lower stratospheric temperature.

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IUGG-1400

Roles of internal and external processes in the Atlantic multidecadal variability

<u>M. Watanabe</u>[1], T. Tahaka[1]
[1]University of Tokyo, Atmosphere and Ocean Research Institute, Kashiwa, Japan

Atlantic multidecadal variability (AMV), as defined by sea surface temperature (SST) anomalies averaged over the North Atlantic basin, is known to fluctuate on interdecadal timescale. A recent study suggests the time evolution of the AMV is controlled by external forcing due mainly to sulphate aerosol emission, but the mechanism counteracts an existing view of the AMV being generated via internal processes associated with changes in Atlantic meridional overturning circulation (AMOC) and thus controversy remains. In this study, we performed ensemble historical simulations with the MIROC climate model for attributing the AMV to internal and external processes. The historical run with all the radiative forcing drivers reproduced well the time evolution of the AMV index whereas a similar historical experiment with fixed sulphate aerosol failed, suggesting a crucial role of aerosol induced radiative forcing in AMV. However, the reproducibility of the AMV is confined to mid- and low-latitudes in historical runs, and internally generated oscillation has a large amplitude in high-latitudes where SST anomalies are strongly coupled with AMOC. These results suggest that, based on a single model though, the observed AMV is not a unique mode of variability but a mixture of externally forced response to sulphate aerosol and internally generated multidecadal oscillation.

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IUGG-2478

On the extreme 2013/2014 Boreal Winter: role of sea surface temperature and sea ice

H.H. Hsu[1], *M.Y. Lee*[2], *C.C. Hong*[3]
[1]*Academia Sinica, Research Center for Environmental Changes, Taipei, Taiwan Republic of China*
[2]*Central Weather Bureau, Division of Extended Forecast, Taipei, Taiwan Republic of China*
[3]*University of Taipei, Department of Earth and Life, Taipei, Taiwan Republic of China*

A series of record-breaking circulations with extreme weather and climate events occurred in the extratropical Northern Hemisphere during the winter of 2013/14. The observed anomalous circulations were the manifestation of the known Pacific pattern or the NPO-WP teleconnection pattern but with a record-breaking amplitude. Results of numerical simulations suggest that the extreme sea surface temperature anomalies in the tropical Pacific and the extratropical North Pacific and the low sea ice concentration in the Arctic constructively induced the anomalous atmospheric circulations. Natural variability played a major role in inducing the anomaly pattern, whereas the rising sea surface temperature and reducing sea ice contributed to the extremity of the event. If the anthropogenic warming has a significant effect in causing the synchronization of aforementioned extreme sea surface temperature and sea ice and continues doing so in the near future, the possibility that a severe winter like the boreal winter 2013/14 occur more frequently can not be ruled out.

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IUGG-4546

Impact of Solar variability of hemispheric climate changes on multilateral time scales

R.K. Tiwari[1], *R. Rekapalli*[1]
[1]*CSIR-NGRI- AcSIR-NGRI- Uppal Road- Hyderabad- India,*
Theoretical Modeling and Engineering Geophysics Group, Hyderabad, India

Several past studies indicated diversified result on the solar impact on northern and southern hemispheric climate pattern. Here we attempt to analyze the hemispheric surface air temperature (SAT) variation and sea surface temperature (SST) variability data during 1850 to present. We employ Singular Spectrum Analysis (SSA) and Wavelet methods to address the hemispheric climate departure, solar induced periodicities, and modulation, if any. As the ocean atmospheric dynamical coupling shows an important effect on the climate pattern, the combined study of SST and SAT would allow us to demonstrate the solar induced forcing on climate. The correlation, cross correlation and cross spectral analysis of SAT and SST with sun spot number (SSN) and total solar irradiance (TSI) performed to know the solar forcing on hemispheric climate through SAT and SST variations. More or less both the hemispheric SAT shows synchronicity with solar variability. Interestingly, the SST data revealed that the inverse cooling and warming reversals in every 53 years which could be the mechanism for the known ocean- atmospheric oscillations of the same periodicity. This reversals take place at the second half of the minimum solar active period rendering that the so called ocean atmospheric cycles is also driven by the solar effect.

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IUGG-4729

Impact of the winter NAO on the WP pattern in the following winter through Arctic sea ice and ENSO

Y. Tachibana[1], *M. Oshika*[1], *T. Nakamura*[2], *M. Hara*[3]
[1]*Mie University, Fac. of Bioresources, Mie, Japan*
[2]*Hokkaido University, Faculty of Environmental Earth Science, Sapporo, Japan*
[3]*Saitama Prefecture, International Environmental Center, Kasu, Japan*

This study tested the hypothesis that Asian weather and climate in a given winter can be predicted 1 year in advance. On the basis of a 51-year statistical analysis of reanalysis data, we propose for the first time that the positive phase of the Western Pacific (WP) pattern in the winter is linked to the negative phase of the North Atlantic Oscillation (NAO) in the previous winter, and vice versa. We show that there are two possible mechanisms responsible for this interannual remote linkage. One is an Arctic mechanism. The negative phase of the winter NAO changes oceanic currents in the North Atlantic and weakens oceanic heat transport into the Arctic. This weakened heat transport also slows down the reduction of sea ice in the spring. Extensive Arctic sea ice in the summer after a negative NAO acts as a bridge to the positive phase of the WP in the next winter. The other mechanism involves the tropics. An El Niño occurrence after a negative winter NAO acts as another bridge to the positive phase of the WP in the following winter. The timescale of the Arctic route is nearly decadal, whereas that of the tropical route is about 3–5 years. The tropical mechanism indicates that the NAO remotely excites an El Niño in the second half of the following year. A process perhaps responsible for the El Niño occurrence was investigated statistically. A negative NAO in the winter increases Eurasian snow cover. This anomalous snow cover then intensifies the cold air outbreak from Asia to the western tropical Pacific. This outbreak can intensify the westerly wind burst and excite El Niño in the following year. We suggest that the phase of the NAO in the winter could be a predictor of the WP in the following year. Detailed is in Oshika, Tachibana and Nakamura (2014), **Climate Dynamics**.

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IUGG-5144

Interdecadal Pacific and Atlantic Ocean variability and the ongoing warming 'hiatus'

M. ENGLAND[1]
[1]*UNSW, Climate Change Research Centre, Sydney, Australia*

In this talk I will discuss modes of Pacific and Atlantic variability that can lead to a slowdown, or hiatus, in global surface warming despite increases in anthropogenic greenhouse gases. I will show that while Atlantic-driven hiatuses are entirely plausible, the climate of the North Atlantic has enhanced global-average air temperature since 2001, not reduced it. In contrast a pronounced strengthening in Pacific trade winds over the past two decades – unprecedented in observations and reanalysis data – is sufficient to account for the cooling of the tropical Pacific and a substantial slowdown in surface warming via increased subsurface ocean heat uptake. In contrast, hiatus decades originating in the North Atlantic appear to require unrealistic freshwater anomalies: well beyond those observed over the past few decades. In addition, they occur during a slowdown in NADW overturn, wherein the surface waters of the North Atlantic cool, in contrast to a mechanism proposed in recent studies. Simulations using coupled climate models suggest the present hiatus could persist for much of the present decade if the Pacific trade wind trends continue, however a rebound of rapid warming is expected once the anomalous trade wind trends abate.

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IUGG-5331

Recent changes in the atmospheric energy transport of the northern high latitudes

J. Ukita[1], M. Honda[1], M. Kadono[2], K. Iwamoto[3], Y. Harada[4], H. Kanzawa[4]
[1]Niigata University, Faculty of Science, Niigata, Japan
[2]Niigata University, Graduate School, Niigata, Japan
[3]NIPR, Niigata University, Niigata, Japan
[4]Nagoya University, Graduate School, Nagoya, Japan

Analyses based on the ERA-Interim data reveal that over the period of 1979-2010, the annually averaged poleward atmospheric energy transport (AET) increased in the northern highlatitudes (approximately >60N). This increase was dominated by the stationary component of the AET, especially that of the dry static energy (DSE), as opposed to the slightly decreasing transient component over the same period. For the annual mean, the stationary DSE component significantly accounts for the total interannual variability of the AET. Furthermore, this increase in the stationary DSE results from seasonally dependent contributions. The summer contribution to this long-term change in the AET is associated with structural changes in mean meridional circulation, in particular those of the Ferrel and polar cells. In comparison, the winter contribution is associated with changes in the stationary eddy component due to the modulation of planetary waves, especially in the Pacific sector. For the northern high latitudes, the transient component dominates the amount of the AET itself, to which the contribution from the latent heat is significant. Despite of this, as far as the long-term change is concerned, the stationary DSE component plays a more dominant role.

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IUGG-0231

The effects of different sudden stratospheric warming types on the ocean

A.H. O'Callaghan[1], M.M. Joshi[1], D.P. Stevens[2], D.M. Mitchell[3]
[1]University of East Anglia,
Climatic Research Unit- School of Environmental Sciences, Norwich, United Kingdom
[2]University of East Anglia, School of Mathematics, Norwich, United Kingdom
[3]University of Oxford, Department of Physics, Oxford, United Kingdom

There is a confirmed link between the stratosphere and surface climate with recent studies also displaying stratospheric interactions with the ocean. One process that can manifest strong stratosphere-surface coupling is a sudden stratospheric warming, hereafter SSW. Here we analyse splitting and displacement SSWs to assess their separate impacts on the ocean. The Intermediate General Circulation Model 4 is used to isolate the direct stratospheric influence on the ocean. Splitting and displacement SSWs are identified and their simulation is evaluated using dynamical benchmarks.

Following SSWs it is observed that the North Atlantic surface wind stress curl weakens for over 30 days: this is also evident in reanalysis. In the model it is found that splitting SSWs possess an enhanced ability to affect the surface climate. The splitting SSW composite displays stronger anomalies in the; tropospheric Northern Annular Mode index, surface wind stress curl, implied Ekman heat flux and net atmosphere-surface flux, with the latter two fields directly contributing to the mixed layer heat budget. The overall signal is one of warming/cooling over the North Atlantic subpolar/subtropical gyre with the exact magnitude being dependant on the mixed layer depth.

These results highlight that the ocean can provide an extra source of memory for impacts following SSWs and that splitting and displacement SSWs should be considered as separate phenomena in coupled stratospheric/tropospheric/ocean models.

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IUGG-0317

Deep ocean temperature variability - informing a strategy for Deep Argo temperature observations

F. Garry[1], *C. Roberts*[2], *E. McDonagh*[3], *A. Blaker*[4]
[1]*University of Southampton, Ocean and Earth Science, Southampton, United Kingdom*
[2]*Met Office- United Kingdom, Hadley Centre, Exeter, United Kingdom*
[3]*National Oceanography Centre, Marine Physics and Ocean Climate, Southampton, United Kingdom*
[4]*National Oceanography Centre, Marine Systems Modelling, Southampton, United Kingdom*

The ocean has the largest available capacity for heat uptake in the Earth's climate system. However, sparse and infrequent measurements of ocean temperatures below 2000 metres limit our ability to observe deep ocean heat content changes and therefore close the global heat budget or improve projection capability of future climate change and sea level rise.

We present analysis of deep (below 2000 metres) temperature variability from state of the art climate model experiments that inform the optimal design of a deep ocean observing system of automated floats that repeatedly sample to either 4000 or 6000 metres and transmit data via satellite (a deep water extension of the current core Argo array). Using long control simulations and forced experiments, we consider to what depths and in which regions we need observations to effectively capture internal variability of temperature in the oceans and emergent signals of climate change.

Our results highlight the continuing importance of the core Argo array (to 2000 metres) for measuring total ocean heat content variability accurately (with associated implications for climate prediction and sea level rise estimates). In forced scenarios we find additional deep ocean sampling below 2000 metres is essential in most ocean basins to accurately estimate total ocean heat content changes, but monitoring in the Atlantic and Southern Ocean is most critical.

Analysis of model output indicate that deep ocean sampling below 2000 metres is much more important in some areas than others. For example, we highlight the

particular importance of monitoring temperature changes in the Southern Ocean to at least 4000 metres to gain accurate estimates of global ocean heat content change and the thermosteric component of sea level rise.

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IUGG-2099

Influence of explosive cyclones on ocean in OGCMs

A. KUWANO-YOSHIDA[1], *H. Sasaki*[1], *Y. Sasai*[2]
[1]*Japan Agency for Marine-Earth Science and Technology, Application Laboratory, Yokohama, Japan*
[2]*Japan Agency for Marine-Earth Science and Technology, Research and Development Center for Global Change, Yokosuka, Japan*

Extratropical cyclones, whose central sea-level pressure deepening rates are larger than 24 hPa/24 h normalized by sine of the latitudes, are called as “explosive cyclones”. Explosive cyclones can affect ocean because they are accompanied with strong winds as large as typhoons. To understand influence of explosive cyclone on ocean, ocean responses to explosive cyclones over the North Pacific in 0.1-degree simulations by the OGCM for the Earth Simulator (OFES) are investigated. OFES data has snapshot per 3 day from 1980 to 2013 forced by daily mean wind stress of NCEP-NCAR reanalysis. Explosive deepening is defined by local deepening rate, which is local tendency of surface pressure normalized by sine of the latitude. Cyclone relative composite analysis shows that positive wind stress curl under the cyclones induces horizontal divergence in ocean from surface to 50 m depth, and upwelling appears from surface to 2000 m depth. These oceanic responses are not found for a non-explosive cyclone. However, the response in OFES is much smaller than observations. For example, the upwelling associated with explosive cyclones is found in observations by The NOAA Kuroshio Extension Observatory (KEO) buoy. When the explosive cyclone passes over the KEO buoy on 14 January 2013, mooring sensors are lifted up about 100 m for 12 hours (0.2 cm/s), although the upwelling in OFES is 0.03 cm/s.

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IUGG-3314

Dynamical response of the North Pacific Ocean to the tropical variability

M. Nonaka[1], *B. Taguchi*[2], *N. Schneider*[3]
[1]*Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan*
[2]*Japan Agency for Marine-Earth Science and Technology, Application Laboratory, Yokohama, Japan*
[3]*Univ. of Hawaii, IPRC, Honolulu, USA*

While teleconnections from the tropical Pacific to the North Pacific sea surface temperature are well known, the dynamical response of the North Pacific Ocean to the tropical atmosphere-ocean variability is not well investigated. Based on observed and reanalysis data, we investigate this link through a correlation analysis using the indices of Nino3, Nino3.4, and El Nino Modoki Index (EMI). The simultaneous correlation maps of the wind-stress curl indicate that the signal associated with EMI in the eastern North Pacific is stronger than the counterparts with Nino3 and Nino3.4. Responding to these signals in wind-stress curl, sea surface height (SSH) anomalies develop following EMI, but almost no SSH responses are found to Nino3 and Nino3.4. As El Nino Modoki lasts for a longer period than canonical El Nino, the stronger wind-stress curl signal to EMI drives the ocean more persistently, and induces substantial SSH signals. The induced SSH signals propagate westward to the western boundary region around 35N. Those signals might affect intensity and/or latitude of the Kuroshio Extension (KE) and atmospheric response to the changes of the KE.

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IUGG-5275

Impact of oceanic front on the northern hemispheric coupled stratosphere/troposphere-system

N.E. Omrani[1], *F. Ogawa*[1], *H. Nakamura*[2], *N. Keenlyside*[1], *K. Matthes*[3]
[1]*Univercity of Bergen, Geophysical institute, Bergen, Norway*
[2]*Univercity of Tokyo, Climate Science Research Laboratory, Tokyo, Japan*
[3]*GEOMAR Helmholtz Centre for Ocean Research Kiel,*
Department of Ocean Circulation and Climate Dynamics, Kiel, Germany

The dynamical and climatic impact of northern hemisphere oceanic fronts and their signature in the stratosphere/troposphere coupled system are still poorly understood. Using a set of semi-idealized experiments with a stratosphere-resolving AGCM, it is shown that the extratropical northern hemisphere oceanic fronts play a fundamental role in shaping the large-scale atmospheric circulation and transferring the stratospheric circulation changes into the troposphere. The impact of Northern hemispheric extratropical oceanic fronts on the stratosphere is shown to be dominated by the Kuroshio-Oyashio front and it is similar to the simultaneous impact of land/sea contrast and orography. It is associated with a strong adiabatic stratospheric warming, vortex weakening and a strengthening of the Brower-Dobson circulation, which are all caused mainly by resolved and partially by unresolved wave forcing. The stratospheric signature of oceanic fronts is shown to be important for understanding the very weak ozone destruction seen in the northern hemisphere. Regarding the stratosphere/troposphere coupling it is shown that the northern hemisphere oceanic fronts play a crucial role in transferring the stationary wave-induced stratospheric perturbations into the troposphere and dictating the latitudinal position of the stratosphere/troposphere coupling. The implications of our results for the mechanisms of the stratosphere/troposphere coupling are discussed.

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IUGG-5687

The influence of the gulf stream on European wintertime blocking: impacts and mechanism

S. Minobe[1], C. O'Reilly[1], A. Kuwano-Yoshida[2]
[1]Hokkaido University, Graduate School of Science, Sapporo, Japan
[2]JAMSTEC, Earth Simulator Center, Yokohama, Japan

The influence of the Gulf Stream on European wintertime blocking events is investigated by analyzing dataset of National Centers for Environmental Prediction (NCEP)-Climate Forecast System Reanalysis (CFSR) and by conducting experiments using Atmospheric General Circulation Model (AGCM) of 50 km resolution. A pair of 20-year AGCM experiments is conducted with observed satellite SST (realistic SST front associated with the Gulf Stream) and smoothed SST (obscured front) over the North Atlantic. The blocking frequency of smoothed-SST experiment is about 30% less than the observed-SST experiment over central Europe associated with eastward shifted blocking frequency maximum. The difference of the blocking frequency and distribution results in different cold spell distributions between two experiments. Thus, the Gulf Stream influences the blocking frequency and the cold spells over the Europe. Composite analysis of NCEP-CFSR and AGCM for blocking developments indicates that precipitation, eddy meridional heat flux in lower troposphere, and eddy vorticity flux in the upper troposphere are enhanced over the Gulf Stream for the early development stage of the blocking events, associated with stationary blocking ridge development. These results suggest that the local air-sea interaction over the Gulf Stream play an important role in shaping the development of the European blocking events and modifying their impacts on cold spells over Europe.

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JM02p-294

Finite-volume Atmospheric Model of the IAP/LASG (FAMIL)

Q. Bao[1]
[1]*Institute of Atmospheric Physics-CAS, LASG, Beijing, China Peoples Republic*

The Finite-volume Atmospheric Model of the IAP/LASG (FAMIL) is introduced in this talk. FAMIL have the flexible horizontal and vertical resolutions up to 25km and 1Pa respectively, which currently running on the “Tianhe 1A” supercomputer. FAMIL is the atmospheric component of the third-generation Flexible Global Ocean–Atmosphere–Land climate System model (FGOALS3) which will participate in the Coupled Model Intercomparison Project Phase 6 (CMIP6). In addition to describing the dynamical core and physical parameterizations of FAMIL, this talk describes the simulated characteristics of energy and water balances, precipitation, Asian Summer Monsoon and stratospheric circulation, and compares them with observational/reanalysis data. Finally, the model biases as well as possible solutions are discussed.

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JM02p-295

Analysis and forecasting of climate variability on basis of solar activity

E. Shermatov[1], *B. Nurtaev*[2]
[1]*Institute of Irrigation and Water Problems, Hydrology, Tashkent, Uzbekistan- Republic of*
[2]*Solterra Science, Helioclimatology, Frechen, Germany*

The Earth's climate system has constantly evolved throughout its geologic history. It is believed, the large-scale climatic changes of the pre- industrial era were caused by natural causes, such as changes in solar energy, volcanic eruptions, and natural changes in greenhouse gas concentrations.
Since the mid-20th century climate change is considered as a result of human activity or imposition of human activity on the natural climate process.The goal of this study is to identify a contribution of solar variations role in the background of climate change.
The source of virtually all the energy in the climate system is radiation from the Sun.Cloud cover, global wind patterns and precipitation are factors of natural fluctuations and long term climate change, derived due to solar energy.
The averaged temperature on latitude 85–65° in Northern hemisphere and the 10.7 cm Solar Flux were studied to analyses the statistical relationship between temperature over the period 1891-1986 and solar activity.

An empirical relationship between solar activity phases and averaged temperature in Northern hemisphere was found:

$T_{85\text{-}65°} = 257{,}795+0{,}0304F_{10,7} \pm 0{,}456$ °K

-where T 85-65° - averaged temperature on latitude 85–65° in Northern hemisphere

-257,795-air temperature, K

-0,0304- thermal conductivity coefficient of air on latitude 85–65° in Northern hemisphere for one solar cycle

-0,456 °?- a confidence interval (CI)

-$F_{10,7}$ -10.7 cm Solar Flux
This relationship can be used for analyses of temperature change in dependence from solar activity.We recommend using the air temperature of months January and July or averaged annual temperature of any studied weather station to find the contribution of power of radio emission of the Sun in temperature change.

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JM02p-296

Synoptic Situations Causing Extreme Heavy Snowfall Events in the Pacific Coast of Japan in February 2014

M. Honda[1], *A. Yamazaki*[2], *A. Kuwano-Yoshida*[2], *A. Fujita*[3], *Y. Kimura*[3], *K. Iwamoto*[4]
[1]*Niigata University, Faculty of Science, Niigata, Japan*
[2]*Japan Agency for Marine-Earth Science and Technology, Application Laboratory, Yokohama, Japan*
[3]*Niigata University, Graduate School of Science and Technology, Niigata, Japan*
[4]*National Institute of Polar Research, Arctic Environment Research Center, Tachikawa, Japan*

In the synoptic situation around Japan in early February 2014, south-coast cyclones generated every few days, and a strong blocking anticyclone had maintained on the North Pacific for about two weeks. The cyclones passing in the south coast of Japan had progressed northward through the east coast of northern Japan and into the Sea of Okhotsk in early February. Significant heavy snowfall events in the Kanto-Koshin District occurred on 8 and 14 February 2014 by those developing cyclones passing the south coast of Japan. Characteristics of its three-dimensional structures are investigated through a non-hydrostatic regional weather forecast model. Snow fall distributions are essentially simulated though the cyclone path is slightly shifted to the west. In both cases, the cyclones approaching to the south coast of the Kanto district brings warm-moist air uploading over cold air-mass in the boundary layer (about 1000 m thickness) of the west side of the Kanto Plain, caused by northeasterlies associated with an anticyclone covered over the northern Japan. In the lower troposphere (about 2000 m height), prevailing easterlies by the anticyclone and southerlies by the approaching cyclone form a stationary convergence zone over there, which stagnates 12-24 hours causing further snow-accumulation over there.

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Causes of the large warm-bias in the Angola-Benguela Frontal Zone in the Norwegian Earth System Model

S. Koseki[1], N. Keenlyside[1], F. Counillon[2], I. Bethke[3], M.L. Shen[1], T. Toniazzo[3], T. Demissie[3]
[1]University of Bergen, Geophysical Institute, Bergen, Norway
[2]Nansen Environment and Remote Sensing Centre,
Nansen Environment and Remote Sensing Centre, Bergen, Norway
[3]Uni Research, Uni Research, Bergen, Norway

Most current earth system models exhibit a large warm bias in sea surface temperature (SST) in the tropical Atlantic Ocean. The equatorial warm bias can be explained by the amplification of AGCM errors by the Bjerknes feedback. While some previous studies concluded that SST warm bias in the Angola-Benguela Frontal Zone (ABFZ) is related to the propagation of equatorial and coastal Kelvin waves, we focus on the local atmosphere-ocean processes and investigate the causes of the warm SST bias in ABFZ in the Norwegian Earth System Model (NorESM).

Our NorESM simulation has warm biases in the equatorial Atlantic and ABFZ similar to other climate models. Whereas another simulation with initialization by ensemble Kalman Filter (EnKF) is successful to reduce the warm SST bias in the equatorial Atlantic, there is still a large SST bias in the ABFZ. Sea surface height in the simulation shows that the centre of minimum (Angola Dome) shifts more southward compared to the observation. The northerly (geostrophic) Angola Current intrudes more southward and the location of ABFZ moves to 22°S. Correspondingly, the centre of the negative wind stress curl off ABFZ shifts more southward compared to the reanalysis. This wind stress anomaly is associated with the local atmospheric low-pressure anomaly over the warm SST bias in ABFZ. We hypothesize that a certain feedback loop exists among sea level pressure, ocean current and SST in the ABFZ. Sensitivity experiments with standalone AGCM and OGCM component models are performed to test this hypothesis.

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Impacts of sea ice / SST changes for the observed climate change-GREENICE project-

F. Ogawa[1,2], *Y. Gao*[2,3], *N. Keenlyside*[1,2], *T. Koenigk*[4], *V. Semenov*[5], *L. Suo*[2,3], *S. Yang*[6], *T. Wang*[7]
[1]*University of Bergen, Geophysical Institute, Bergen, Norway*
[2]*Bjerknes Centre for Climate Research, -, Bergen, Norway*
[3]*Nansen Environmental and Remote Sensing Center, -, Bergen, Norway*
[4]*Swedish Meteorological and Hydrological Institute, Rossby Centre, Norrköping, Sweden*
[5]*Helmholtz Centre for Ocean Research Kiel, -, Kiel, Germany*
[6]*Danish Meteorological Institute, Danish Climate Centre, Copenhagen, Denmark*
[7]*Chinese Academy of Sciences, Institute of Atmospheric Physics, Beijing, China Peoples Republic*

Under the recent global warming, melting of arctic sea-ice in recent decades could have contributed to recent climate changes including its long-term trend and extreme weather events. While the climatic response to the sea-ice loss have been studied recently, it is still an open question to what extent the sea-ice change has influenced recent climate change. Other factors, such as for example, sea surface temperature (SST) could also have had an influence. A main objective of GREENICE research project is to show what extent of the observed climate trend as well as observed weather extremes could be explained by the change and variability in sea ice and SST, respectively. In this project, we designed two atmospheric general circulation model experiments: In both experiments observed daily sea ice cover variations are prescribed, while for SST, one experiment uses observed daily variations and the other the observed climatology. The experiment is performed with four different state-of-the-art AGCMs. We assess the impact of daily versus monthly SST and sea ice cover, and of resolving stratosphere-troposphere coupling. The results will shed light on the importance of SST and sea ice for the recent climate change. In this presentation, we will show preliminary results from these experiments.

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JM02p-300

Winter weather in Japan controlled by large-scale atmospheric and small-scale oceanic phenomena

Y. Ando[1,2], M. Ogi[3], Y. Tachibana[1], K. Kodera[1,4], K. Yamazaki[1,2,5]
[1]Mie University, Climate and Ecosystems Dynamics Division, Tsu, Japan
[2]National Institute of Polar Research, Arctic Environment Research Center, Tachikawa, Japan
[3]University of Manitoba, Centre for Earth Observation Science, Winnipeg, Canada
[4]Nagoya University, Solar-Terrestrial Environment Laboratory, Nagoya, Japan
[5]Hokkaido University, Graduate School of Environmental Earth Science, Sappro, Japan

The important components of atmospheric circulation in the winter over the Northern Hemisphere are the Arctic Oscillation (AO) and Western Pacific (WP) pattern. Although in general positive (negative) AO and WP phases cause Siberia, East Asia, and Japan to be abnormally warm (cold). The low (high) temperature of the Sea of Japan, which cooling (heating) by these cool (warm) waters, despite the small size of the Sea of Japan, overwhelm the warming (cooling) effect of the positive (negative) AO and WP. Linear regression analyses show that Japan tends to be warm (cool) in years when the Sea of Japan is warm (cool). Consequently, the temperature over Japan is controlled by interannual variations of small-scale oceanic phenomena as well as by large-scale atmospheric patterns. Previous studies have ignored such small-scale oceanic influences on island temperatures.

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JM02p-301

"Wind and fog driven by a sea surface temperature front observed by 3-ship simultaneous atmospheric sounding in the Kuroshio Extension"

H. Nishikawa[1], *Y. Tachibana*[1], *Y. Kawai*[2], *M. Yoshioka*[3], *H. Nakamura*[4]
[1]*Mie University, Climate Ecosystem Dynamic Devision, Tsu- Mie, Japan*
[2]*Japan Agency for Marine-Earth Science and Technology, Research and Development Center for Global Change, Yokosuka, Japan*
[3]*Tohoku University, Center for Atomspheric and Oceanic Studies, Sendai, Japan*
[4]*the University of Tokyo, Climate Science Research Laboratory, Tokyo, Japan*

In 2012 July, 3-ship simultaneous GPS radiosonde observation was carried out over a sea surface temperature (SST) front of the Kuroshio Extension. The three ships were located at a cold SST side (i.e., north side), over the SST front and a warm SST side (i.e. south side) respectively along 143°E. We launched GPS radiosondes simultaneously from each ship every hour for about five days. The temporal changes of atmospheric fields on a meridional cross section were successfully captured. Such observation has not been carried out in this area.

During the 3-ship simultaneous observation, high (low) pressure anomaly in the north (south) side of the SST front (i.e. in the cold (warm) side) was overall observed in association with strong meridional pressure gradient. The pressure gradient corresponding to the SST front was formed by a pressure adjustment mechanism. Our results suggest that the meridional pressure gradient have two roles: One is to strengthen easterly wind by geostrophic balance, and the other is to form a meridional circulation only in the lower altitudes, which is caused by north-south SST contrast like sea-breeze between cold ocean and warm land. During the observation, fog was observed several times only at the cold SST area and over the SST front. In the foggy period, larger difference of the pressure between the cold and warm sides was overall observed than in the no foggy cases. The observational results suggested that radiative cooling at the cloud top of the fog layer strengthen the meridional contrast of the pressure corresponding to the air temperature.

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Effects of interactive atmospheric chemistry on the climate sensitivity of an Earth system model

S. Watanabe[1], H. Shiogama[2], Y. Kamae[2], M. Watanabe[3], T. Ogura[2], K. Tachiiri[4], T. Hajima[5], M. Kawamiya[4]
[1]JAMSTEC, DSEP, Yokohama, Japan
[2]NIES, CGER, Tsukuba, Japan
[3]AORI- Univ. of Tokyo, Department of Climate Variability Research, Kashiwa, Japan
[4]JAMSTEC, ICCPR, Yokohama, Japan
[5]JAMSTEC, PTRICC, Yokohama, Japan

Recently, Nowack et al. (2014) reported that having the interactively coupled ozone chemistry in an atmosphere-ocean coupled climate model (HadGEM3-AO) significantly lowered the model's climate sensitivity by about 1K. They mainly attirubuted the change in climate sensitivity to changes in long-wave radiative feedbacks associated with circulation-driven decreases in tropical lower stratospheric ozone and related stratospheric water vapour and cirrus cloud changes. Here we present our Earth system model (MIROC-ESM) simulation results with and without chemistry interactions. We obtained a similar but much less decrease (4.4->4.2 K) in the climate sensitivity compared to that Nowack et al. (2014) reported. Such an inter-model difference seems to partly be explained by quantitative differences in the long-wave radiative feedbacks occurring in HadGEM3-AO and MIROC-ESM. Another possibility would be uncertainties in simulations, i.e., the climate sensitivity estimated from 10 member ensemble simulations using MIROC-ESM varied as the chemistry-off (4.3-4.8 K) and -on (4.1-4.4 K) simulations, respectively.

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Response of explosively developing extratropical cyclones to sea surface temperature variations over the Kuroshio Extension

H. Hirata[1], *R. Kawamura*[1], *M. Kato*[2], *T. Shinoda*[2]
[1]*Kyushu University, Department of Earth and Planetary Sciences, Fukuoka, Japan*
[2]*Nagoya University, Hydrospheric Atmospheric Research Center, Aichi, Japan*

We examined how the Kuroshio Extension (KE) affects the rapid development and the structural change of extratropical cyclones using Cloud Resolving Storm Simulator. In control experiments, the evolutions of surface fronts of the simulated cyclones resemble the Shapiro-Keyser model. The well-organized nature of the cold conveyor belt (CCB) plays a role not only in enhancing surface evaporation from the KE region but also in importing the evaporated vapor into the bent-back front. The imported vapor converges at the bent-back front, resulting in a deepening of the central pressure of the cyclones through latent heat release. The decrease in the central pressure can, in turn, reinforce the CCB. To verify such a positive air-sea feedback process, we performed additional experiments with positive and negative SST anomalies over the KE region, which are called warm and cool SST runs, respectively. Increased (decreased) surface evaporation at that region and decreased (increased) SLP around the bent-back front are seen in the warm (cool) SST runs. Particularly, these differences between the two runs amplify when the CCB is located over the KE region, whereas such amplification does not occur when the warm conveyor belt lies over that region. This suggests that the KE variability can modulate the cyclone growth more efficiently through the air-sea feedback process when the CCB passes through the vicinity of the KE region. It also appears that the deepening of SLP around the bent-back front induces a zonally asymmetric structure of the cyclone center.

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Inter-comparison of air-sea sensible and latent heat fluxes variability in CMIP5 model simulations and observational datasets

I. Serykh[1], *S. Gulev*[1]
[1]*P.P.Shirshov Institute of Oceanology of the Russian Academy of Sciences, Physics of the ocean, Moscow, Russia*

Surface turbulent heat fluxes are critically important in climate model experiments, since they represent a language of communication between the ocean and atmosphere. Variability of surface heat turbulent fluxes controls the changes in the ocean surface heat balance and diabatic heating of the atmosphere. Being relatively well assessed and validated in reanalyses and observational datasets, surface turbulent heat fluxes were always of a lesser attention in diagnostics of climate model experiments. We analyse variability of sensible and latent heat fluxes in historical climate simulations with several CMIP5 models for the period 1950-2005 (and for longer periods for selected models) with the emphasis on different scales of variability (short-term, interannual, decadal-to-interdacadal). In many CMIP5 models at all scales it has been found a little consistency between the changes in sensible and latent flux turbulent fluxes diagnosed by the models (e.g. INM-CM4, BCC-CSM1.1, BNU-ESM, CMCC-CMS, IPSL, MPI-ESM-MR), while OAFlux and observationally based datasets show relatively consistent sensible and latent fluxes. Regions which surprisingly demonstrate negative correlations at decadal scales between sensible and latent heat fluxes are mostly located in the tropics, while these signatures also were observed in the Southern Hemisphere. Interestingly, variability in air temperature and surface humidity (which could be potentially considered as the reason for autocorrelation between sensible and latent fluxes) demonstrates consistency with each other at most scales. Further we discuss potential reasons for the discovered phenomenon.

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A linkage between summer Arctic sea ice concentration and winter snowfall variability in Japan

K. Iwamoto[1], M. Honda[2], J. Ukita[2]
[1]NIPR/Niigata Univ, Niigata, Japan
[2]Niigata Univ, Faculty of Science, Niigata, Japan

We investigated the relationships among the variations of summer sea ice concentration (SIC) in the Arctic Ocean, large-scale atmospheric circulation in the Northern Hemisphere, and the winter snowfall in Japan. Analyses reveal that the summer SIC reduction is related to positive snowfall anomalies in the coastal area of the Japan Sea and negative anomalies in the Pacific Ocean side of Hokkaido, the northern island of Japan, in the following winter through the intensified Siberian high and associated cold anomalies in the lower troposphere over the eastern Eurasia. These anomalous snowfall patterns can be recognized as the combination of the leading and the third EOF modes in snowfall (EOF1 and EOF3). The positive phase of EOF1, which corresponds to the positive snowfall anomalies in the Japan Sea's coastal region, is associated with the intensification of the Siberian high and the Aleutian low. In contrast, the positive phase of EOF3 is characterized by the negative snowfall anomalies in the Pacific Ocean side of Hokkaido, which is connected with the positive phase of the Arctic Oscillation/North Atlantic Oscillation in winter. Furthermore, we found that in terms of the Arctic-midlatitude linkages, EOF1 is preceded by the sea-ice reduction in the Barents and Kara Seas whereas EOF3 is by the sea-ice reduction in the East Siberia Sea. Together, our findings point to regional-scale dependence in the Arctic-midlatitude linkages.

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Analysis of global climate variability from homogenously reprocessed ground-based GNSS measurements

F. Ahmed[1], *A. Hunegnaw*[1], *N. Teferle*[1], *R. Bingley*[2]
[1]*University of Luxembourg, RUES- FSTC, Luxembourg, Luxembourg*
[2]*University of Nottingham, Nottingham Geospatial Institute, Nottingham, United Kingdom*

The tropospheric delay information obtained through long-term homogenous reprocessing of Global Navigation Satellite System (GNSS) observations can be used for climate change and variability analysis on a global scale. A reprocessed global dataset of GNSS-derived zenith total delay (ZTD) and position estimates, based on the network double differencing (DD) strategy and covering 1994-2012, has been recently produced at the University of Luxembourg using the Bernese GNSS Software 5.2 (BSW5.2) and the reprocessed products from the Centre for Orbit Determination in Europe (CODE). The network of ground-based GNSS stations processed to obtain this dataset consists of over 400 globally distributed stations. The GNSS-derived ZTD has been validated by comparing it to that derived from reanalysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF). After validation and quality control, the ZTD dataset obtained using the DD strategy has been used to investigate the inter-annual, seasonal and diurnal climate variability and trends in the tropospheric delay on various regional to global spatial scales. Precise point positioning (PPP) is a processing strategy for GNSS observations which is based on observations from a single station rather than a network of baselines and is therefore computationally more efficient than the DD strategy. However, the two processing strategies, i.e. DD and PPP, have their own strengths and weaknesses and could affect the solutions differently at different geographical locations. In order to explore the use of PPP strategy for climate monitoring, another experimental dataset covering a shorter period has been produced using the PPP strategy and compared to the DD based ZTD dataset.

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Oceanic forcing of Antarctic climate change: a study using a stretched-grid atmospheric general circulation model

G. Krinner[1], *M. Ménégoz*[1,2], *C. Agosta*[3,4], *C. Brutel-Vuilmet*[5]
[1]*CNRS, LGGE, Grenoble, France*
[2]*IC3, Climate Forecast Unit, Barcelona, Spain*
[3]*University of Liège, Laboratoire de Climatologie et Topoclimatologie, Liège, Belgium*
[4]*CNRS, LGGE, Grenoble, Spain*
[5]*UJF Grenoble, LGGE, Grenoble, Spain*

A variable-resolution atmospheric general circulation model (AGCM) is used for climate change projections over the Antarctic. The present-day simulation uses prescribed observed sea surface conditions, while a set of five simulations for the end of the twenty-first century (2070-99) under the Special Report on Emissions Scenarios (SRES) A1B scenario uses sea surface condition anomalies from selected coupled ocean atmosphere climate models from phase 3 of the Coupled Model Intercomparison Project (CMIP3). Analysis of the results shows that the prescribed sea surface condition anomalies have a very strong influence on the simulated climate change on the Antarctic continent, largely dominating the direct effect of the prescribed greenhouse gas concentration changes in the AGCM simulations. Complementary simulations with idealized forcings confirm these results. An analysis of circulation changes using self-organizing maps shows that the simulated climate change on regional scales is not principally caused by shifts of the frequencies of the dominant circulation patterns, except for precipitation changes in some coastal regions. The study illustrates that in some respects the use of bias-corrected sea surface boundary conditions in climate projections with a variable-resolution atmospheric general circulation model has some distinct advantages over the use of limited-area atmospheric circulation models directly forced by generally biased coupled climate model output.

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JM02p-309

Heliogeophysical basics of the long-term temperature trends.

B. Nurtaev[1]
[1]*Solterra Science, Frechen, Germany*

The source of the virtually all energy in climate system is radiation from the Sun. In fact 99, 97% of energy budget of the earth arrives from the Sun. The sun's heat and light energy are warms the land surface and oceans and radiates heat back into the air above.

The four seasons in year are the result of the tilt of the Earth's axis. The difference in warming and cooling in seasons is due to direct and indirect incident rays of the sun. The simplest example of the influence of the sun to the earth is a temperature change during the day and night, which reaches in the desert Sahara 50 C°. The biggest difference between summer and winter temperature is 106.7 C° (from - 70C° to + 36.7C°) in Verhojansk.

The F10,7 cm index is a standard characteristic of solar activity using in research concerning the solar influence on Earth’s climate. Comparison of F10, 7 cm index with Wolf’s Numbers detected correlation between these both parameters r=0, 99.

Taking into account the solar F10.7 cm record extends back to 1947 and sunspots record more longer, since 1750, we examined relationships between evolution of the long- term mean temperature and sunspots for one solar cycle. Results show that above 80% level of statistically significant correlations exist between sunspots and air temperature for about 200 weather stations around the world.

This report presents relationships between sunspots and air temperature for different weather stations over the period 1878-1996.

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Impacts of climate change to extreme hydrological event for the Huaihe river basin, China

J. Junliang[1], *W. Guoqing*[1]
[1]*Nanjing Hydraulic Research Institute, Hydrology and Water Resources, Nanjing, China Peoples Republic*

Based on the data of CNRM under RCP emissions scenarios and variable infiltration capacity model, temperature, precipitation and flood in future over Huaihe river basin were analyzed. The results show that the temperature keeps on significant rising in the 2030s(Year from 2021 to 2050), with rising of 1.13?,1.10? and 1.35? under RCP2.6, RCP4.5 and RCP8.5 scenarios compared with baseline(Year from 1961 to 1990) respectively. Precipitations under the three RCP scenarios were projected to increase by 5.81%, 8.26% and 6.94% during 2021~2050 compared to the baseline in 1961~1990. The VIC model has the good ability to simulate the hydrological process over Huaihe river basin. The VIC model can effectively simulate the daily or monthly runoff procedure, water balance errors between simulated and recorded runoffs for two hydrometric station are less than 5% while Nash-Sutcliffe coefficients of daily discharge simulation are both beyond 0.73.The extreme flood events in Huaihe river basin would be more severe and the risk for flood would be further expanded in the future under the changing climate change.

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JM02p-312

A generation model for tropical cyclone tracks for GCM outputs

K. Suzuki[1], *S. Nakano*[1], *G. Ueno*[1]
[1]*The Institute of Statistical Mathematics,*
Research and Development Center for Data Assimilation, Tachikawa, Japan

The goal is a prediction of risks to the human life caused by tropical cyclones (TC) in the future climate that are predicted by GCMs. Because the number of TCs is not enough to calculate their probabilities of typhoon coming to big cities in the GCM outputs, we are developing a new stochastic TC model to generate a sufficient number of artificial TCs for that calculation. Here, we focus on the presumption of range for variations of TC tracks for GCM outputs.
The TC tracks are mainly controlled by the atmospheric circulation such as the trade winds and the Westerlies as well as are influenced to move northward by the Beta effect. We model the movement of TCs due to the atmospheric circulation using trajectory analysis in the wind field of MRI-AGCM. The beta effect is represented by an additional adjustment parameter.
This model can gain a suitable range for distribution of calculated TC tracks by fitting to the Best Track (BT) using particle filtering. After parameter optimization using the BT data for about sixty years, we adapt the parameters to the wind field in the future climate. Because the parameters will reflect the characteristics of GCM itself, we think it is possible to do that. TC genesis points will be given by a genesis model. The genesis model is based on SST, latitudes and wind shear.
From the generated artificial TC trajectories between the present and future GCM outputs, the characteristics of TCs of both will be clarified.

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Long-term trend of polar cold air mass amount below a designated potential temperature in winter hemispheres

Y. Kanno[1], *T. Iwasaki*[1]
[1]*Tohoku University, Geophysics, Sendai, Japan*

This study shows a long-term trend of polar cold air mass amount below 280K plane in Northern and Southern Hemispheric winters using six reanalysis datasets (JRA-55, JRA-55C, JRA-25, ERA-interim, CFSR, NCEP-NCAR). Isentropic coordinate facilitates a quantitative analysis of polar cold air mass amount and its heat budget.

The results show that there has been statistically significant decrease in hemispheric total polar cold air mass amount in NH winter for the period from 1980 to 2012 and from 1959 to 2012 in common with six reanalysis datasets. Geographical distribution of polar cold air mass amount trend in NH winter is also consistent between six reanalysis. Decreasing appears over Barents-Kara Sea, Greenland Sea, northern part of Atlantic, Greenland, northern part of North America, and East Asia. Increasing appears over Central Siberia, East Siberia, and Bering Sea. In SH winter, on the other hands, there is a discrepancy of changes in hemispheric total polar cold air mass amount between reanalysis datasets for the period from 1980 to 2012. JRA-25 shows statistically significant increasing, but JRA-55, JRA-55C, and NCEP-NCAR show statistically significant decreasing. These results indicate that long-term trend of polar cold air mass amount in NH winter is highly reliable, but that in SH winter has uncertainty.

Comparison of polar cold air mass amount between JRA-55 and JRA-55C shows the impact of assimilating satellite data. The results indicate that there might be artificial changes in sub-polar regions of SH due to inhomogeneity of observational data.

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JM03a - JM3 Geochemical Process and Cycles (IAMAS, IAPSO, IAVCEI, IAHS, IACS)

IUGG-3308

Photosensitized chemistry at the air/sea interface: Biology vs chemistry

C. GEORGE[1], R. Ciuraru[2], P. Alpert[2], T. Rossignol[2], S. Rossignol[2], S. Perrier[2], N. Charbonnel[2], Y. Dupart[2], H. Fu[3], J. Chen[3]
[1]CNRS-IRCELYON, Villeurbanne, France
[2]CNRS, IRCELYON, Villeurbanne, France
[3]Fudan University, Department of Environmental Science & Engineering, Shanghai, China Peoples Republic

The sea-surface microlayer (SML) chemical composition, driven by biogeochemical and physical processes in the ocean, influences not only the organic fraction of marine aerosol produced by sea spray processes but also controls trace gas deposition to the ocean and may be involved in secondary organic aerosol formation in the marine boundary layer. Hence, a better chemical characterization and understanding of the oceanic microlayer and its processes is highly desirable. The SML, covering up to 70% of the ocean's surface has different physical, chemical and biological properties compared to the subsurface water, with an enrichment of organic matter i.e., dissolved organic matter including UV absorbing humic substances, fatty acids, amino acids, proteins, lipids, phenolic compounds, as well as trace metals, particulate matter and microorganisms. Here we present new experimental evidences that when exposed to sunlight, these compounds can initiate photosensitized reactions at the air/sea interface leading to the production of significant amount of unsaturated products, such as isoprene which was up to now supposed to be produced in the marine boundary layer (MBL) via biological activities. The isoprene fluxes derived from our experiments do compare very favourably to actual fluxes measured in the marine boundary layer. The existence of organic films on the ocean surface due to biological activities therefore influences air/sea exchanges in an unexpected significant manner, as interfacial photosensitized chemistry is significant source of isoprene, in the absence of any biological source, in the marine boundary layer. This interfacial chemistry simply involves fatty acids as surfactants and dissolved organic matter as photosentitizers, ubiquitous in the marine environment.

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IUGG-3345

The southern hemisphere additional ozonesondes (SHADOZ, 1998-) strategic ozonesonde network: Overview and scientific accomplishments

A. Thompson[1]
[1]*NASA-Goddard Space Flight center, Atmospheric Chemistry & Dynamics Branch, Greenbelt, USA*

Ozonesonde data support satellite validation, model assimilation and evaluation as well as studies of atmospheric dynamics. Strategic ozonesonde networks coordinate and schedule launches in a fixed region to answer specific questions (Thompson et al., 2011)*. We have organized five such networks in the past 15 years. This talk focuses on the Southern Hemisphere Additional Ozonesondes (SHADOZ; <http://croc.gsfc.nasa.gov/shadoz>) network that consists of a dozen tropical and subtropical stations, with 2-4 launches monthly. An overview of SHADOZ origins and workings will be given along with illustrative findings in the troposphere and stratosphere: construction on new ozone profile climatologies for satellite retrievals, pollution trends** and signatures of convection in near-tropopause ozone.

* Strategic ozone sounding networks: Review of design and accomplishments, http://dx.doi.org/10.1016/j.atmosenv.2010.05.002. Or Atmos. Environ.,**45,** 2145-2163, 2011.

** J. Aschmann, et al: On the hiatus in the acceleration of tropical upwelling since the beginning of the 21st century, Atmos. Chem. Phys., **14**, 12803-12814, 2014.

A. M. Thompson, et al. Is tropospheric ozone over southern Africa really increasing? Evidence from sonde and aircraft profiles, Atmos. Chem. Phys., **14,** 9855-9869, 2014.

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JM03a - JM3 Geochemical Process and Cycles (IAMAS, IAPSO, IAVCEI, IAHS, IACS)

IUGG-4086

Twenty years of ozone soundings from Easter Island (109 W, 27S, 51 m.a.s.l.)

L. Gallardo[1], *A. Thompson*[2], *P. Velásquez*[3], *A. Henríquez*[4], *J. Carrasco*[5]
[1]*University of Chile- Center for Climate and Resilience Research, Geophysics, Santiago, Chile*
[2]*NASA/Goddard Space Flight Center, Atmospheric Chemistry and Dynamics Lab, Washington, USA*
[3]*Dirección Meteorológica de Chile, Climatología, Santiago, Chile*
[4]*Center for Climate and Resilience Research, Modeling and obsrving systems, Santiago, Chile*
[5]*Center for Climate and Resilience Research, Modeling and Observing Systems, Santiago, Chile*

The Global Atmospheric Watch (GAW) program in collaboration with the Chilean Weather Office has held an ozone sounding station on Easter Island (27ºS, 109ºW, 51 m.a.s.l.) since the mid-1990's. This record contains more than 300 soundings. We characterize the relevant circulation patterns as well as the impact of long-range transport. We analyze O_3 profiles over this remote area of the Pacific by means of statistical analyses that consider, on the one hand, a traditional climatology that describes the data in terms of seasonal cycles and, on the other hand, a more process oriented analysis based on self-organizing maps. Our analyses show the influence of both tropical and mid-latitude air masses at Easter Island, and the occurrence of stratospheric intrusions in late winter and spring in connection with deep troughs and the presence of the subtropical jet stream. The seasonal variability of the tropospheric ozone column is in good agreement with the corresponding data derived from satellites. The stratospheric contribution to the spring maximum in ozone in the upper troposphere is also supported by ozone reanalysis from the European Center for Medium-range Weather Forecasts. We look forward to an enhancement of the Rapa Nui observing site, given its location that offers a privileged position to observe climate change over the sparsely sampled and vast South Pacific Ocean.

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IUGG-4828

Human impact on the role of dust as carrier of nutrients to the ocean.

M. Kanakidou[1], S. Myriokefalitakis[1], P. Nikolaou[1], N. Daskalakis[1], C. Theodosi[1], A. Nenes[2], K. Tsigaridis[3], N. Mihalopoulos[1,4]
[1]University of Crete,
Chemistry Department- Environmental Chemical Processes Laboratory ECPL, Heraklion, Greece
[2]Georgia Institute of Technology,
School of Earth and Atmospheric Sciences & School of Chemical and Biomolecula r Engineering, Atlanta, USA
[3]Columbia University & NASA Goddard Institute for Space Studies,
Center for Climate Systems Research, New York, USA
[4]National Observatory of Athens,
Institute for Environmental Research and Sustainable Development IERSD, Athens, Greece

Atmospheric deposition of trace constituents, both of natural and anthropogenic origin, can act as a nutrient source into the open ocean and affect marine ecosystem functioning and subsequently the exchange of CO_2 between the atmosphere and the global ocean. Dust is known as a major source of nutrients (Fe and P) into the atmosphere, but only a fraction of these nutrients is released in soluble form that can be assimilated by the ecosystems. Dust is also known to enhance N deposition by interacting with anthropogenic pollutants and neutralization of part of the acidity of the atmosphere by crustal alkaline species. The link between the soluble iron (Fe) and phosphorus (P) atmospheric deposition and atmospheric acidity, as well as anthropogenic sources, is investigated. The global atmospheric Fe, P and N cycle are parameterized in the global 3-D chemical transport model TM4-ECPL. Both primary emissions of total and soluble Fe and P associated with dust and combustion processes are taken into account, as well as inorganic and organic N emissions. The impact of atmospheric acidity on nutrient solubility is parameterized based on experimental findings. The model results are evaluated by comparison with available observations. The impact of air-quality changes on soluble nutrient deposition is studied by performing sensitivity simulations using pre-industrial, present and future emission scenarios. The response of the chemical composition of nutrient-containing aerosols to environmental changes is demonstrated and quantified. This work has been supported by ARISTEIA –

PANOPLY grant co-financed by European Union (ESF) and Greek national funds NSRF.

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IUGG-4323

The near-term potential of climate change mitigation through reduction in anthropogenic methane emissions

M. Gauss[1]*, V. Arora*[2]*, C. Koven*[3]*, D. Olivié*[4]*, A. Søvde*[5]*, L. Höglund-Isaksson*[6]*, T. Christensen*[7]*, F.J. Parmentier*[7]*, D. Plummer*[2]*, M. Shepherd*[8]*, M. Kuperberg*[9]*, E. Bush*[10]
[1]*Norwegian Meteorological Institute, Research and Development Department, Bergen, Norway*
[2]*Environment Canada, Canadian Centre for Climate Modelling and Analysis, Victoria, Canada*
[3]*Lawrence Berkeley National Laboratory, Earth Sciences Division, Berkeley, USA*
[4]*Norwegian Meteorological Institute, Research and Development Department, Oslo, Norway*
[5]*Center for International Climate and Environmental Research, CICERO, Oslo, Norway*
[6]*International Institute for Applied Systems Analysis, IIASA, Laxenburg, Austria*
[7]*Lund University, Department of Physical Geography and Ecosystem Science, Lund, Sweden*
[8]*Environment Canada, Climate Research Division, Toronto, Canada*
[9]*U.S. Department of Energy, Climate and Environmental Sciences Division, Washington D.C., USA*
[10]*Environment Canada, Canadian Centre for Climate Modelling and Analysis, Toronto, Canada*

The climate response to maximum technically feasible reductions in anthropogenic methane emissions, implemented globally over the 2015-2050 period, is assessed. The analysis is carried out using future methane emissions scenarios from an integrated assessment model (GAINS). Future abatement potentials considered by the GAINS model are based on emission reductions with current abatement technologies. The climate impact of these emissions reductions is calculated by three Earth System Models, which all have contributed to the IPCC-AR5 report (CanESM2, CESM1, and NorESM). Changes in ozone due to changes in methane emissions are calculated by a chemical transport model including detailed calculations of atmospheric chemistry (OsloCTM3). The study, carried out for the Arctic Monitoring and Assessment Programme (AMAP), concludes that maximum feasible reductions in methane emissions may reduce global climate warming for the period 2036-2050 by around 0.2 K. Different scenarios of changes in natural

emissions are also considered and compared to the effect of potential mitigation in anthropogenic emissions of methane.

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IUGG-4396

Elucidating severe urban haze formation in China

R. Zhang[1]
[1]*Texas A&M University, College Station, USA*

As the world's second largest economy, China has experienced severe haze pollution, with fine particulate matter (PM) recently reaching unprecedentedly high levels across many cities, and an understanding of the PM formation mechanism is critical in the development of efficient mediation policies to minimize its regional to global impacts. The formation mechanisms leading to severe haze episodes with exceedingly high PM2.5 levels in China remain highly uncertain, and the abundance and chemical constituents of PM2.5 vary considerably, depending on complex interplay between mete- orology, pollution sources, and atmospheric chemical processes We illustrate the similarity and difference in PM formation between Beijing and other world regions. The periodic cycle of PM events in Beijing is regulated by meteorological conditions. While the particle chemical compositions in Beijing are similar to those commonly measured worldwide, efficient nucleation and growth over an extended period in Beijing are distinctive from the aerosol formation typically observed in other global areas. Gaseous emissions of volatile organic compounds and nitrogen oxides from urban transportation and sulfur dioxide from regional industry are responsible for large secondary PM formation, while primary emissions and regional transport of PM are insignificant. Our results indicate that reductions in emissions of the aerosol precursor gases from transportation and industry are essential to mediate severe haze pollution in China.

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IUGG-4743

The Chemistry-Aerosol Mediterranean Experiment: Interplay between anthropogenic (especially shipping) and natural emissions in a complex system with high policy impact

M. Beekmann[1], *A. Cholakian*[1,2], *A. Borbon*[1], *A. Colomb*[3], *C. Di Biagio*[1], *B. D'Anna*[4], *P. Durand*[5], *E. Freney*[3], *P. Formenti*[1], *H.D. van der Gon*[6], *V. Gros*[7], *N. Marchand*[8], *S. Sauvage*[9], *J. Sciare*[7,10], *K. Sellegri*[3]
[1]*CNRS- UPEC- UPD, LISA/IPSL, Créteil, France*
[2]*INERIS, Risques Chroniques, Verneuil, France*
[3]*OPGC, LAMP, Clermont-Ferrand, France*
[4]*CNRS - UNiversity of Lyon, IRECELYON, Lyon, France*
[5]*CNRS - Univ. Paul Sabatier, Laboratoire d'Aérologie, Toulouse, France*
[6]*TNO, Dept. Climate- Air and Sustainability, Utrecht, Netherlands*
[7]*CNRS - CEA - UVSQ, LSCE/IPSL, Saclay, France*
[8]*University of Aix-Marseille, LCE, Marseille, France*
[9]*Mines Douai, Sciences de l'Atmosphère et Génie de l'Environnement, Douai, France*
[10]*The Cyprus Institute, Energy Environment Water Research Center EEWRC-, Nicosia, Cyprus*

Atmospheric composition over the Mediterranean basin is determined by a variety of intrinsically linked processes. Various types of emissions from highly populated coastal areas, linked to the water surface, or occasionally to fires, are processed in-situ by intense photo-chemistry, and mixed with advected pollutants. Impacts on society are large, since the Mediterranean area is vulnerable with respect to air quality and climate change.

During the ChArMEx (the Chemistry-Aerosol Mediterranean Experiment) project, intensive campaigns with detailed measurements of trace gases and aerosol chemical composition and physical properties were performed in summers 2013 and 2014 over the western part of the basin, in addition to long term observations.

We first will present the general framework of ChArMEx and then focus on first specific results. Current shipping emission inventories still show large differences, especially in the Gulf of Genoa. CTM modelling and comparison to observations at Cape Corsica, Lampedusa, Mallorca, and from aircraft will allow reducing these uncertainties. This is mandatory to back-up any emission regulation measures.

Our results show that shipping emissions can shift the overall NOx limited regime of ozone production over the basin to a VOC limited one, for particular days, and particular areas. This is highly policy relevant, especially as we also show from very detailed VOC measurements over Cap Corsica that a large part of VOC reactivity is due to biogenic VOC's.

Shipping emissions not only strongly impact as expected sulfate and soot concentrations, but also primary, and through several interactions, even secondary aerosol. By comparison, the possible contribution of marine emissions to primary and secondary organic aerosol is also discussed.

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IUGG-4778

Long-Term Monitoring of Carbon Monoxide with the MOPITT Instrument

J. Drummond[1]*, M. Deeter*[2]*, J. Gille*[2]*, F. Nichitiu*[3]*, J. Zou*[3]*, C. Lee*[1]
[1]*Dalhousie University, Physics and Atmospheric Science, Halifax, Canada*
[2]*National Center for Atmospheric Research, Atmospheric Chemistry Division, Boulder, USA*
[3]*University of Toronto, Physics, Toronto, Canada*

On 18th December 1999 the Terra platform was launched from the Vandenberg Air Force base carrying the Measurements Of Pollution In The Troposphere (MOPITT) instrument. MOPITT has now completed more than years of operation measuring carbon monoxide (CO) over the planet and it i still working!

The 15 year continuous data series that MOPITT has provided (so far) affords a great opportunity to look at longer-term changes over the planet. However a time series this long was not part of the design criteria of the instrument and therefore care must be taken to ensure that trends are not artifacts. Fortunately, the instrument has been more stable than originally predicted and care has been taken throughout the mission to ensure that the data are properly validated.

The result is a well-characterised 15 year time record that can now be “mined” for a variety of phenomena charting decadal changes (or stability) in carbon monoxide and looking at the frequency of events that often drive anomalies in the carbon monoxide distribution. A global trend of decreasing carbon monoxide has been observed, but other phenomena has also been observed caused by a mix of changes in sources, transport and sinks, particulary with the increasing trend for the concentration of people in (mega)cities. This paper will consider some of these phenomena by way of case studies and statistics.

MOPITT was provided to the Terra spacecraft by the Canadian Space Agency and was built by COMDEV of Cambridge, Ontario. Data processing is performed by the MOPITT team at the National Center for Atmospheric Research, Boulder, CO. Instrument control is by the team at the University of Toronto.

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IUGG-5402

Observing the anthropocene from space: Past achievements and challenges

J.P. Burrows[1]
[1]*University of Bremen, Institute of Environmental Physics and Remote Sensing, Bremen, Germany*

From the beginning of the Neolithic revolution up 1800 A.D., the earth's human population is estimated to have risen from several million nomadic hunter gathers to 1 Billion rural settlement and city dwellers. This rapid development is dwarfed by the impact of the industrial revolution over the past two centuries. There are no over 7 Billion people on earth with over half living in cities, e.g. there are ~ 3 billion more citizens since I was bron. This industrialisation and urbanisation has been fuelled by the use of cheap energy from fossil fuel combustion. It has resulted in large scale changes in land use, air pollution, and the destruction of stratospheric ozone, the anthropogenic modification of biogeochemical cycling, the destruction of species, ecosystems and ecosystem services. In order to test our knowledge and understanding of the Earth system, accurate long term global measurements of atmospheric constituents and surface parameters are essential.

The remote sounding of the atmosphere from instrumentation on satellite platforms provides a unique opportunity to retrieve regional and global observations of key trace atmospheric constituents (gases, aerosol and clouds) and surface parameters (ocean colour, ice extent, flora etc.). This talk describes results from the SCIAMACHY (SCanning Imaging Absorption spectrometer for Atmospheric CHartographY) project and its spin offs, GOME (Global Ozone Monitoring Experiment), GOME-2, and their successors ESA Sentinel 4 (GeoSCIA), Sentinel 5, CarbonSat and SCIA-ISS. The interpretation of the data from these instruments has provided a paradigm shift in our understanding of global atmospheric composition. In addition they deliver unique evidence for the development and verification of international environmental policy.

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IUGG-5590

Factors controlling the solubility of trace metals in atmospheric aerosols over the eastern mediterranean

N. Mihalopoulos[1,2], *P. Nikolaou*[1], *M. Kanakidou*[1]
[1]*University of Crete,*
Chemistry Department- Environmental Chemical Processes Laboratory ECPL, Heraklion, Greece
[2]*National Observatory of Athens,*
Institute for Environmental Research and Sustainable Development IERSD, Athens, Greece

Atmospheric input of aerosols is recognized, as an important source of nutrients for the oceans. Atmospheric aerosols interacting with air masses of variable composition are coated by sulfate, nitrate and organic compounds. This enhances their solubility and their role as a carrier of nutrients and pollutants to ecosystems. Recent studies have highlighted the importance of atmospheric inputs of nutrients and trace metals for the marine ecosystem functioning at semi-enclosed or enclosed water bodies such as the eastern Mediterranean.

This study aims to determine the factors controlling the variability of nutrients in the eastern Mediterranean. It focuses on the solubility of trace elements considered either as key nutrients for phytoplankton growth such as iron (Fe), phosphorus (P) or inhibitors such as copper (Cu). Size segregated aerosol samples collected at the background site of Finokalia in Crete for an entire year have been analyzed.

P shows high levels in air masses influenced both by anthropogenic activities in northeast Europe and by Sahara dust outbreaks. More than 70% of total P has been found to be associated with anthropogenic sources. The solubility of P and Fe has been found to be closely related to the acidity and dust amount in aerosols. The aerosol pH was calculated using thermodynamic modeling (ISORROPIA-II), meteorological observations, and gas/particle observations. Both P and Fe solubility appear to be inversely related to the crustal elements levels, while they increase in acidic environment. The significance of our findings for the eastern Mediterranean marine ecosystems is thoroughly discussed.

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IUGG-5697

Measurements of CO2, CH4 and other pollutants from urban areas and natural gas operations in the eastern US

R. Dickerson[1], *X. Ren*[2], *P. Shepson*[3], *J. Burrows*[4], *J. Thornton*[5], *J. Whetstone*[6], *S. Brown*[7], *A. Thompson*[8]
[1]*The University of Maryland, Atmospheric and Oceanic Science, College Park- MD, USA*
[2]*The University of Maryland, AOSC, College Park- MD, USA*
[3]*Purdue University, Chemistry, West Lafayette- IN, USA*
[4]*Uni Bremen, IUP, Bremen, Germany*
[5]*Univ. Washington, Department of Atmospheric Sciences, Seattle- WA, USA*
[6]*NIST, Greenhouse Gas and Climate Science Measurements, Gaithersburg- MD, USA*
[7]*NOAA, ESRL, Boulder- CO, USA*
[8]*NASA, GSFC, Greenbelt- MD, USA*

Natural gas operations and urban areas in the eastern US are major sources of pollutants including greenhouse gases, but the magnitude of these emissions remains uncertain especially for unconventional gas recovery such as fracking in the Marcellus Shale region. This presentation describes in situ (aircraft) and remotely sensed data to help quantify these flux of these trace gases. Details from recent field campaigns in Indianapolis, IN (INFLUX), Maryland (FLAGG-MD), and and the greater American eastern coast (WINTER) will be presented. Initial analysis indicates substantial net loss between drilling and consumption by the end users with substantial consequences for climate forcing.

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JM03p - JM3 Geochemical Process and Cycles (IAMAS, IAPSO, IAVCEI, IAHS, IACS)

JM03p-531

Uncertainty of sulfate aerosols against differences between host climate models

D. Goto[1], *T. Nakajima*[2], *T. Dai*[3], *T. Takemura*[4], *M. Kajino*[5], *H. Matsui*[6], *A. Takami*[1], *N. Sugimoto*[7], *A. Shimizu*[1], *T. Ohara*[8]
[1]*National Institute for Environmental Studies, Center for Regional Environmental Research, Tsukuba- Ibaraki, Japan*
[2]*Atmosphere and Ocean Research Institute- The University of Tokyo, Center for Earth Surface System Dynamics, Kashiwa- Chiba, Japan*
[3]*Institute of Atmospheric Physics- Chinese Academy of Sciences, State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Beijing, China Peoples Republic*
[4]*Research Institute for Applied Mechanics- Kyushu University, Center for East Asian Ocean-Atmosphere Research, Kasuga- Fukuoka, Japan*
[5]*Meteorological Research Institute, Atmos. Environ. & Appl. Meteor. Res. Dept, Tsukuba- Ibaraki, Japan*
[6]*Japan Agency for Marine-Earth Science and Technology, Department of Environmental Geochemical Cycle Research, Yokohama- Kanagawa, Japan*
[7]*National Institute for Environmental Studies, Center for Environmental Measurement and Analysis, Tsukuba- Ibaraki, Japan*
[8]*National Institute for Environmental Studies, Planning Department, Tsukuba- Ibaraki, Japan*

Air pollution has been increasing in East Asia, and transboundary air pollution is an important issue for air quality and human health throughout the world. The one of the largest contributor to the air pollution is sulfate, but their modelings still include various uncertainties. In this study, sulfate aerosols simulated by an aerosol module, SPRINTARS, coupled to a global climate model, NICAM, were evaluated by a comparison with in situ observations and the aerosol module coupled to another climate model, MIROC, over East Asia for January, April, July, and October 2006. The results indicated that a horizontal gradient of sulfate from the source over China to the outflow over Japan was present in both the simulations and the observations. At the observation sites, the correlation coefficients of the sulfate concentrations between the simulations and the observations were high (NICAM: 0.49-0.89, MIROC: 0.61-0.77), although the simulated sulfate concentrations were lower than those obtained by the observation. The difference in the simulated sulfate concentrations between NICAM and MIROC was large,

especially above 2 km heights over the source regions and over the outflow regions. It was directly caused by differences in the sulfate formation within clouds. It suggests that the uncertainty of the meteorological and cloud fields as well as the vertical transport patterns among the different host climate models has a substantial impact on the simulated sulfate distribution.

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JM03p-532

Rapid economic growth leads to boost in NO2 pollution over India, as seen from space

A. Hilboll[1], *A. Richter*[1], *J.P. Burrows*[1]
[1]*University of Bremen, Institute of Environmental Physics, Bremen, Germany*

Over the past decade, the economy of India has grown at an exceptionally pace. This economic growth was accompanied by a strong increase of the Indian population. Consequently, traffic, electricity consumption, and industrial production have soared over the past decade, leading to a strong increase in fuel consumption and thus pollutant emissions.

Nitrogen oxides (NO+NO2) are a major anthropogenic air pollutant, playing key part in reaction cycles leading to the formation of tropospheric ozone. They are mainly emitted by fossil fuel combustion; other sources include lightning, biomass burning, and microbial activity in soils.

Since the mid-1990s, space-borne measurements of tropospheric nitrogen dioxide (NO2) have been conducted by the GOME, SCIAMACHY, GOME-2, and OMI instruments. These instruments perform hyperspectral measurements of scattered and reflected sunlight and apply differential optical absorption spectroscopy (DOAS) to yield vertically integrated columnar trace gas abundances.

Here, we will present the results of almost 20 years of NO2 measurements over India. After showing the spatial distribution of NO2 pollution over India, we will present time series for individual states and urban agglomerations. These time series will then be related to various indicators of economic development. Finally, we will highlight several instances where single industrial pollution sources and their development can clearly be identified from the NO2 maps and estimate their NO2 emissions.

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JM03p-533

Detected methane emissions from landfills in the Los Angeles Basin during the COMEX campaign by airborne remote-sensing and in-situ measurements

S. Krautwurst[1], K. Gerilowski[1], R. Kolyer[2], H. Jonsson[3], T. Krings[1], M. Horstjann[1], I. Leifer[4], S. Vigil[5], M. Buchwitz[1], D. Schüttemeyer[6], M.M. Fladeland[2], J.P. Burrows[1], H. Bovensmann[1]
[1]Institute of Environmental Physics IUP- University of Bremen, Atmospheric Physics and Chemistry, Bremen, Germany
[2]NASA Ames Research Center ARC, Earth Science Division, Moffett Field, USA
[3]Center for Interdisciplinary Remotely.Piloted Studies CIRPAS, -, Marina, USA
[4]Bubbleology Research International BRI, -, Santa Barbera, USA
[5]California Polytech State University, -, San Luis Obispo, USA
[6]ESA-ESTEC, Mission Science Division, Noordwijk, Netherlands

Methane (CH_4) is the second most important anthropogenic greenhouse gas beside carbon dioxide (CO_2).
Significant contributors to the global methane budget are fugitive emissions from landfills.

In this work, we show how airborne based remote-sensing measurements of the column-averaged dry air mole fraction of CH_4 can be utilized to estimate fugitive emissions from landfills in an urban environment by a mass balance approach. Subsequently, these emission rates are compared to airborne in-situ horizontal cross section measurements of CH_4 taken within the planetary boundary layer upwind and downwind of the landfill at different altitudes immediately after the remote-sensing measurements were finished. Additional necessary meteorological parameters for the data inversion are provided by a standard instrumentation suite for atmospheric measurements aboard the aircraft, and nearby ground-based weather stations.

These measurements were part of the CO_2 and Methane EXperiment, which was executed during the summer 2014 in California and was co-funded by ESA and NASA. The remote-sensing measurements were taken by the Methane Airborne MAPper (MAMAP) developed and operated by the University of Bremen and the German Research Center for Geoscience in Potsdam. The in-situ measurements were obtained by a greenhouse gas (GHG) in-situ analyser operated by NASA's Ames Research Center. Both instruments were installed aboard a DHC-6 Twin

Otter aircraft operated by the Center for Interdisciplinary Remotely-Piloted Aircraft Studies.

Initial results – including estimated fugitive emission rates - will be presented for the landfill Olinda Alpha in Brea, Orange County, Los Angeles Basin, California, which was overflown on four different days during the COMEX field campaign in late summer 2014.

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Impacts of manufactured nanomaterials on marine ecosystem: Toxicity and interaction with the existing pollutants

X. Zhu[1]*, S. Tian*[2]*, L. Zhao*[1]*, Y. Wang*[1]
[1]*Tsinghua University,*
Division of Ocean Science and Technology- Graduate School at Shenzhen, Shenzhen, China Peoples Republic
[2]*Tianjin University of Science and Technology,*
College of Marine Science and Engineering, Tianjin, China Peoples Republic

Manufactured nanomaterials (MNMs) with at least one critical dimension below 100 nm, specially engineered for applications, are the building blocks of a new industry of nanotechnology. The small size and special structure of MNMs confer them with various excellent physicochemical characteristics, such as nanoscale size effects, and so on. Hence, MNMs are widely used in economic industries, commercial, and even environmental sectors, which resulted in a higher risk for people and environment exposed to them. The novel properties of MNMs, which are the basis of their advantage, however, may also cause unique environmental contamination and associated effects on the whole ecosystem including marine ecosystem. In the last decade, the safety and risks of MNMs have been raised concerned in governments and scientists. Different reports focusing on the environmental hazard assessment and ecotoxicology of MNMs have been published. However, few of the reports are specially focus on the behavior and ecotoxicity of MNMs in marine environment. It should be recognized that most industrial discharges are to estuarine or marine environments, and it is expected that the MNMs may follow the same fate. Therefore, the impacts of MNMs on marine ecosystem should not be neglected. We presented here the behavior and toxicity of MNMs (such as TiO_2 nanoparticles, etc.) in marine environment. The interaction between MNMs and the existing pollutants in various marine organisms was also reported. The future needs in marine nanoecotoxicology were discussed in the end.

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Space-borne measurement of sun-induced terrestrial plant fluorescence

N. Khosravi[1], *M. Vountas*[1], *V.V. Rozanov*[1], *A. Bracher*[1], *J. Burrows*[1]
[1]*IUP Institut für UmweltPhysic, FB01, Bremen, Germany*

Global carbon cycle has a close correspondence to terrestrial vegetation as an important sink of CO_2. Plants contribution to the global carbon uptake is through photosynthesis, utilizing absorbed sun light (as the energy source) and CO_2. Fluorescence as a side-product of photosynthesis is a fraction of surplus energy, re-emitted to the environment. Sun-Induced plant Fluorescence (SIF) is therefore an indicator of photosynthesis efficiency and of interest for many scientific and environmental purposes. Space-borne observations of vegetation has been practiced since decades due to its good global coverage and economical efficiency per unit area. Recently, measuring SIF is gaining substantial attention in space-borne land observation field.

In the present study, we introduced a novel approach to retrieve SIF at Top of Atmosphere (TOA). Our method has been developed and tested on simulated data, created by a comprehensive radiative transfer model. Sensitivity studied implied feasibility of the method and enlightened the important measurement parameters for the retrieval. The method is then applied on long-term data from SCIAMACHY and GOME-2 instruments and produced promising results.

Furthermore, the relation between SIF values and vegetation's contribution to the global CO_2 uptake is investigated.

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JM03p-536

Evaluation of the terrestrial carbon cycle under nitrogen limitation in the common land model

Q. Zhang[1]

[1]*Beijing Normal University, College of Global Change and Earth System Sciences, Beijing, China Peoples Republic*

Nitrogen is the most important nutrient regulating plant growth and productivity in many ecosystems. However in current Earth System models the mechanisms of how nitrogen availability on plant photosynthesis and respiration are rather simplistically represented. In this study, we use the Common Land Model coupled a carbon (C) and nitrogen (N) cycling scheme from the DyN model to evaluate the impact of N on global carbon cycle. The representation of plant productivity in the model is improved based on the relationships between leaf level nitrogen and plant photosynthesis and respiration rates from global plant traits observations (TRY database). Global-scale results of CoLM-CN show that the model produces realistic estimates of current period C and N stocks, despite some regional biases. In response to rising atmospheric CO_2 concentration, the simulated Gross Primary Production (GPP) and Net Primary Production (NPP) increases are suppressed by N limitations by 30% and 20%, respectively. The relative response of NPP to CO_2 (12% per 100 ppm) when N is accounted for compares well with the sensitivity derived from Free-Air CO2 Enrichment (FACE) experiments (13% per 100 ppm). For the last 30 years, N limitation decreases the Net Biosphere Production (NBP) sensitivity to atmosphere CO_2 by 16%. In response to the climatic changes, our results show that the interannual variability of C fluxes (GPP, NPP, NBP) is more closed controlled by precipitation in tropical and temperate ecosystems, while temperature is more important in boreal ecosystems. Our results show that the prognostic linkage between leaf nitrogen and plant production and a consistent soil nitrogen cycle scheme leads to significant improvements in terrestrial carbon cycle simulations.

Joint Inter-Association Symposium

JM03p - JM3 Geochemical Process and Cycles (IAMAS, IAPSO, IAVCEI, IAHS, IACS)

JM03p-537

Impact of central European cities emissions on the regional air-quality

P. Huszar[1], M. Belda[1], T. Halenka[1]
[1]Charles University- Prague, Dept. of Atmospheric Physics, Prague 8, Czech Republic

The impact of central European city emissions of short lived gases and aerosols (i.e. the non-CO_2 impact) on the tropospheric chemistry is examined focusing on Central Europe. A coupled modeling system with two way interactions consisting of the regional climate model RegCM (version 4.2) and the chemistry transport model CAMx (version 5.4) was implemented on a 10 km x 10 km resolution domain centered over central Europe. For anthropogenic emissions, the TNO MACC gridded emission database was used. City emissions were masked using the 500 000 population threshold over western Europe and 100 000 over eastern part of the domain. Derived from this database, carbon monoxide (CO) forms the majority of the city emissions (around 55 % as mass fraction), further nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOC), sulfur dioxide (SO_2), PM10, PM2.5 and NH_3 follow with 14%, 13.7%, 11.6%, 2.9%, 1.6% and 0.6% contribution (as average of the selected cities), respectively. For the period of 2001-2010, two sets of experiments were performed: one with urban emissions removed and one with all urban emissions included (reference experiment). For validation, the results were compared with the EMEP and Airbase surface observations. The chemistry impact is evaluated as the difference between the corresponding experiments. The results showed significant ozone reduction (caused by titration) especially over the western and northern part of the domain. However, city emissions contribute to ozone production over southern Europe. An increase of sulfate, nitrate aerosols and black/organic is significant as well and it is not limited to urbanized areas only. The threshold exceedances and their changes according to the EC guidelines are examined as well.

Joint Inter-Association Symposium

JM04a - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-1379

Alleviating the bias induced by the linear analysis update with an isopycnal ocean model

Y. Wang[1], *F. Counillon*[1], *L. Bertino*[1]
[1]*Nansen Environmental and Remote Sensing Center, Mohn-Sverdrup Center, Bergen, Norway*

When applying data assimilation to Lagrangian coordinate models, it is profitable to correct its grid (position, volume). In isopycnal ocean coordinate model, such information is provided by the layer thickness that can be massless but must remains positive (truncated Gaussian distribution). A linear Gaussian analysis does not ensure positivity for such variable. Existing methods have been proposed to handle this issue – e.g. post processing, anamorphosis or resampling – but none ensures conservation of the mean, which is imperative in climate application. Here, a framework is introduced to test a new method, which proceed as following. First, layers for which analysis yields negative values are iteratively grouped with neighboring layers, resulting in a probability density function with a larger mean and smaller standard deviation that prevent appearance of negative values. Second, analysis increments of the grouped layer are uniformly distributed, which prevent massless layers to become filled and vice-versa. The new method is proved fully conservative with e.g. OI or 3DVAR but a small drift remains with ensemble-based methods (e.g. EnKF) during the update of the ensemble anomaly. However, the resulting drift with the latter is small and the increase of the computational cost moderate. The new method is demonstrated with a realistic application in the Norwegian Climate Prediction Model (NorCPM) that provides climate prediction by assimilating sea surface temperature with the EnKF in a fully-coupled Earth System model with an isopycnal ocean model. Over 25-year analysis period, the new method does not impair the predictive skill of the system but corrects the artificial steric drift introduced by data assimilation, and provide estimate in good agreement with IPCC AR5.

Joint Inter-Association Symposium

JM04a - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-1746

Adding value to the Global Observing System: Making sense of high-resolution air quality observations using data assimilation techniques

W. Lahoz[1], *P. Schneider*[2], *N. Castell*[2], *A. Bartonova*[3]
[1]*NILU, Kjeller, Norway*
[2]*NILU, INBY, Kjeller, Norway*
[3]*NILU, Admin, Kjeller, Norway*

With increasing amount of environmental observations available from increasing use of high-resolution low-cost sensors, a major challenge is making sense of the amount of collected observations and providing citizens with relevant value-added products. The expectation is that this new information will extend traditional in situ and satellite observations.

For air quality, a high-density network of low-cost sensors has significant potential for improving spatial mapping in urban areas. These data provide information at spatio-temporal scales of interest to citizens, 100m; a few minutes. However, most of these datasets contain data gaps and are generally point measurements. This poses significant challenges for mapping applications. One way to overcome this is to combine these data with data from a model.

We discuss efforts to apply data assimilation techniques to urban air quality information, highlighting opportunities and challenges, drawing from the EU-funded CITI-SENSE project. Opportunities include extending traditional observations; challenges include simulation of smaller spatial scales, noisy data and error representation.

In CITI-SENSE, there is a deployment of a dense network of low-cost sensors measuring air quality in European cities. We will use data assimilation to combine these high-resolution observations with model output to provide detailed maps of urban air quality. We present first results, building on data fusion efforts to add value to high-resolution urban quality information. We identify examples of added value in urban air quality maps, e.g., helping users find the currently least polluted route in a city. We map the way forward for adding value to traditional observations from high-resolution information, and identify benefit to citizens.

Joint Inter-Association Symposium

JM04a - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-2809

Theoretical developments in data assimilation, with reference to chemical data assimilation

M. Bocquet[1]
[1]*Ecole des Ponts ParisTech, CEREA, Marne la Vallée, France*

In this presentation, I will give an overview of recent theoretical developments in data assimilation. The pros and cons of optimal interpolation/3D-Var, the ensemble Kalman filter and 4D-Var will be recalled. I will explain why new methods based on the hybridation, or even merging, of the ensemble and variational methods has recently been brought forward, and subsequently generically called EnVar methods.

One of these new methods, the iterative ensemble Kalman smoother (IEnKS) has been introduced with a view to outperform the ensemble Kalman filter and 4D-Var in all regimes and conditions of the forecast models. I will show that this is indeed the case, at least with several low-order models.

I will discuss the potential of these new methods for chemical data assimilation, especially for parameter estimation. A low-order photochemical and transport model, which can be used online or offline, has been developed to test these new methods and ideas.

Joint Inter-Association Symposium

JM04a - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-3913

Monitoring a changing environment: The role of OSSEs in determining the future global observing system

W. Lahoz[1], J.L. Attie[2], P. Ricaud[3], L. El Amraoui[3]
[1]NILU, Kjeller, Norway
[2]U. Toulouse, Aerology, Toulouse, France
[3]Meteo-France, CNRM, Toulouse, France

A changing environment in the 21st Century, in particular because of constituents associated with air quality and climate change, and with consequences for societal well-being, illustrates the need to monitor the environment, including compliance with environmental regulations from societal actors such as public authorities, governments and industry. For air quality, this monitoring involves, inter alia, measurements of key pollutants (e.g., ozone and carbon monoxide) in the lowermost troposphere even in the atmospheric boundary layer at spatio-temporal scales relevant to policy makers (temporal frequencies of order less than 1 hour; spatial scales of order less than 10 km).

In this presentation, we identify the role of data assimilation observing system simulation experiments (OSSEs) in determining the future global observing system (GOS) to monitor air quality in a changing environment. We describe requirements for constructing such OSSEs, and discuss caveats associated with setting up and interpreting the OSSEs. To illustrate the concept, we present OSSEs performed to assess the added value of planned and proposed geostationary satellite platforms to measure constituents affecting air quality.

Joint Inter-Association Symposium

JM04a - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-5328

Comparison of geomagnetic field models using data assimilation

A. Tangborn[1], *W. Kuang*[2]
[1]*University of Maryland Baltimore County, Baltimore, USA*
[2]*Goddard Space Flight Center, Planetary Geodynamics Laboratory, Greenbelt, USA*

We show how comparisons between geomagnetic field models over the last 400 years can be made using data assimilation. Because of the substantial increase in measurements over this time period, the accuracy of field models has increased greatly in recent years. Thus geomagnetic forecasts from a geodynamo model simulation that is constrained by input from field models can be used to determine the dynamical consistency between these models by comparing forecasts (F) with observations from field models (O). The observation minus forecast (O-F) is a combination of observation and forecast errors. Since we expect greater accuracy in recent years, most of the errors should originate in the forecasts and O-F statistics can be used to determine the accuracy of the forecast. And because information from observations in early years is carried forward by the model, these statistics can also be used to assess the accuracy of the field models from these times. This work makes use of the gufm1 and CM5 field models.

Joint Inter-Association Symposium

JM04b - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-1661

Data assimilation for real-time prediction of earthquake ground shaking: "Numerical shake prediction" for Earthquake Early Warning

M. Hoshiba[1]
[1]*Meteorological Res. Inst.- JMA, Seismology and Tsunami Research Department, Tsukuba, Japan*

Real-time prediction of earthquake ground shaking is a strong tool for prevention/mitigation of earthquake disaster, and it has been applied for earthquake early warning (EEW). EEW has been operated for general public in Japan since 2007 and in Mexico since early 1990s, and possible use of such systems has been investigated in the United States, Taiwan, EU, Turkey, and other countries. Many of the present EEW systems first quickly determine the earthquake hypocenter and magnitude, and then they predict the strengths of ground shaking at various locations using the hypocenter distance and magnitude. The 2011 Tohoku earthquake (M_w 9.0), however, revealed some technical issues with such methods: under-prediction at large distances due to the large extent of the fault rupture, and over-prediction because the system was confused by multiple aftershocks that occurred simultaneously. To address these issues, we propose a new concept for EEW, in which the distribution of the present wavefield is estimated precisely in real time (real-time shake mapping) by applying a data assimilation technique, and then the future wavefield is predicted time-evolutionally by simulation of seismic wave propagation. We call this method, in which physical processes are simulated from the precisely estimated present condition, "numerical shake prediction" by analogy to "numerical weather prediction" in meteorology. By applying the proposed method to the 2011 Tohoku Earthquake and the 2004 Mid-Niigata Earthquake (M_w 6.7), we show that numerical shake prediction can precisely and rapidly predict ground shaking in real time manner.

Joint Inter-Association Symposium

JM04b - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-2622

Potential of space-borne GNSS reflectometry to constrain numerical simulations ofthe ocean circulation

J. Saynisch[1], M. Semmling[1], J. Wickert[1], M. Thomas[1,2]
[1]Helmholtz-Zentrum Potsdam- Deutsches GeoForschungsZentrum, Geodesy and Remote Sensing, Potsdam, Germany
[2]Freie Universität Berlin, Institute of Meteorology, Berlin, Germany

The Agulhas current system transports warm and salty water masses from the Indian ocean into the Southern Ocean and into the Atlantic. The transports impact past, present and future climate on local and global scales but size and variability of the respective transports are still much debated. In this study, an idealized model based twin experiment is used to study if sea surface height (SSH) anomalies estimated from reflected signals of the Global Navigation Satellite System (GNSS-R) can be used to determine the internal water mass properties and transports of the Agulhas region. A space-borne GNSS-R detector on the International Space Station (ISS) is assumed and simulated. The proposed GNSS-R measurements surpass the radar-based satellite altimetry missions in temporal and spatial resolution but are less precise. Artificial but characteristic observations are sampled from a regional ocean model of the Agulhas region. The observations are subsequently assimilated with a 4DVAR adjoint data assimilation method into the same ocean model but with a different background state. The assimilated and the original, i.e., the sampled model state are compared to systematically identify improvements and degradations in the model variables that arise due to the assimilation of the SSH observations. We show how and when modelled SSH and independent, i.e., not assimilated model variables improve by the assimilation of GNSS-R based SSH observations.

Joint Inter-Association Symposium

JM04b - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-3368

Assimilating GRACE terrestrial water storage estimates into a regional hydrological model: A case study of the Rhine River basin

N. Tangdamrongsub[1], S.C. Steele-Dunne[2], B.C. Gunter[1,3], P.G. Ditmar[1], A.H. Weerts[4,5]
[1]Delft University of Technology,
Department of Geoscience and Remote Sensing- Faculty of Civil Engineering and Geosciences, Delft, Netherlands
[2]Delft University of Technology,
Department of Water Resources- Faculty of Civil Engineering and Geosciences, Delft, Netherlands
[3]Georgia Institute of Technology, School of Aerospace Engineering, Atlanta, USA
[4]Wageningen University,
Hydrology and Quantitative Water Management Group- Department of Environmental Sciences, Wageningen, Netherlands
[5]Deltares, Operational Water Management, Delft, Netherlands

The ability to estimate Terrestrial Water Storage (TWS)variations realistically is important for better understanding the hydrological cycle. Imperfections in model physics and uncertainties in model land parameters and meteorological data commonly limit the accuracy of hydrological models in simulating TWS. This study investigated the benefits of assimilating TWS estimates derived from the Gravity Recovery And Climate Experiment (GRACE) data into the OpenStreams wflow_hbv model using an Ensemble Kalman Filter (EnKF) approach. The study area chosen was the Rhine River basin, which has both well-calibrated model parameters and high-quality forcing data that were used for experimentation and comparison. Four different case studies were examined which were designed to evaluate different levels of forcing data quality and resolution including those typical of other less well-monitored river basins. The results were validated using in situ groundwater and gauge data. The analysis showed a noticeable improvement in groundwater estimates when GRACE data were assimilated, with a best-case improvement of 71% in correlation coefficient and 35% in RMS error compared to the ensemble open-loop case. Averaging from all four cases, correlation and RMS error improvements were 13% and 14%, respectively. Due to sporadic short-term, but sizeable, errors in the forcing data, and the lack of sufficient constraints on the soil moisture component,only a slight overall improvement was observed in streamflow estimates when GRACE data were assimilated. Overall, the results

highlight the benefit of assimilating GRACE data into hydrological models, particularly in data-sparse regions, while also providing insight on future refinements of the data assimilation methodology.

Joint Inter-Association Symposium

JM04b - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-4550

Assimilation of GPM precipitation observations in the NASA Unified WRF Ensemble Data Assimilation System

S. Zhang[1]*, M. zupanski*[2]*, P. chambon*[3]*, S. cheung*[4]
[1]*NASA, GSFC, Greenbelt, USA*
[2]*CSU, CIRA, fort collins, USA*
[3]*Meteo France, CNRM-GAME, toulouse, France*
[4]*UC Davis, Math Dept., Davis, USA*

Currently, millions of observations are incorporated in operational data assimilation for numerical weather prediction (NWP) and re-analyses for climate studies. However, precipitation observations indirectly measured by satellite instruments are not routinely used. Because precipitation is a non-linear microphysics process, when radiances are affected by precipitation, it remains a scientific challenge to connect the observed signals to model physical and dynamic states to make effective corrections to forecasts and analysis. Global Precipitation Measurement (GPM) is a NASA and JAXA joint mission. The core observatory carrying a microwave imager and a dual-frequency precipitation radar has been launched in February 2014. The NASA Unified WRF Ensemble Data Assimilation System has been developed with a focus on utilizing satellite observed precipitation information and incorporating microwave and radar techniques, particularly in estimation of precipitation distributions in liquid and frozen phases. We present the bias correction implementation and the ensemble assimilation algorithms developed for GPM observations, and results from experiments carried out during a mid-latitude winter storm. The data impact to storm structures and precipitation estimates will be examined by using level-1 multi-sensor multi-channel observations at field-of-view resolutions.

Joint Inter-Association Symposium

JM04b - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-5033

Data-driven approaches beneficial to data assimilation in earthquake researches

H. Nagao[1,2], *M. Kano*[1], *S. Mizusako*[1], *A. Suzuki*[2]
[1]*The University of Tokyo, Earthquake Research Institute, Tokyo, Japan*
[2]*The University of Tokyo, Graduate School of Information Science and Technology, Tokyo, Japan*

The current framework of data assimilation basically relies on a priori given simulation model rather than observation data, so that phenomena which the simulation model does not assume are neither extractable nor predictable. Since it is impossible to provide a perfect simulation model that reproduces all complex phenomena, data assimilation that implements a cutting-edge data-driven approach would open a new paradigm in geophysical modeling (Nagao [2014]). We aim to establish methodology of such data assimilation driven by both simulation models and observation data beneficial to the solid Earth science.

One of our data-driven methods relates to GNSS data assimilation that investigates frictional features at a plate boundary, which control behavior of afterslips triggered by earthquakes. Kano et al. [2013] applied an adjoint method to GNSS data when the 2003 Tokachi-oki Earthquake occurred, and clarified the spatial distribution of the frictional features in the afterslip region. The simulation of propagating afterslips based on the equation of motion and the frictional law costs much computational time when fine computational grids are used. We have developed a data-driven method using the k-means clustering, which is capable of a coarse graining of computational grids and saving the computational costs.

Another data-driven method relates to a sparse modeling procedure based on 'lasso' in order to image seismic wave field in the Tokyo metropolitan area from the dense seismic array MeSO-net (Metropolitan Seismic Observation network). Such imaging is needed, as an input ground motion, in a simulation of seismic responses of a number of constructions in an urban area, which will contribute to a rapid prediction of damage on constructions to prevent secondary disasters.

Joint Inter-Association Symposium

JM04b - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-5079

Assimilation of the observed geomagnetic SV and constraints on core fow beneath the core-mantle boundary

W. Kuang[1], *A. Tangborn*[2]
[1]*NASA Goddard Space Flight Center, Planetary Geodynamics, Greenbelt, USA*
[2]*University of Maryland- Baltimore County,*
Joint Center for Earth System Technologies, Baltimore, USA

Surface geomagnetic measurements are often used to construct the Gauss coefficients of the internal field (the core field). These coefficients vary continuously in time. Their first order time derivatives, i.e. the geomagnetic secular variation (SV), are “concurrently” measured. While the Gauss coefficients provide constraints on the poloidal component of the core field and its first order radial derivative (via potential field properties) at the core-mantle boundary, the SV provides the constraints on the second order radial derivative of the field and/or on the core fluid velocity field. Therefore, assimilation of the observed SV could be potentially utilized to improve forecast accuracies and to reduce numerical model spin-up time. Such assimilation can be achieved via construction of a new observation operator for the velocity field in the outer core, and modification of the existing observation operator for the magnetic field.

We have carried out several assimilation experiments with the geomagnetic field model solutions from 1900 to 2000. In these experiments, the SV is used only to modify the magnetic field in the dynamo solutions. Our results show that the observed SV can consistently reduce the forecast errors. This improvement is in large part due to substantial changes in the core fluid velocity field of the model solutions flow. In particular, the strongest changes occur in the large-scale axisymmetric toroidal velocity, followed by a suite of small-scale velocity components (with the span from spherical harmonic degree 10 to 20); the non-axisymmetric part of the poloidal flow also changes substantially. Such changes can be utilized for constructing optimal observation operator for the velocity field in future assimilation algorithm development.

Joint Inter-Association Symposium

JM04c - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-3312

Maximum likelihood approach for estimating uncertain parameters in data assimilation for a plasmasphere model

S. Nakano[1], *M.C. Fok*[2], *P.C. Brandt*[3], *T. Higuchi*[1]
[1]*The Institute of Statistical Mathematics, Department of Statistical Modeling, Tachikawa, Japan*
[2]*NASA, Goddard Space Flight Center, Greenbelt- MD, USA*
[3]*The Johns Hopkins University, Applied Physics Laboratory, Laurel- MD, USA*

The plasmasphere is the inner part of the magnetosphere, where cold plasma is densely concentrated. Extreme ultraviolet (EUV) imaging data taken from the IMAGE satellite provides the vital information on the temporal evolution of the plasmasphere. In order to reproduce the temporal evolution of the plasmasphere, we employ a data assimilation approach based on the ensemble transform Kalman filter. Combining the EUV images with the dynamical model of the plasmasphere, we can also estimate the electric field around the plasmapause, which strongly controls the motion and the spatial structure of the plasmapause. However, the estimates obtained with the ensemble transform Kalman filter still contains uncertainties. For example, since a single EUV image is two-dimensional, it is difficult to effectively constrain the parameter describing a three-dimensional structure at each assimilation cycle. In order to resolve this problem, we introduce the marginal likelihood of the parameters given the sequence of EUV imaging data. This marginal likelihood can be used to determine optimal values for the parameters. The results and performances of the parameter estimation will be demonstrated.

Joint Inter-Association Symposium

JM04c - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-3455

Developments in particle filtering

P.J. Van Leeuwen[1], *J. Amezcua*[1]
[1]*University of Reading/ NCEO, Meteorology, Reading, United Kingdom*

With increasing computer power and rapid development of sophisticated techniques, nonlinear data assimilation is becoming a reality in the geosciences. Most promising for high-dimensional systems seems to be the so-called particle filter. The particle filter makes no assumption on the shape of the probability densities (pdf), so is very general, but because of that not directly efficient. Recently, however, particle filters have been developed that work in systems of any dimension, such as the Equivalent-Weights Particle Filter, and examples of the application of this filter to models with state-spaces with over a million variables are discussed.

Unfortunately these methods require tuning to work well, and the tuning exercise can be very expensive in high-dimensional systems. The search is for more robust particle filters, and it will be shown how they can be formulated. It turns out that some of these can use ideas from traditional data-assimilation methods as 4DVar and the Ensemble Kalman Filter. For instance, in one variant a weak-constraint 4Dvar has to be solved for each particle, but with fixed in initial condition as the so-called background error covariance is zero. This so-called implicit particle filter is degenerate, but it can be made robust by combining it with ideas from the Equivalent-Weights Particle Filter. A whole family of robust filters can be constructed, borrowing ideas from e.g. optimal transportation. Application of these more robust particle filters to high-dimensional geophysical systems will be shown.

This field is by no means fully explored, and potentially fruitful directions for further research will be identified.

Joint Inter-Association Symposium

JM04c - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-3465

A meso hybrid data assimilation system based on the JMA nonhydrostatic model

K. Ito[1], M. Kunii[2], T. Kawabata[2], K. Saito[2], L. Duc[3]
[1]University of the Ryukyus, Department of Physics and Earth Sciences, Naha, Japan
[2]Meteorological Research Institute, Forecast Research Department, Tsukuba, Japan
[3]Japan Agency for Marine-Earth Science and Technology, Seamless Environmental Prediction Research, Yokohama, Japan

This work evaluates the potential of a hybrid ensemble Kalman filter and four-dimensional variational (4DVAR) data assimilation system for predicting severe weather events from a deterministic point of view. This hybrid system (HYBRID) is an adjoint-based 4DVAR system using a background error covariance matrix constructed from perturbations in a local ensemble transform Kalman filter (LETKF) data assimilation system, both of which are based on the Japan Meteorological Agency nonhydrostatic model. An assimilation of pseudo single-observation located in the north of a tropical cyclone (TC) yielded an analysis increment suited to the dynamics of TCs in HYBRID, whereas the analysis increment did not follow the dynamics of TCs in a 4DVAR system using a so-called NMC method. Real data assimilation experiments showed that HYBRID provided better initial conditions than the NMC-based 4DVAR, both for predicting the intensity and track forecast of TC Roki in September 2011 and for the location and amount of local heavy rainfall in the Kyushu region, Japan, in July 2012. In these cases, HYBRID provided better initial conditions than LETKF for short-term predictions of high-impact weather events, while LETKF provided better initial conditions for relatively longer-term predictions.

Joint Inter-Association Symposium

JM04c - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-4327

The gamma/inverse-gamma (gig) filter and its potential use in Earth-system analysis and prediction

C. Bishop[1]
[1]*Naval Research Laboratory, Monterey, USA*

Observations and predictions of near-zero positive variables such as aerosols, water vapor, cloud, precipitation and plankton concentrations have error distributions whose standard deviations are typically proportional to the value of the variable. Many of these variables play a critical role in climate and severe-weather prediction. The Kalman filter and ensemble Kalman filter are both ill-suited to estimating distributions of these variables because they incorrectly assume that error variances are independent of the actual values of the variables. Here, we present a new tool (the gig filter) that solves the classical filtering and prediction problem for the non-linear case in which errors are proportional to the underlying magnitude of the variable being estimated rather than independent of this magnitude. In such systems, error dynamics are often non-linear. The proposed approach precisely solves Bayes' theorem in special cases where the observation error likelihood and prior forecast error distributions are gamma and inverse-gamma (gig) distributions. Regardless of the precise form of the prior and likelihood distributions, the gig filter delivers the minimum error variance estimate as well as a posterior error covariance matrix consistent with the assumption that analysis error magnitudes are proportional to the magnitude of the analysis mean. A simple coordinate transformation allows the gig filter to simultaneously accommodate variables whose error variances are independent of variable magnitude (such as temperature). Idealized systems are used to compare and contrast the gig filter with the Ensemble Kalman filter.

Joint Inter-Association Symposium

JM04c - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

IUGG-4530

Deriving optimal combinations of static and flow dependent variances using hidden error variance theory

D. Kuhl[1], *E. Satterfield*[2], *C. Bishop*[2]
[1]*Naval Research Lab, Remote Sensing, Washington, USA*
[2]*Naval Research Lab Monterey, Marine Meteorology, Monterey, USA*

Data assimilation systems such as Hybrid variational DA schemes employ forecast error covariance models that are linear combinations of static covariance models and flow-dependent ensemble based covariance models, we will refer to these systems as Hybrids. Currently, to determine the optimal weighting of the flow-dependent and static parts components, numerical weather prediction (NWP) centers must perform computationally expensive trials to compare each set of plausible weights. Since it is likely that the accuracy of ensemble based error covariances varies with vertical level and latitude, it also seems reasonable to assume that the optimal weights for a Hybrid covariance model would be a slowly varying function of latitude and height. However, the amount of tuning required to optimize such spatially varying weights would be even more computationally expensive. Here, we introduce and demonstrate a new method for deriving spatially varying weights for Hybrid error covariance models. This method is based on empirical techniques arising from hidden error variance theory which enable estimates of aspects of the climatological distribution of true error variances and the likelihood distribution of ensemble variances given a true error variance. If the assumptions of the approach are satisfied, the method would recover optimal weights for the ensemble and climatological estimates of the true error variance from archives of innovation and ensemble variance pairs. Here we evaluate the assumptions of the univariate model applied to the Lorenz ‘96 system as well as the Navy’s 2016 operational DA scheme NAVDAS-AR-hybrid. Results indicate that the derived optimal weights perform comparably to the optimal weights found through brute force tuning.

Joint Inter-Association Symposium

JM04p - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

JM04p-488

A particle swarm optimizer based on directions and its application to the four dimensional variational data assimilation

Q. Zheng[1], *J. Sha*[2], *H. Shu*[1]
[1]*Institute of Science- PLA University of Science and Technology, Mathematics Department, Nanjing, China Peoples Republic*
[2]*Troop, PLA, Suzhou, China Peoples Republic*

A variant particle swarm optimizer based on directions (PSOBD) is presented and applied to the four dimensional variational data assimilation (4DVar). In the PSOBD update process, not only both the historical optimal positions of the particle swarm and the current particle are utilized, but also for each direction (component) of particles, both the historical optimal directions of the particle swarm and the current particle are used. To verify the performance of the PSOBD in the 4DVar, an idealized simple model with "on-off" switches is firstly employed as the governing equation, and three assimilation schemes are performed. One is the 4DVar based on the traditional adjoint method (ADJ_4DVar), the second is based on the classic PSO (PSO_4DVar), and the last is based on the PSOBD (PSOBD_4DVar). Twin numerical experiment results show that both the classical PSO and the PSOBD can produce satisfied assimilation retrieval with high probability, while the traditional adjoint method fails to work. Compared with the PSO_4DVar, the PSOBD_4DVar only takes 1/30 of time on average to obtain good assimilation retrievals with 99.7% probability, which is larger than 88.5% with the classical PSO. Furthermore, the PSOBD is applied to the shallow-water equation (SWE) 4DVar to test its effectiveness for complex model. Twin experiment results show that the PSOBD_4DVar keeps its strong search ability and yield good assimilation retrievals with 99.5% probability. Besides, the parallel PSOBD is designed and applied to the SWE 4DVar. Numerical experiment results show that, on average, the assimilation time of the parallel PSOBD is 1/13 of the one of the serial PSOBD, which is encouraging and demonstrates the potential of the PSOBD to apply to the 4D-Var in real atmospheric or oceanic models.

Joint Inter-Association Symposium

JM04p - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

JM04p-489

A simple evaluation of a ocean data assimilation system in the Indian-Pacific Oceans

C. Yan[1]
[1]*Institute of Atmospheric Physics- CAS, ICCES, Beijing, China Peoples Republic*

An ocean data assimilation system is developed in the Indian-Pacific Oceans. The specific assimilation schemes depend on different types of observations. For in-situ observations, instead of direct temperature or salinity profiles. The Layer thickness is assimilated to adjust the model layer thickness, barotropic and baroclinic fields. They are based on an ensemble-based method which estimates the background error covariance matrix by an ensemble sampled from the output of model. The model used is the hybrid coordinate ocean model(HYCOM) with the resolution of 0.2^ox0.2^ox28 levels. The experiment which assimilates various types of observations including profiles from XBT, CTD,TAO,ARGO etc, altimetry data and remotely-sensed sea surface temperature into the HYCOM in the Indian-Pacific oceans is carried out during the period of 1992-2012. Some evaluations on the assimilation system are made by the comparison to independent observations including temperature, salinity, current from drifters, and other reanalysis products.

Joint Inter-Association Symposium

JM04p - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

JM04p-490

Data assimilation of ionospheric magnetic field perturbations into a global magnetopspheric model

D. kondrashov[1], *S. Merkin*[2]
[1]*UCLA, Los Angeles, USA*
[2]*John Hopkins University, Applied Physics Laboratory, Laurel, USA*

Ionosphere is tightly coupled with the magnetosphere and is the only region of geospace where in situ observations approaching global scale are possible. This capability is owing to the emergence of new datasets of key ionospheric measurements with global spatial and high-frequency temporal coverage, such as AMPERE (Active Magnetosphere and Planetary Electrodynamics Response Experiment) magnetic field data measured onboard Iridium satellites. We are reporting first results for assimilation of low-altitude ionospheric measurements of magnetic field perturbations into a Lyon-Fedder-Mobarry (LFM) global magnetospheric model coupled with Rice-Convection Model (RCM). We adopt optimal interpolation approach and rely on quasi-steady, linear approximation between equatorial magnetospheric pressure and field-aligned currents in the ionosphere. This approximation is estimated numerically by perturbing the LFM-RCM model and by considering only large-scale modes from the Fourier decompositions of the ionospheric magnetic field and equatorial magnetospheric pressure. The developed methodology was validated by using so called 'fraternal-twins' model-based assimilation tests. The numerical LFM-RCM model with one set of parameters is used to generate synthetic observations, while model with differing set of parameters is used for assimilation and to calculate magnetospheric pressure corrections to be applied in order to reproduce synthetic observations.

Joint Inter-Association Symposium

JM04p - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

JM04p-491

An incremental local ensemble transform kalman filter method for mesoscale numerical weather prediction and its quantitative precipitation forecast performance

T. Kuroda[1], *T. Fujita*[2], *H. Seko*[3], *K. Saito*[3]
[1]*Japan Agency for Marine-Earth Science and Technology, yokohama, Japan*
[2]*Japan Meteorological Agency, Numerical Prediction Division, Tokyo, Japan*
[3]*Meteorological Research Institute, Forecast Research Department, Tsukuba, Japan*

The variational incremental method has been widely used in routine analyses. It executes variational calculation and forward integration with the lower and the higher resolutions, respectively, and is considered to save calculation cost without losing precision. On the other side, Local Ensemble Transform Kalman Filter (LETKF) is another important method which shows the high performance on parallel computers and does not need the variational code development. Techniques such as covariance inflation and localization allow application study with the limited ensemble size. An analysis system shown in this study can analyze the end (conventional 4D-LETKF) and the beginning (so called no-cost smoother) of the analysis time window. Furthermore, it is possible to execute an incremental LETKF when the smoother is executed by using the ensemble forecast with the lower resolution to save calculation cost, and by using the higher resolution forecast which uses the smoother analysis as the initial value. In order to see the precipitation prediction performance, four methods such as a conventional 15km LETKF, 15km smoother, incremental LETKF with 15km and 5km resolutions, and a conventional 5km LETKF are conducted with the use of forty member ensemble, and the extended forecasts are compared. They are applied to a heavy rain case occurred in Kyushu of Japan in July 2011 and then the rain rate threat score on the extended forecast of the incremental LETKF showed favorable result which was comparable to that of 5km LETKF in spite of the reasonable calculation cost.

Joint Inter-Association Symposium

JM04p - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

JM04p-492

Inverse problem in volcanic lava flow modeling

D. Kovtunov[1,2], A. Korotkii[1,2], I. Tsepelev[1,2], A. Ismail-Zadeh[1,3], O. Melnik[1,4]
[1]Russian Academy of Sciences,
Institute of Earthquake Prediction Theory and Mathematical Geophysics, Moscow, Russia
[2]Russian Academy of Sciences, Institute of Mathematics and Mechanics, Yekaterinburg, Russia
[3]Karlsruhe Institute of Technology, Institute of Applied Geosciences, Karlsruhe, Germany
[4]Lomonossov Moscow State University, Institute of Mechanics, Moscow, Russia

We develop a two-dimensional numerical model for a temperature assessment of a steady-state thermo-convective flow in a volcanic lava channel when the measurements of temperature and heat flow are known at the surface of this channel. This problem belongs to a class of ill-posed inverse problems. We propose a numerical approach to solving this problem when the lava viscosity and thermal conductivity depend on temperature. The mathematical problem consists of the Stokes equations for incompressible viscous fluis, equation of state, and heat balance equation with the appropriate boundary conditions. We use an adjoint method to solve the problem. The problem is then reduced to minimization of a special functional using a gradient method. We demonstrate the possibilities of this approach to determine the temperature in the lava channel from the surface data.

Joint Inter-Association Symposium

JM04p - JM4 Data Assimilation in Geophysical Sciences (IAMAS, IAGA, IACS, IASPEI, IAPSO, IAG)

JM04p-493

A non-variational consistent hybrid ensemble filter

C. Bishop[1]
[1]*Naval Research Laboratory, Monterey, USA*

A Consistent Hybrid Ensemble Filter (CHEF) for using Hybrid forecast error covariance matrices that linearly combine aspects of both climatological and flow dependent matrices within a non-variational ensemble data assimilation scheme is described. The CHEF accommodates the ensemble data assimilation enhancements of (a) model space ensemble covariance localization for satellite data assimilation and (b) Hodyss' method for improving accuracy using ensemble skewness. Like the Local Ensemble Transform Kalman Filter (LETKF), the CHEF is computationally scalable because it updates local patches of the atmosphere independently of others. Like the sequential Ensemble Kalman Filter (EnKF), it serially assimilates batches of observations and uses perturbed observations to create ensembles of analyses. It differs from the deterministic (no perturbed observations) Ensemble Square Root Filter (ESRF) and the EnKF in that (i) its analysis correction is unaffected by the order in which observations are assimilated even when localization is required, (ii) it uses accurate high rank solutions for the posterior error covariance matrix to serially assimilate observations, and (iii) it accommodates high rank Hybrid error covariance models. Experiments were performed to assess the effect on CHEF and ESRF analysis accuracy of these differences. In the case where both the CHEF and the ESRF used tuned localized ensemble covariances for the forecast error covariance model, the CHEF's advantage over the ESRF increased with observational density. In the case where the CHEF used a Hybrid error covariance model but the ESRF did not, the CHEF had a substantial advantage for all observational densities.

Joint Inter-Association Symposium

JP01a - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-0556

High-frequency sea-level oscillations in the Mediterranean Sea: analysis and synoptic preconditioning

I. Vilibic[1], J. Sepic[1], A. Lafon[2], L. Macheboeuf[2], Z. Ivanovic[3]
[1]Institute of Oceanography & Fisheries, Physical Oceanography Laboratory, Split, Croatia
[2]École Navale, BCRM Brest, Brest, France
[3]Faculty of Science, Department of Physics, Split, Croatia

The study focuses on an analysis of 1-min sea level time series collected at 32 Mediterranean tide gauge stations with 4 or more years of data available between 2008 and 2014. The data is available at the IOC website (http://www.ioc-sealevelmonitoring.org). Sea level time series were de-spiked, de-tided, linearly interpolated, high-pass filtered and analysed. Several important points were revealed: (i) high-frequency sea level oscillations are often widespread and can affect areas from the eastern Spanish to the western Greek coast; (ii) during the Mediterranean-wide events, oscillations typically first occur in the Western Mediterranean, and then their occurrence propagates within the next few days to the Eastern Mediterranean (Greece); (iii) oscillations occur throughout the year but are, depending on area, strongest from April to August; and (iv) high-frequency sea level oscillations are often associated with higher-than-average mean sea level conditions, adding to a possible danger of flooding; also, they are occasionally related to dangerous meteotsunami events. Synoptic conditions observed during the 48 strongest events were also analysed in more detail. These events typically occur during: (i) presence of low mean sea level pressure with a centre northwest from the affected area; (ii) inflow of warm African air in the lower troposphere; (iii) strong south-western winds and the jet at mid-tropospheric levels embedded in (iv) instable atmospheric levels. High-frequency sea level events may strongly affect the computation of sea level extremes and therefore their connection to a favourable synoptic pattern has a potential to further contribute to the studies of sea level extremes and flooding hazard assessment studies.

Joint Inter-Association Symposium

JP01a - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-1653

Time of emergence for regional sea-level change

K. lyu[1], X. Zhang[1], J. Church[1], A. Slangen[1], J. Hu[2]
[1]CSIRO, Oceans and Atmosphere Flagship, Hobart, Australia
[2]Xiamen University, College of Ocean and Earth Sciences, Xiamen, China Peoples Republic

Determining the time when the climate change signal from increasing greenhouse gases exceeds and thus emerges from natural climate variability (referred to as the time of emergence, ToE) is an important climate change issue. Previous ToE studies were mainly focused on atmospheric variables. Here, based on three regional sea-level projection products available to 2100, which have increasing complexity in terms of included processes, we estimate the ToE for sea-level changes relative to the reference period 1986–2005. The dynamic sea level derived from ocean density and circulation changes alone leads to emergence over only limited regions. By adding the global-ocean thermal expansion effect, 50% of the ocean area will show emergence with rising sea level by the early-to-middle 2040s. Including additional contributions from land ice mass loss, land water storage change and glacial isostatic adjustment generally enhances the signal of regional sea-level rise (except in some regions with decreasing total sea levels), which leads to emergence over more than 50% of the ocean area by 2020. The ToE for total sea level is substantially earlier than that for surface air temperature and exhibits little dependence on the emission scenarios, which means that our society will face detectable sea-level change and its potential impacts earlier than surface air warming. This study was recently published by Nature Climate Change (DOI: 10.138/NCLIMATE2397).

Joint Inter-Association Symposium

JP01a - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-2053

Controls on time-mean coastal sea level: Consistency between models and observations, and the role of the Mediterranean inflow.

C. Hughes[1]*, R. Bingham*[2]*, V. Roussenov*[1]*, J. Williams*[3]*, P. Woodworth*[3]
[1]*University of Liverpool, School of Environmental Sciences, Liverpool, United Kingdom*
[2]*University of Bristol, School of Geographical Sciences, Bristol, United Kingdom*
[3]*National Oceanography Centre - Liverpool, Joseph Proudman Building, Liverpool, United Kingdom*

If we are to have confidence in 100-year projections of the steric and dynamical component of coastal sea level, we need to understand the underlying mechanisms on these time scales. In the absence of multi-century observations, this means we must focus on the mechanisms responsible for maintaining spatial variations in the time-mean coastal sea level. Here we compare tide gauge data and satellite data with ocean model data to show that the spatial patterns are quite robustly represented in the present day, but that an important component of inter-model variability is the size of the sea level fall across the Strait of Gibraltar. We demonstrate that this fall, and the mean Mediterranean sea level, are controlled in the models by the strength of the Mediterranean inflow, thus enabling two observational estimates of that inflow which are both consistent with previous results.

Joint Inter-Association Symposium

JP01a - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-2247

The dependence of extreme sea levels on the major modes of the climate system

P. Woodworth[1], M. Menendez[2], J. Hunter[3]
[1]National Oceanography Centre, Marine Physics, Liverpool, United Kingdom
[2]Universidad de Cantabria, Environmental Hydraulics Institute "IH Cantabria", Santander, Spain
[3]University of Tasmania,
Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Australia

It is well-known that the rates of change of mean sea level are far from being spatially uniform but vary depending on many regional factors. Amongst these factors are the major modes of the climate system that are usually represented as simple indices (SOI, IOD, NAO etc.) that are proxies for changes in large-scale meteorological and oceanographic forcings. Less well-known, but more relevant for coastal dwellers, is how changes in extreme sea levels also depend on these major modes. This presentation discusses an analysis of both tide gauge and satellite altimeter sea level data, and presents findings of mean and extreme sea level variability in relation to the major modes, pointing to differences between the mean and extreme levels. In addition, it considers how allowances for future sea level rise for adaptation (e.g. coastal defences) may have to be modified to take such dependencies into account.

Joint Inter-Association Symposium

JP01a - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-3216

A fresh look at sea levels and sea-level trends

M. Orlic[1], *Z. Pasaric*[1]
[1]*University of Zagreb- Faculty of Science, Department of Geophysics, Zagreb, Croatia*

When considering sea level, one usually starts with the comparison of past sea levels obtained by a method to the observed values and then proceeds by applying the method to determine future sea levels. The method utilized may be either process-based or semi-empirical. Here we use three variants of the semi-empirical method in the analysis and projection of not only sea levels but also sea-level trends. The variants differ in assuming that the response of sea level to temperature forcing is equilibrium, inertial or a combination of the two. All variants enable the temperatures, sea levels and/or sea-level trends to be successfully regressed, albeit with controlling parameters that differ among the cases. The related response times vary considerably, with a realistic value (ca. 50 years) obtained only if both the equilibrium and inertial dynamics are taken into account. Comparison of computed sea levels to those measured over the last century or so shows that the best agreement is provided by the purely inertial variant of the semi-empirical method. Comparison of computed sea-level trends to the corresponding values determined from available measurements points to the equilibrium-cum-inertial variant of the semi-empirical method as the most successful one. Sea levels projected by using the three variants are similar through the middle of the 21st century, but they radically diverge by the end of the 23rd century. Sea-level trends considerably differ throughout the projection interval. The present study reveals how careful one has to be while calibrating a method on the data having a specific spectral content and then using the method to prepare projections under the forcing having different spectral characteristics.

Joint Inter-Association Symposium

JP01a - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-5729

Measuring and quantifying geophysical causes of global sea-level rise

C.K. Shum[1], *C.Y. Kuo*[2], *J.Y. Guo*[1]
[1]*The Ohio State University,*
Division of Geodetic Science- School of Earth Sciences, Columbus, USA
[2]*National Cheng Kung University, Dept. of Geomatics, Taiwan,*
Taiwan Republic of China

Half of the world's population (3.2 billion) lives within 200 km of coastlines. The potential for accelerated sea-level rise under anthropogenic warming is a significant societal problem. Quantifying the geophysical sources of sea-level rise with the goal of improved projection at local scales remains a challenging problem. The causes of sea-level rise could be partially explained by a number of competing geophysical processes. They include ice-sheet/glacier ablations, steric sea-level, GIA uplift, geocenter motion, tectonics, sediment loading or anthropogenic causes, hydrologic imbalance, and human processes including water retention in reservoirs and aquifer extraction. The 2013 IPCC AR5 concluded that the observed and explained geophysical causes of sea-level rise, 1993–2010, is much closer towards closure. However, the discrepancy indicates that circa 1.3→37.5% of the observed sea-level rise remains unexplained. This relatively large discrepancy is primarily attributable to the wide range of estimates of respective contributions of ice-sheets (Greenland and Antarctic) and glaciers to sea-level rise. In addition, the solid Earth motions in coastal regions and sea-floor, with natural and anthropogenic origins, are not known at the required accuracy and spatial resolutions to address coastal vulnerabilities. Here we use radar altimetry, GRACE, tide gauges, and hydrographic data, reconstructed sea-level trend estimates, GPS, and InSAR for measuring and understanding coastal land subsidence processes, towards improved quantification of various contributors of global sea-level rise, narrowing of the sea-level budget, and improved projection of relative sea-level change at practical local spatial scales and to the end of the 21st century.

Joint Inter-Association Symposium

JP01b - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-0785

Analysis and forecasting of sea level anomalies in the Pacific Ocean derived from satellite altimetry

Y.C. Chen[1], *M. Imani*[1], *C.Y. Kuo*[1]
[1]*National Cheng Kung University, Department of Geomatics, Tainan, Taiwan Republic of China*

Sea level rise, one of the consequences of global warming, has a significant impact on economic and living environment, especially in low-lying coastal regions to damage human life and property. Therefore, monitoring and analyzing highly spatial and temporal sea level variations are critical for understanding ocean characteristics while accurate predicting sea level changes is important for coastal management as well. The purpose of this study is to develop and validate different approaches for analyzing and forecasting sea level anomalies derived from satellite altimetry that is used to provide unprecedented accuracy of highly spatial and temporal sea surface heights. First, Empirical Orthogonal Function (EOF), complex-EOF, and Trend EOF are used to decompose monthly gridded sea level anomalies data in order to reduce the complexity of altimetric data and extract significantly dominated signals in spatial and corresponding temporal domain. We focus on tropical Pacific Ocean and Taiwan surrounding oceans to detect meaningful physical ocean phenomena; for example, ENSO event, local trends and small-scale structures. Furthermore, Autoregressive Integrated Moving Average (ARIMA) model which is underlying linear process and Support Vector Regression (SVR) which considers nonlinear phenomenon are applied for forecasting of sea level derived from the previous decomposition process in the study oceans.

Joint Inter-Association Symposium

JP01b - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-0809

Regional sea-level variations in the western Pacific Ocean

W.H. Lan[1], *C.Y. Kuo*[1], *L.C. Lin*[2], *C.K. Shum*[3]
[1]*National Cheng Kung University, Department of Geomatics, Tainan, Taiwan Republic of China*
[2]*National Cheng Kung University, International Wave Dynamic Research Center, Tainan, Taiwan Republic of China*
[3]*the Ohio State University, School of Earth Sciences, Columbus, USA*

In recent years, sea-level rise resulting from global warming is one of important issues. The rates of sea-level rise in the western Pacific Ocean have significantly increased more than global averaged trend over the past 20 years. Since the short-term (< 20 years) data cannot avoid significant impacts of low-frequency signals, such as El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), on determination of sea-level trends, reducing low-frequency effects accurate on estimation of absolute sea-level variations in the western Pacific Ocean is extremely important. Tide gauges and satellite altimetry are traditionally the common instruments used to determine sea-level changes; however, the time spans of tide gauge records are not constant and the measurements of satellite altimetry only cover about 20 years. Therefore, in the study, low-frequency effects derived from the long-term tide gauge records by Hilbert-Huang Transformation (HHT) and wavelet are removed from altimetry to calculate absolute sea-level trend in the western Pacific Ocean. In addition, we also focus on understanding the contributions of sea-level rise in the western Pacific Ocean using the combination of satellite altimetry, Gravity Recovery and Climate Experiment (GRACE) and in-situ ocean temperature and salinity data.

Joint Inter-Association Symposium

JP01b - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-1257

Detecting trends in ocean bottom pressure using hydrographic moorings and altimetry.

J. Williams[1], *C.W. Hughes*[1], *M.E. Tamisiea*[1]
[1]*National Oceanography Centre, Sea Level, Liverpool, United Kingdom*

Ocean bottom pressure, measured at only a few locations, can theoretically be used to derive global mean mass changes in the ocean. In many places bottom pressure has much smaller variability that the corresponding sea-level signal, and so the time required to detect a trend of given magnitude is much shorter. However bottom pressure sensors suffer notoriously from non-linear drift. Therefore we investigate an alternative method to measure the small bottom pressure signal as the difference between the two large signals of steric pressure (from a hydrographic mooring) and sea-surface height (from altimetry). We test the method on data from the Rapid mooring array at 26N in the Atlantic, and determine how many years would be required to detect a trend in bottom pressure from this technique.

Joint Inter-Association Symposium

JP01b - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-2768

Uncertainties in sea level reconstructions due to GIA corrections

S. Jevrejeva[1], *J. Moore*[2], *A. Grinsted*[3], *A. Matthews*[4], *G. Spada*[5]
[1]*National Oceanography Centre, Liverpool, United Kingdom*
[2]*College of Global Change and Earth System Science- Beijing Normal University- Beijing- China,*
State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing, China Peoples Republic
[3]*Niels Bohr Institute- University of Copenhagen- Denmark,*
Centre for Ice and Climate, Copenhagen, Denmark
[4]*National Oceanography Centre, PSMSL, Liverpool, United Kingdom*
[5]*Università degli Studi "Carlo Bo"- I-61029 Urbino- Italy,*
Dipartimento di Scienze di Base e Fondamenti, Urbino, Italy

We use 1277 tide gauge records since 1807 to compose a global sea level reconstruction and analyse the evolution of sea level trend and acceleration. There is a good agreement between the rate of sea level rise (3.2 mm/yr) calculated from satellite altimetry and the rate of 3.1 mm/yr from tide gauge based reconstruction for the overlapping time period (1993-2009). The new reconstruction suggests a linear trend of 1.9 mm/yr during the 20th century, with only 1.5 mm/yr since 1960. Regional linear trends for 14 ocean basins since 1960 show the fastest sea level rise for the Arctic (3.8 mm/yr), Antarctica (3.5 mm/yr) and North West Pacific region (3.3 mm/yr). Choice of GIA correction is critical in the trends for the local and regional sea level, introducing up to 6 mm/yr uncertainties for individual tide gauge records, up to 2 mm/yr for regional curves and up to 0.8 mm/yr in global sea level reconstruction.

Joint Inter-Association Symposium

JP01b - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-4487

A near-uniform fluctuation dominating sea level and ocean bottom pressure variations across the Arctic Ocean and the Nordic Seas

I. Fukumori[1], *O. Wang*[1], *W. Llovel*[1], *I. Fenty*[1], *G. Forget*[2]
[1]*California Institute of Technology, Jet Propulsion Laboratory, Pasadena, USA*
[2]*Massachusetts Institute of Technology,*
Earth- Atmospheric and Planetary Sciences, Cambridge, USA

Across the Arctic Ocean and the Nordic Seas, a basin-wide mode of sea level and ocean bottom pressure fluctuation is identified using satellite and in situ observations in conjunction with a global ocean circulation model and its adjoint. The region is central to studies of sea level change because it is where the ocean interacts with the cryosphere including Greenland's ice sheet. The basin-wide variation extends across the interconnected deep ocean basins of these Arctic seas with near-uniform amplitude and phase. The fluctuation is depth-independent and dominates the region's large-scale variability from sub-monthly to interannual timescales. The fluctuation results from bifurcating coastally trapped waves generated by winds along the continental slopes of the Arctic region and its neighboring seas, including the North Atlantic Ocean. The winds drive Ekman transport between the shallow coastal area and the deep ocean basins, creating sea level anomalies of opposite signs in the two regions. The anomalies rapidly propagate away as barotropic coastally trapped waves that subsequently bifurcate at the shallow straits connecting the Arctic region with the rest of the globe. Anomalies that enter the deep Arctic basins equilibrate uniformly across the domain, isolated from neighboring shallow variations, due to the basins' homogeneous depth-integrated planetary potential vorticity distribution. The study, from a technical perspective, illustrates how a thoughtful application of the adjoint technique provides an explanation of physics that statistical analysis of model results and/or observations cannot. Whereas correlation does not imply causation, adjoints do.

Joint Inter-Association Symposium

JP01b - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

IUGG-5060

Rigorous statistical testing of model fits to global mean sea level time series

G.T. Mitchum[1], *Y. Zhu*[1], *K. Doran*[2]
[1]*University of South Florida, College of Marine Science, Saint Petersburg, USA*
[2]*USGS, Coastal Sciences Center, Saint Petersburg, USA*

Understanding climate requires us to make distinctions between different model fits to climate time series that are often not ideal for our purposes. In the case of sea level change, for example, we need to decide if the change is linear, or whether there is statistically unassailable evidence of acceleration, and we also need to eliminate the possibility that long period variability is not being misinterpreted as acceleration. And we need to do this with global mean time series that are global but short (altimetry-based), or long but spatially under-sampled (tide gauge-based). We will describe the development of a robust statistical model for the noise in both the altimetry-based and the tide gauge-based global mean sea level time series. These models account for over-fitting errors that substantially reduce the variance of the residual time series used to derive error models, and also implement a novel non-parametric fit to an adjusted periodogram of the residual time series. Results will be shown for selected model fits to both the altimetry-based and tide gauge-based global mean time series.

Joint Inter-Association Symposium

JP01p - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

JP01p-091

Celebrating 30 years of the South Atlantic Tide Gauge Network

P. Woodworth[1]*, A. Hibbert*[1]*, P. Foden*[1]*, J. Pugh*[1]*, G. Hargreaves*[1]*, S. Mack*[1]
[1]*National Oceanography Centre, Marine Physics, Liverpool, United Kingdom*

It is now thirty years since the South Atlantic Tide Gauge Network of the National Oceanography Centre (Liverpool) was set up, at what was then called the Institute of Oceanographic Sciences, Bidston. In this poster, we present some of the scientific and technological advances that have originated from the Network. These include improved understanding of Antarctic Circumpolar Current (ACC) variability and the development of tide gauge instrumentation to facilitate accurate datum control. We describe the scientific products currently afforded by the South Atlantic Network and how they form an important part of the UK contribution to the Intergovernmental Oceanographic Commission's (IOC) Global Sea Level Observing System (GLOSS). Finally, we outline proposals for further technological and scientific development of the Network, including plans to improve the resilience of tide gauge technology operating in hostile and/or remote locations.

Joint Inter-Association Symposium

JP01p - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

JP01p-092

New and improved data products from the Permanent Service for Mean Sea Level

A. Matthews[1], E. Bradshaw[2], K. Gordon[1], A. Hibbert[3], S. Jevrejeva[1], L. Rickards[1,2], M. Tamisiea[1], S. Williams[1], P. Woodworth[1]
[1]National Oceanography Centre, Permanent Service for Mean Sea Level, Liverpool, United Kingdom
[2]British Oceanographic Data Centre, British Oceanographic Data Centre, Liverpool, United Kingdom
[3]National Oceanography Centre, National Oceanography Centre, Liverpool, United Kingdom

The Permanent Service for Mean Sea Level (PSMSL) is the internationally recognised data bank for long term sea level change information from tide gauges. Established in 1933, the PSMSL continues to be responsible for the collection, publication, analysis and interpretation of sea level data. The PSMSL operates under the auspices of the International Council for Science (ICSU) and is one of the main data centres for both IAPSO and IAG. The PSMSL continues to work closely with other members of the sea level community through the Intergovernmental Oceanographic Commission's Global Sea Level Observing System (GLOSS).

Currently, the PSMSL data bank for monthly and annual sea level data holds over 65,000 station-years of data from over 2200 stations. Data from each site are carefully quality controlled and, wherever possible, reduced to a common datum, whose stability is monitored through a network of geodetic benchmarks. Last year, the PSMSL also made available a data bank of measurements taken from in-situ ocean bottom pressure recorders from over 60 locations across the globe.

Here, we present an overview of the data available at the PSMSL, and describe some of the ongoing work that aims to provide more information to users of our data. In particular, we describe the ongoing work with the Système d'Observation du Niveau des Eaux Littorales (SONEL) to use measurements from continuous GNSS records located near tide gauges to provide PSMSL data within a geocentric reference frame. We also highlight changes to the method used to present estimated sea level trends to account for seasonal cycles and autocorrelation in the data, and provide an estimate of the error of the trend.

Joint Inter-Association Symposium

JP01p - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

JP01p-093

Altimetry based global estimates of propagating wave characteristics compared to predictions by linear theory based on climatological hydrographic data

B. Vogel[1]*, R.J. Greatbatch*[1]
[1]*GEOMAR Helmholtz Centre for Ocean Research,*
RD1: Ocean Circulation and Climate Dynamics, Kiel, Germany

Absolute dynamic topography anomalies (ADTA) from 21 years of satellite altimetry are used to estimate representative zonal and meridional propagation speeds of the dominant signals in detrended sea level variability by finding the lag at which two ADTA time series with a certain zonal or, respectively, meridional distance exhibit the highest correlation. Throughout large parts of the open ocean the dominant moving features propagate westward, suggestive of long baroclinic Rossby waves. However, on the equator eastward propagating equatorial Kelvin waves seem to dominate over equatorial Rossby waves and in mid and higher latitudes it is difficult to distinguish Rossby waves from mesoscale eddies. In the Antarctic Circumpolar Current (ACC), most sea level signals propagate eastward due to the Doppler shift by the strong flow of the ACC. The estimated phase speeds and wave lengths are compared to the Rossby wave characteristics that are predicted by standard linear theory using climatological hydrographic data. Consistently with previous studies, it is found that westward propagation tends to be faster than implied by linearisation about a state of rest.

Joint Inter-Association Symposium

JP01p - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

JP01p-094

Contribution of inter-annual wind stress variability to recent global and basin-averaged steric sea level changes

T. Suzuki[1]
[1]*JAMSTEC, Yokohama, Japan*

Using the Ocean General Circulation Model COCO, we investigated the physical nature of recent global and basin-averaged steric sea level changes. We spun the model up for 200 yeas under cyclic atmospheric condition from 1980 to 1989 based on ERA-Interim. For the hindcast simulation, we continue the integration from 1980 to 2012. The model reproduced the dominant features of observed steric sea level changes. To investigate contributions of the inter-annual wind stress forcing, we conducted the hindcast simulation replacing the inter-annual wind stress forcing with the climatological forcing. The results show that the thermo-steric sea level rise for the last 10years in the Pacific and the Indian Ocean is strongly influenced by the wind stress changes.

Joint Inter-Association Symposium

JP01p - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

JP01p-095

Sources of Spread in Multi-model Projections of the Greenland Ice-Sheet

F. SAITO[1], A. Abe-Ouchi[2], K. Takahashi[1]
[1]Japan Agency for Marine-Earth Science and Technology,
Department of Integrated Climate Change Projection Research, Yokohama, Japan
[2]Univ. of Tokyo, Atmosphere and Ocean Research Institute-, Chiba, Japan

The study revisits the future surface-climate experiments of the Greenland ice-sheet proposed by the Sea-level Response to Ice Sheet Evolution (SeaRISE, Bindschadler et al. 2013) study. The projections of the different SeaRISE participants show diversion, which has not been examined in detail to date. A series of sensitivity experiments are conducted and analyzed using the Ice-sheet model for Integrated Earth-system Studies (IcIES) by replacing one or more formulations of the model parameters with those adopted in other model(s). The results show that the main sources of the diversion between the projections of the different SeaRISE participants are differences in the initialization methods and in the surface mass balance methods, and both aspects have almost equal impact on the results. Treatment of ice-sheet margins in the simulation has a secondary impact on the diversion. We conclude that spinning-up the model using fixed topography through the spin-up period while the temperature is allowed to evolve according to the surface temperature history is the preferred representation at least for the experiment configuration examined in the present paper. A benchmark model experiment set-up that most of the numerical model can perform is proposed for future intercomparison projects, in order to evaluate the uncertainties relating to pure ice-sheet model flow characteristics.

Joint Inter-Association Symposium

JP01p - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

JP01p-096

Predictability of regional sea level on seasonal-to-decadal time scales in a global climate model

C. Roberts[1]*, N. Dunstone*[1]*, L. Hermanson*[1]*, M. Palmer*[1]*, D. Smith*[1]
[1]*Met Office, Hadley Centre, Exeter, United Kingdom*

On seasonal time scales, regional sea level variability is dominated by changes to the barotropic and baroclinic ocean circulation associated with modes of internal climate variability. Previous studies have demonstrated that some aspects of ocean variability (including large scale temperature and circulation changes) are predictable on seasonal time scales using global climate models that have been initialized with an appropriate ocean state. However, the predictability of regional sea level on multi-annual time-scales has yet to be evaluated. Here, we present an initial evaluation of predictability in time-mean dynamic sea level using five-year hindcasts from the latest configuration of the UK Met Office Decadal Prediction System (DePreSys3), a coupled ocean-atmosphere-sea ice model with an eddy-permitting ocean resolution. Hindcasts are initialized from a model assimilation of a full-depth ocean analysis and skill is evaluated against satellite altimetry and tide-gauge reconstructions of sea surface height.

Joint Inter-Association Symposium

JP01p - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

JP01p-097

Sensitivity of sea-level rise reconstruction from 1900 to present

B. LEGRESY[1], *J. CHURCH*[1], *N. WHITE*[1], *D. MONSELESAN*[1], *A. SLANGEN*[1]
[1]*CSIRO, Oceans and Atmosphere Flagship, Hobart, Australia*

We reconstruct the sea level rise from 1900 to present, revisiting the reconstruction from Church and White (2011). We update this reconstruction, which is based on satellite altimetry learning and projects tide gauges records on the derived modes of variability. We performed or repeated a number of sensitivity tests on the learning period, number of modes, and inversion parameters. We also tested the sensitivity to variations in the mathematical method, in the learning process as well as the number of tide gauges, vertical crustal movement and contemporary mass load redistribution at the surface of the Earth. For global mean sea level, the length of the learning period seems to be of little importance beyond one decade. The same applies, for example, to the number of modes, it does not improve the solution to use more than 4 modes for the longer records of global mean sea level. We show sensitivity results for the long term global mean sea level and for regional mean sea level over the 1950-2015 period. We revisit the error budget. Finally, we compare to other reconstructions in view of this sensitivity analysis.

Joint Inter-Association Symposium

JP01p - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

JP01p-098

The regional sea surface height response to volcanic eruptions in CMIP5 models

K. Richter[1], *B. Marzeion*[1]
[1]*University of Innsbruck, Institute for Meteorology and Geophysics, Innsbruck, Austria*

We investigate the impact of volcanic eruptions on simulated regional dynamic sea surface height in an ensemble of CMIP5 (Coupled Model Intercomparison Project Phase 5) models as well as on the contribution of the worlds glaciers to sea level using a glacier model forced with output from the same models. Volcanic eruptions emit SO2 into the stratosphere eventually causing a temporal negative radiative forcing. It has been shown that this results in an abrupt drop in global ocean heat content and consequently in thermosteric sea surface height, followed by a subsequent warming recovery that potentially lasts for decades.
However, the spatial pattern of the response is unclear. To identify whether different regions are affected differently by volcanic eruptions, we investigate the regional sea surface height change up to several decades after a volcanic eruption. To do so, we analyse historical simulations (1850-2006) with natural forcing only, with volcanic forcing only and simulations of the past millennium. As regional observations of ocean temperature and salinity observations are sparse for the past century, the results are compared to output from the Simple Ocean Data Assimilation (SODA) model which assimilates the available observations.
Regional detection is complicated by the enhanced magnitude of internal variability on local scales. However, the magnitude of trends related to internal variability can be identified using control simulations with constant forcing only and it can be assessed whether, on local scales, volcanic eruptions induce trends that are larger than those that can be expected from internal variability only. This is of particular importance when attempting to attribute observed sea level rise to anthropogenic forcing.

Joint Inter-Association Symposium

JP01p - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

JP01p-099

Recent and future sea level changes in the Eastern Pacific and US West-Coast: new insights from observations and CMIP5 models

F. Landerer[1], *P. Thompson*[2]
[1]*Jet Propoulsion Laboratory / Caltech, Pasadena, USA*
[2]*University of Hawaii, Sea Level Center, Honolulu, USA*

A prominent sea level rise pattern in the Pacific Ocean – large increases of 12 mm/yr in the West and near-stagnant levels in the East – has been observed in the satellite altimeter record since the mid 1990ies. A significant fraction of this dipole trend pattern has been attributed to the Pacific Decadal Oscillation (PDO), a large-scale mode of internal interannual to decadal climate variability with potentially some degree of predictability. However, while the PDO can explain part of the Eastern Pacific sea level changes and thus US West Coast sea level trends, recent work has highlighted the dominant contribution of Pacific equatorial zonal wind stress forcing to the sea level trends since about 1990.

Here, we use a large ensemble of CMIP5 coupled climate model simulations (more than 150 runs from ~30 different model setups) in combination with long tide gauge records to further investigate the roles and contributions of the PDO and other atmospheric modes of equatorial variability to decadal Eastern Pacific sea level rates. We find that the models tend to reproduce the observed distribution of equatorial wind variability better than the observed distribution of sea level, where differences are noticeable in particular in the tails of the distribution. Additionally, it appears that the correlation between equatorial wind stress and Eastern Pacific sea level variability is lower in the models than observed, which may in part arise from the relatively coarse resolution of CMIP5 ocean models. We investigate this relationship for annual to decadal time scales, and assess the potential for near-term decadal predictions of regional sea level rates in the Eastern Pacific based on the behavior of relevant atmospheric modes in the an ensemble of CMIP5 simulations.

Joint Inter-Association Symposium

JP01p - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

JP01p-100

The praia grande sea level limits

A.R. Mesquita[1], *J.L.A. Trabanco*[2], *M.Q. Monteiro*[1], *R.A. de Carvalho*[1], *M.B. Galzarano*[2]
[1]*Universidad de Sao Paulo, Instituto Oceanografico, Sao Paulo, Brazil*
[2]*University of Campinas, FEC Unicamp, Sao Paulo, Brazil*
The 1831 sea level of "Praia Grande" (PG), (Lat 24º 00' S; Long 46º 24' W), in the shores of the State of São Paulo, as established by the Brazilian Law Number 9760 of 1946, has been estimated and materialized. The 5 days sea level data at PG was obtained by continuous, day and night pressure measurements, recorded with a data logger and also by discrete visual readings against a tide staff fixed on a pier, during the day. The motivation, the leveling and methods utilized are described, with a short history of the Brazilian "Terrenos de Marinha". The estimates followed plausible hypotheses, on the global relative sea level variation, since 1831 until the present, on the rate of sea level changes as measured at: a)-the port of Brest, France, b)- the port of Cananeia, Brazil, and c)-from the global estimates of Intergovernmental Panel for Climate Change (IPCC) of the United Nations Organization (UNO). The retro-prediction for 1831, allowed the demarcation of the "Terrenos de Marinha" (Union Sea Land Limits) of PG, along the terms of the Law. The procedures, based on the assumption of the same sea level of the geoid, for transferring the long term sea level trend of Cananeia to PG, was accepted. Geometrical leveling was used to refer the PG levels to the national geodetic network levels for the Brazilian Institute of Geography and Statistic (IBGE). Results indicate that the limits at Praia Grande, are within the beach, and are according to the terms of the 1946 Law.

Joint Inter-Association Symposium

JP01p - JP1 Sea Level Change and Variability: Past, Present and Future (IAPSO, IAG, IACS)

JP01p-611

Extreme sea levels along the coast of the Baltic Sea

E. Kulikov[1], *I. Medvedev*[1]
[1]*P.P.Shirshov Institute of Oceanology- Russian Academy of Sciences, Tsunami Lab, Moscow, Russia*

Statistical analysis of extreme events in the Baltic Sea was done to examine the probability of floods and ebbs in various parts of the sea. Based on long period sea level observations along the coast, we estimated return periods of extreme sea level changes. A specific peculiarity of the Baltic Sea is the significant intensification of surges in the heads of the Gulf of Finland, Gulf of Bothnia and Riga Bay. A particular feature of extreme sea level changes in the sea is the significant asymmetry in the return period distributions for positive and negative sea level deviations. In particular, it was found that floods in the Gulf of Finland and along the east coast of the sea, in general, are much more pronounced than the sea level receding. We discuss the reasons of such asymmetry and its relation to the wind rose over the Baltic Sea. One of the findings of our study is a noticeable correlation between the temporal changes in flood intensity and the NAO climate index.

Joint Inter-Association Symposium

JP04a - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

IUGG-0711

Variability of wind stress curl and its relationship with sea level in the Japan Sea

O. Trusenkova[1]
[1]*V.I. Il'ichev Pacific Oceanological Institute- Far-Eastern Branch- Russian Acade, Laboratory of Physical Oceanography, Vladivostok, Russia*

Wind stress curl is the fundamental factor affecting ocean circulation. As for the Japan Sea, it is believed that the hydrographic conditions are mostly conditioned by the warm water inflow in the Korea Strait. It is also recognized that the strong winds of the winter monsoon force the cyclonic gyres in the northern Japan Sea. However, no attention was paid to wind stress curl variability beyond the winter monsoon period, neither to its possible impact on circulation in the Japan Sea. The purpose of this study is to estimate curl variability throughout a year and reveal its relationship with circulation patterns in the Sea. To this end, the 6-hour, 0.5 degree QSCAT/NCEP Blended Ocean Winds dataset lasting from July 1999 through July 2009 is employed. Semiannual variability of wind stress curl is revealed over the central Japan Sea, the curl being cyclonic in mid winter and late summer and anticyclonic in late winter – spring and fall. AVISO 1/4°-gridded daily sea level anomalies for 1993-2013 are used for representing the east – west seesaw pattern between the pathways of the northward warm water transport along the Honshu coast and in the western Sea, respectively. Statistical linkages of wind stress curl with the sea level index of the east – west pattern are revealed. The joint wind stress curl and sea level variability evolves on the semiannual, annual, and quasibiennial time scales, with sea level lagging curl by one month on the semiannual time scale.

Joint Inter-Association Symposium

JP04a - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

IUGG-2036

A review of satellite missions and applications to oceanography and climatology

J.L. Fellous[1]
[1]*COSPAR, Secretariat, Paris, France*

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 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 holds the promise of many new discoveries and more generally, a better in-depth understanding of the role of the ocean in climate and the Earth system.

Joint Inter-Association Symposium

JP04a - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

IUGG-2120

Improving the ocean's mean dynamic topography: Complementary information from altimetry, gravity, sea surface temperature and ocean models.

C. Hughes[1], *C. Wilson*[2], *J. Williams*[2], *T. Gruber*[3]
[1]*University of Liverpool, School of Environmental Sciences, Liverpool, United Kingdom*
[2]*National Oceanography Centre- Liverpool, Joseph Proudman Building, Liverpool, United Kingdom*
[3]*Technical University Munich, Institute for Astronomical and Physical Geodesy, Munich, Germany*

Starting with a mean sea surface height and new gravity field based on a combination of GOCE and GRACE satellite data with in situ measurements, we use either an ocean model, or microwave temperature data to develop adaptive filters which lead to two estimates of the 5-year mean dynamic topography. We show that these dynamic topographies are consistent, and that they improve on pre-GOCE solutions. In the Southern Ocean in particular, the filter based on model data produces a field in which mean mesoscale currents are better aligned with mean temperature contours.

Joint Inter-Association Symposium

JP04a - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

IUGG-4077

A collocation approach for the estimation of a GOCE-based Mediterranean Sea geostrophic circulation

M. Gilardoni[1]*, M. Reguzzoni*[1]*, A. Borghi*[2]*, A. Albertella*[1]
[1]*Politecnico di Milano, Department of Civil and Environmental Engineering, Milano, Italy*
[2]*Università degli Studi e-campus, Faculty of Civil and Environmental Engineering, Novedrate CO, Italy*

A mean dynamic topography (MDT) of the Mediterranean Sea has been directly computed by subtracting a gravimetric geoid from an altimetry-based mean sea surface (MSS). As for the geoid, one the latest releases of the GOCE global gravity models with its prevailingly block-diagonal error covariance matrix has been used in combination with local geoids based on ground data, at least for some parts of the Mediterranean Sea, like the Tyrrhenian Sea. As for the MSS, the global CNES-CLS2011 model has been used with its error variance description.
The obtained MDT has been filtered by taking into account the maximum degree of the GOCE global gravity model and the error information of the corresponding geoid (in case combined with local data) and of the altimetry-based MSS. This filtering has been done by a collocation approach, adapting the global MDT signal covariance function to the local characteristics of this semi-enclosed basin. In order to obtain a numerically stable MDT solution by collocation, a Monte Carlo approach has been studied and implemented to fill continental areas, like the Italian mainland, with fictitious data. From the filtered MDT the corresponding geostrophic currents have been computed and their accuracy has been derived by covariance propagation of the original data errors.
In order to validate the obtained results, the GOCE-based MDT and geostrophic currents have been compared with other available MDT models for the Mediterranean Sea and with drifter data, respectively.

Joint Inter-Association Symposium

JP04a - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

IUGG-5249

Overview of Japan's GNSS-R research program for ocean observations

K. Ichikawa[1], T. Ebinuma[2], H. Akiyama[3], Y. Kitazawa[4], . JAPAN's GNSS-R Research Team[5]
[1]Kyushu University, Research Institute for Applied Mechanics, Kasuga, Japan
[2]Tokyo University of Marine Science and Technology,
The graduate school of Marine Science and Technology, Tokyo, Japan
[3]Wakayama University, Institute for Education on Space, Wakayama, Japan
[4]IHI Corporation, Space Development Department, Tokyo, Japan
[5]University of Tokyo- Kobe University- JAMSTEC- Nagoya University- RESTEC-Kyoto University- IHI Corporation- Meisei Electoric Co.,
Oceanography and Space Engineering, Tokyo- Yokohama- Nagoya- Kyoto- Kobe, Japan

With respect to conventional hydrographic observations, satellite oceanography has advanced the coverage and repeatability of ocean surface observations. However, rapidly moving and/or growing phenomena such as tsunamis and typhoons are still not well monitored. Moreover, sparse sampling may record aliased results of short-term variations such as the diurnal modulations of the air-sea interactions. To solve those problems, more satellites are necessary, but which would be unrealistically expensive.
The GNSS-R that uses reflected signals of the well-established GNSS system is a promissing technique for a such continuous monitoring.
We have started a 3-year research program for GNSS-R applications on oceanographic observations under a contract with MEXT (Ministry of Education Culture, Sports, Science and Technology, JAPAN).
Actual GNSS-R data obtained by multi-copters, ships and towers are compared with in-situ observations of the wave spectrum, the sea surface height (SSH) and the wind speed profile. The sensitivity of the GNSS-R to the wind speed, or variations of the mean squared sea slope, is to be discussed using observations in both open oceans and swell-free lakes. Moreover, the accuracy of the SSH observations, dependency on the footprint size and the incident angle of the GNSS-R receivers, and the detection of sea ices with estimates of its height will be discussed.

Joint Inter-Association Symposium

JP04b - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

IUGG-0366

Hydrophysical processes revealed in the SAR/ASAR imagery of the Southeastern Baltic Sea

A. Kostianoy[1], *E. Bulycheva*[2]
[1]*P.P.Shirshov Institute of Oceanology, Moscow, Russia*
[2]*Atlantic Branch of P.P. Shirshov Institute of Oceanology, Laboratory of Geoecology, Kaliningrad, Russia*

From 2004 to present, satellite monitoring of oil pollution of the sea surface of the Southeastern Baltic is carried out in the framework of the industrial environmental monitoring of the oil field 'Kravtsovskoe', where an offshore ice-resistant fixed oil platform D-6 is operated by the 'LUKOIL-Kaliningradmorneft' Ltd., and in a number of Russian national and international research projects. The monitoring is based on the analysis of satellite SAR/ASAR imagery acquired by Envisat, Radarsat-1, Radarsat-2, and Cosmo-SkyMed satellites. Besides the oil slicks at the sea surface, SAR/ASAR imagery allows to observe and identify a set of hydrophysical and meteorological processes displayed at the sea surface by changes in the sea surface roughness. In 2004-2014 more than 1800 satellite radar images were received and analyzed where hydrophysical processes specific for the Southeastern Baltic Sea were observed, including calm water, wind shadow, algal bloom, sea ice, coastal upwelling vortex structures in the sea (eddies, dipoles, filaments), atmospheric (weather) fronts and intensive vortices, internal waves in the sea and atmosphere, etc. Some of these structures look like oil slicks at the sea surface and represent a problem to identification of oil spills at SAR/ASAR imagery. Investigation of hydrophysical processes using satellite radar imagery is obligatory taking into account that the Baltic Sea is very often covered by clouds which impede investigation of these processes and structures by infra-red and optical imagery. The research was supported by the Russian Science Foundation under the Project N 14-17-00555.

Joint Inter-Association Symposium

JP04b - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

IUGG-0367

Satellite monitoring of sea ice in the Southeastern Baltic Sea, Vistula and Curonian Lagoons in 2004-2014

E. Bulycheva[1], *A. Kostianoy*[2], *Z. Stont*[1]
[1]*ABIO RAS, Geoecology department, Kaliningrad, Russia*
[2]*P.P.Shirshov Institute of oceanology of RAS,*
Ocean Experimental Physics Laboratory, Moscow, Russia

Satellite radar imagery is a very useful tool for identification of ice cover in the sea. In the framework of the industrial environmental monitoring of the oil field 'Kravtsovskoe' (D-6) (operated by the 'LUKOIL-Kaliningradmorneft' Ltd.), located in the Southeastern Baltic Sea, we collected more than 1,800 SAR/ASAR images from Envisat, Radarsat-1, Radarsat-2, and Cosmo-SkyMed satellites in 2004-2014. This set of radar imagery was used to identify and calculate the area of ice cover in the study area of the Southeastern Baltic Sea. The analysis of interannual variability of ice cover was done in combination with an analysis of average daily air temperature and wind speed. As a result we discriminated three winter's types observed during the last decade: mild winters (2004/2005, 2006/2007, 2007/2008, 2008/2009, 2012/2013, and 2013/2014), normal winters (2005/2006, 2009/2010, 2011/2012), and severe winter (2010/2011). We also investigated the dates and places of appearance of the first ice and disappearance of ice, as well as the period of ice cover in the Vistula and Curonian Lagoons. This is very important for navigation and fishery in coastal waters of the Southeastern Baltic Sea, and in the Vistula and Curonian Lagoons. In winter time sea ice could be a reason for false alarm when identifying oil spills on satellite radar images. From the other hand ice cover area, total time of the sea ice observation and frequency of its appearance from year to year are the key climatic parameters which allow to investigate regional climate change. The research was supported by the Russian Science Foundation under the Project N 14-50-00095.

Joint Inter-Association Symposium

JP04b - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

IUGG-0433

Evidence of the Chandler wobble in the El Nino dynamics

D. Sonechkin[1], *I. Serykh*[1]
[1]*P.P.Shirshov Institute of Oceanology- Russian Academy of Sciences, Physics of ocean, Moscow, Russia*

Based on a study of the monthly satellite altimetry data covering the entire ocean surface of the Earth for the period 1993-2012 (provided by the project AVISO) it is found that on time period of Chandler wobble in the Earth's pole motion (~14-month) anomalies of sea level are very similar to anomalies during the El Niño - Southern Oscillation (ENSO). We suppose that ENSO is driven not only by the annual Sun-induced periodic heating, but also by two more external periodicities (incommensurate to the annual period) associated with the ~18.6-year lunar-solar nutation of the Earth rotation axis and the pole tides, that excite specific motions in extratropics of all oceans. Because of the incommensurability of their periods all three forces affect the system in inappropriate time moments. As a result, the shape of the ENSO power spectrum looks to be very complex (strange in mathematical terms). It reveals numerous peaks located at the periods that are multiples of the above periodicities as well as at their sub- and super-harmonic. In spite of this strangeness, a mutual order seems to be inherent to this spectrum. This order reveals itself in the existence of a scaling of the power spectrum peaks and respective rhythms in the ENSO dynamics that look like the power spectrum and dynamics of the so-called strange nonchaotic attractor well-known in the quasi-periodically forced nonlinear dynamical systems. It means there is no limits to forecast ENSO, in principle. In practice, it opens a possibility to forecast ENSO for several years ahead.

Joint Inter-Association Symposium

JP04b - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

IUGG-0781

Influence of dynamic processes on the propagation of the anthropogenic and biogenic pollution based on the combined satellite information

O. Lavrova[1], *M. Mityagina*[1], *T. Bocharova*[1], *A. Strochkov*[1]
[1]*Space Research Institute of RAS, Remote Sensing of the Earth, Moscow, Russia*

Methods to retrieve parameters of sea surface pollution, investigate the effect of dynamic and circulation processes on the spread of pollutants based on comprehensive analysis of satellite data are developed. The solving of the tasks implied complex use of data different in physical nature (active and passive microwave sensing, optical data of multi- and hyperspectral sensors) and spatial resolution.

The variety of data accumulated by Space Research Institute of RAS (IKI RAS) on satellite remote sensing of the Black and Caspian Seas for 2004-2014 were systematized, analyzed and integrated into a geoportal “See The Sea” developed by IKI RAS.

Thematic processing of the selected satellite data was performed along with phenomenological identification of various types of anthropogenic and biogenic pollution. Four main types of sea surface film pollution were discriminated: ship spills of liquids containing oil; outflow of sewage and river waters; underwater mud volcanoes and natural seeps of hydrocarbons; increased bioproductivity, related to life cycles of chlorophyll-a and intense algae bloom.

Areas of intense algae bloom and biogenic films were identified and mapped based on satellite SAR and optical data. The main task – discrimination between different kinds of seaweed based on the analysis of satellite data and subsatellite measurement data.

Based on satellite data, an investigation was undertaken to highlight the spatial and temporal structure and dynamics of meso- and submesoscale processes influencing the transport and distribution of pollutants in various regions of the Black and Caspian Seas.

The study was completed with financial support from the Russian Scientific Foundation grant #14-17-00555 and the RFBR grant 13-07-12017.

Joint Inter-Association Symposium

JP04b - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

IUGG-1625

Exciting oceanography around the southern tip of Africa using satellites and models

F. Shillington[1]
[1]*University of Cape Town, Oceanography/Nansen-Tutu Centre, Rondebosch, South Africa- Republic of*

The southern tip of Africa is an important junction for currents from the three adjacent oceans: the Indian Ocean to the east, the Atlantic Ocean to the west, and the Southern Ocean to the south. It is the only place in the World Oceans where a warm, fast flowing, poleward, Western Boundary Current (the Agulhas Current) meets a cool, slow moving, equatorward flowing Eastern Boundary Current (the Benguela Current). South of the Subtropical Front, the flow is easterly in the Antarctic Circumpolar Current, with the largest volume transport on the planet. With the recent advent of satellite remote sensing of sea surface temperature, sea surface heigh from altimetry, synthetic aperture radar, wind, and ocean colour radiometry, and the concomitant use of suitable scale numerical ocean models, there have been many exciting advances in the observation and understanding of this complex ocean circulation at and near the tip of Africa. The area is also of global importance to climate in terms of providing salt, heat and water to the north Atlantic through the southern link of the Meridional Overturning Circulation. The nature of the oceanography plays an important part in the understanding of the biological interactions and fisheries of the region. There are however, many new challenges at a range of mesoscale and sub-mesoscale space and various shorter time scales that still lie ahead. These aspects will be addressed in this talk.

Joint Inter-Association Symposium

JP04p - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

JP04p-159

Satellite and terrestrial data analysis of the Caspian Sea Level changes in relation to Cosmo-Geophysical Processes

V. Kaftan[1]*, B. Komitov*[2]*, S. Lebedev*[3]
[1]*Geophysical Center of the Russian Academy of Sciences,*
Laboratory of Geodynamics, Moscow, Russia
[2]*Institute of Astronomy and NAO "Rozhen" of Bulgarian Academy of Science,*
Department "Sun and Solar System", Sofia, Bulgaria
[3]*Geophysical Center of the Russian Academy of Sciences,*
Laboratory of Geoinformatics and Geomagnetic Studies, Moscow, Russia

The Caspian Sea basin appears to be a giant water collection of the largest European rivers and underground stream flows. Sea level changes of the last century were going on unpredictable from the fast shallowing (- 5 cm/yr) to the catastrophic rise (12 cm/yr). The end of the last century was finished by the unexpected sharp change of the fast rise to the equally fast lowering with the velocity of 1.5 cm/yr. The last decades are characterized by the intensive development of satellite and space observation techniques. Now the more informative means of the Caspian Sea level study are satellite altimetry of TOPEX/Poseidon, Jason-1 and Jason-2 missions. At the last decades the Earth's rotation parameters are determining permanently using such recent measurement techniques as GNSS and VLBI. The results of the resent precise observation data analysis with high resolution as well as the long Caspian Sea level time-series combining terrestrial and space observation are proposed to the research community. Spectral characteristics of the Caspian Sea level changes, Earth's rotation parameters (Length of Day), solar activity, geomagnetic activity and other processes are studying. High amplitude and low frequency oscillation components having close periods are revealed in the spectra of all analysed processes. Caspian Sea level oscillations are following in an antiphase to the solar activity changes. Approximation models of low frequency behaviour of the Caspian Sea level and associated cosmo-geophysical processes allow predicting future tendencies. There is a probability of the new Caspian level rise in the nearest years.

Joint Inter-Association Symposium

JP04p - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

JP04p-160

Time-space variability of petroleum hydrocarbon background concentrations in the Baltic Sea based on remote sensing data and simulation

S.A. Lebedev[1]
[1]*Geophysical Center of the Russian Academy of Science- bSpace Research Institute of Russian Academy of Siencies, Moscow, Russia*

Ecological monitoring of a marine environment of last years has shown, that alongside with destruction and precipitating processes of petroleum hydrocarbon not last role is played by dynamics of a marine surface, as the basic and pollutant transfer. The models, existing on the present time, of calculation of currents usually use the in-situ oceanographic and meteorological data. The successes in development of ocean remote sensing methods (satellite radiometry and altimetry) open a path to investigation of space-time variability of petroleum hydrocarbon background concentrations. The sea surface or dynamic topography calculated by satellite altimetry data, allows to analyze dynamics of the surface currents, which are not having brightly expressed thermal nature, as for instance, strong jet streams. In turn sea surface temperature, obtained by the satellite radiometry data, was used for more precise count of destruction processes of petroleum hydrocarbon. Time-space scale of the satellite data from a ocean surface allow actively to use them in different models, that enables with a split-hair accuracy to make the physically reasonable forecast.

Joint Inter-Association Symposium

JP04p - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

JP04p-161

Climatic change of the Baltic Sea level and sea surface temperature based on remote sensing data

S.A. Lebedev[1]
[1]*Geophysical Center of the Russian Academy of Sciences, Moscow, Russia*

For the period from January 1993 to June 1994 the Baltic Sea level (BSL) was dropped at a rate of -18.39±2.31 cm/yr. In the next six month (to December 1994) there was a rising in its rate (+39.28±4.02 cm/yr). A short period of sharp dropper of BSL at a rate of -29.40±3,72 cm/yr was observed from December 1994 to January 1995. Then, from January 1995 to November 19988, it was rising again at a rate of +7.44±0.65 cm/yr, and from November 1998 to November 2002, the BSL dropped at a rate of -5.53±0,32 cm/yr. Then, from November 2002 to January 2005 the BSL was rising at a rate of +12.25±1.71 cm/yr. A short period of sharp drope of BSL at a rate of -15.40±3,72 cm/yr was observed from January 2005 to March 2006. Maximum rate of the sea level rising 66.02±0,83 cm/yr was obtained from March 2006 to January 2008, and from January 2008 to February 2010, BSL was dropped at a rate of -7.25±0.32 cm/yr. Until now the Baltic Sea level rise to rate +13.80±1.37 cm/yr.

Average in 1993-2012 the Baltic Sea dropper to rate 0.35±0.07 cm/yr. In this time period sea surface temperature (SST) rise also to rate +0.07±0.03 °C/yr according to remote sensing data.

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Joint Inter-Association Symposium

JP04p - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

JP04p-162

Estimation of topographic changes from the seasonal variation effect using waterline method

Z. Xu[1], *D.J. Kim*[1], *S.H. Kim*[1]
[1]*Seoul National University, School of Earth and Environmental Science, Seoul, Korea- Republic of Korea*

Morphologic and topologic changes in tidal flat and intertidal areas have attracted world-wide interest due to its function and value of tidal flat. However, morphologic and topological changes in tidal flat are difficult to estimate due to the poor accessibility, short exposure, and lack of suitable transportation. Recently, a number of research were performed to detect and estimate the temporal topographic changes in the tidal flat using the waterline methods based on various remote sensing data. Although seasonal cycles of deposition and erosion have been well documented for tidal flats and inner shelves around the world, these seasonal variations had not been taken into consideration so far. In this study, a total of 15 scenes of Landsat ETM+ data during the period of 2006 and 2013 and corresponding tide gauge observation data were used to estimate the topographic changes due to the seasonal variations in the tidal flat using the waterline method. Two types of tidal flat were investigated from the study area, such as open coast tidal flat (Baeksu-Bay) and semi-open coast tidal flat (Gomso-Bay and Hampyeong-Bay). Our result showed that erosion effect was dominant in the open coast tidal flat that most of Baeksu-Bay eroded in the amount of about 0~50cm. In the semi-open coast tidal flat, erosion and deposition effect were similar in the Gomso-Bay whereas the deposition effect is more dominantly than the erosion effect in the Hampyeong-Bay. The results also infer that the sedimentelogical process is consistent in the open coastal tidal flat whereas the process becomes more complicate in the semi-open coastal tidal flat.

Joint Inter-Association Symposium

JP04p - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

JP04p-163

Statistical patterns of wind variability over the Japan Sea based on satellite scatterometer data

O. Trusenkova[1], *M. Pichugin*[2], *D. Kaplunenko*[1], *I. Gurvich*[2]
[1]*V.I. Il'ichev Pacific Oceanological Institute- FEB RAS,*
Laboratory of Physical Oceanology, Vladivostok, Russia
[2]*V.I. Il'ichev Pacific Oceanological Institute- FEB RAS,*
Laboratory of Satellite Oceanology, Vladivostok, Russia

High quality satellite data on marine winds became available after the launch of the NASA Quick Scatterometer in 1999. By now, they are widely used for process studies; the global climatology based on these data was also developed (Risien, Chelton, 2008). However, a decade long data record calls for more comprehensive analysis of marine wind variability. The purpose of this study is multivariate analyses of wind in the Japan Sea area using QuikSCAT data. The 0.5-degree gridded 6-hour QSCAT/NCEP Blended Ocean Winds data set spanning the period from July 1999 through July 2009 is used. Wind vectors are expanded into empirical orthogonal functions in the complex form. The leading mode, covering more than 50% of the total variance represents the East Asia Monsoon pattern featuring characteristic seasonal changes of the general wind speed and direction over the Japan Sea. On average, the strong northwestern wind prevailing during winter monsoon shifts towards the weaker western and southwestern winds in spring and then towards the southern and southeastern winds by late summer. The wind resumes the northwestern direction by November, usually through the southwest and west. The average variation is interrupted by abrupt intraseasonal wind changes, in particular by detours towards easterlies and northerlies in fall. Monthly histograms of wind directions are unimodal from November through February, bi-modal in March and July and rather fuzzy in other months, especially in April and September, due to the transition between winter and summer monsoons, and in June due to the transition between two stages of summer monsoon. New features include frequent northeastern winds in August and September and lower frequency of zonal winds during the monsoon change in fall than in spring.

Joint Inter-Association Symposium

JP04p - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

JP04p-164

Investigation of the caspian sea level variations and sea surface temperature by the modern methods

E. Safarov[1]*, A. Arsen*[2]*, E.A. Oskouei*[3]*, N.F. Mojtahedi*[3]
[1]*Laboratoire d'Etudes en Géophysique et Océanographie Spatiales,*
UMR 5566CNES-CNRS-IRD-UPS, Toulouse-, France
[2]*Laboratoire d'Etudes en Géophysique et Océanographie Spatiales,*
Géophysique- Océanographie et Hydrologie Spatiales, Toulouse, France
[3]*Iran Meteorological Organization,*
The meteorological applied research center of Guilan Province, Rasht, Iran

The Caspian Sea is the largest lake in the world. Sea level fluctuations are among the most outstanding issues of the Sea. These changes contribute to active debates among scientists. Although the network of sea level stations covers the coasts of all regions of the sea, they are not capable to reflect the sea level variations over the all surface. Satellite altimetry demonstrates a great potential in study of the sea level variability. Since many years The Caspian Sea monitored with satellite altimetery. Therefore, water levels can be measured over the whole basin. This research illustrates the comparative analysis of seasonal sea level fluctuations in the Caspian Sea based on satellite altimetry and in situ data from more than 20 stations from 1992 to 2011. Investigation was carried out throughout the Northern, Middle and Southern Caspian regions. The comparative analysis of average seasonal sea level of the Sea with satellite altimetry data revealed that the Middle Caspian exhibits higher coefficients of correlation than any other region of the Sea. In order to determine the rate of influence between sea level variations and sea surface temperature (SST) changes induced by global climate change, a comparative analysis between Caspian Sea level variations and two types of SST data is made. Continuous wavelet transform is used to investigate the influence and correlation between SST anomalies of the Sea from in situ (1961-2011) and NOAA (1982-2014) data sets, and Southern Oscilation Index (SOI) and North Atlantic Oscilation (NAO) index. The detailed comparative analysis revealed that data from NOAA exhibits highest rate of correlation if compare with in situ. Analysis of all data with SOI and NAO indices did not reveal significant relation among them.

Joint Inter-Association Symposium

JP04p - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

JP04p-165

Evaluation of sea-surface salinity observed by Aquarius

H. Abe[1], *N. Ebuchi*[1]
[1]*Hokkaido university, Institute of Low Temperature Science, Sapporo, Japan*

Sea-surface salinity (SSS) observed by Aquarius was compared with global observation from Argo floats and offshore moored buoys to evaluate the quality of satellite SSS data and to assess error structures. Aquarius products retrieved by different algorithms (Aquarius Official Release version 3.0 (V3.0), Combined Active-Passive (CAP) algorithm version 3.0, Remote Sensing Systems testbed algorithm version 3) were compared. The Aquarius SSS was in good agreement with in situ salinity measurements for all three products. Root-mean-square (rms) differences of the salinity residual, with respect to Argo salinity, ranged from 0.41 to 0.52 psu. These three Aquarius products exhibit high SSS deviation from Argo salinity under lower sea-surface temperature conditions (< 10 °C) due to lower sensitivity of microwave emissivity to SSS. The CAP product deviates under strong wind conditions (> 10 ms^{-1}), probably due to model bias and uncertainty associated with sea-surface roughness. Furthermore, significant SSS differences between ascending (south-to-north) and descending (north-to-south) paths were detected. The monthly-averaged Aquarius SSS (1° × 1° grid) was also compared with outputs from the ocean data optimal interpolation (OI) system operated by the Japan Agency for Marine-Earth Science Technology (JAMSTEC) and the ocean data assimilation system used by the Meteorological Research Institute, Japan Meteorological Agency (MRI/JMA). Negative bias, attributed to near-surface salinity stratification by precipitation, was detected in tropical regions. For 40°S–40°N, rms difference, with respect to the JAMSTEC OI, is 0.26 psu for the V3.0, while the CAP product rms difference is only 0.22 psu, which is close to the Aquarius mission goal.

Joint Inter-Association Symposium

JP04p - JP4 Satellite Oceanography and Climatology (IAPSO, IAG)

JP04p-166

Dynamic response of ocean tides in the icy satellites

R. Tyler[1]
[1]*UMD College Park / NASA GSFC, Astronomy / Planetary Geodynamics, University Park, USA*

Observations by the Galileo and Cassini spacecrafts have provided a strong indication that our massive water ocean is only one of at least several others in the Solar System. It seems clear that these oceans would have long ago frozen if not for an internal heat source. It also seems clear that in at least some of these cases (e.g. Enceladus), the heat sources previously presumed are insufficient. Recently, it has been shown by the author that if these oceans occupy one of several plausible resonant configurations, then the tidal response and associated dissipative heat can easily maintain liquid oceans on most of the large satellites in close orbits. It has also been shown that these resonant configurations are not just possible but may be inevitable because an ocean attempting to freeze will be pushed into the resonant configurations, with the increase in heat acting to stall further freezing.

More specifically, the eigenvalues of the equations describing the ocean's dynamic response depend on the ocean thickness and several other parameters. Where any of these parameters show dependence on the ocean tidal response (e.g. dissipative heat, tidal torques altering spin/orbit), stable and unstable solutions can be identified that can help in constraining the likely range of ocean parameters. These likely "attractor" solution scenarios as well as the constraints they pose on parameters will be discussed.

Joint Inter-Association Symposium

JP05a - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-0473

Concept of Tsunami hazard levels 1 and 2 for the reconstruction in Tohoku, Japan and its implementation

F. Imamura[1], *A. Muhari*[2]
[1]*Tohoku University, International Research Institute of Disaster Science, Sendai, Japan*
[2]*Ministry of Marine Affairs and Fisheries- Indonesia,*
Directorate General for Marine- Coasts and Small Islands, Jakarta, Indonesia

After the 2011 Tohoku tsunami, Japanese government submitted the guidelines for reconstruction with a concept of ‘multiple-defense’ and tsunami hazard levels, which are used to build the disaster resilient community. The new act in Japan mandating tsunami safe city that enforces local government to simulate the impacts of massive tsunamis to develop zoning policy. As the implementation of this concept, two levels for potential tsunami hazard affected area have been proposed as; Level 1 (structural protection) is defined as high frequency but low impact one with a return period from 50 to 150 years and level 2 (comprehensive countermeasure including evacuation) as low frequency but high impact one with more than several hundred or thousands. The improved design of physical structures will be used to minimize the impact of tsunamis to save human and properties in the area of Level 1. In the area of Level 2, the coverage of flooded area is much wider; therefore improvements on the evacuation facilities and education are the major efforts to save lives. Based on the concept of two levels, the plans of the reconstruction at the affected areas especially the design of seawall has been made. The local government is provided with the two levels including the inundation from numerical simulations with the historical tsunami data at each area. The tsunami heights in the level 1 are considered to be the designed height of the structure technically. However, some are not accepted by the local community. What kind of discussions or communication among the residents, government, experts and NGO/NPO are done? Why the agreement among them could be achieved (or not)?

Joint Inter-Association Symposium

JP05a - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-2019

Historical and geological evidence of recurrent large earthquake tsunamis in Japan

K. Satake[1]
[1]*The University of Tokyo, Earthquake Research Institute, Tokyo, Japan*

Historical and paleoseismological data, mostly tsunami-deposits, have shown evidence of infrequent giant earthquakes in subduction zones with recurrence intervals longer than seismologically documented ones in the recent centuries. Along the Kuril Trench off Hokkaido, average recurrence interval of giant earthquakes that left tsunami deposits is estimated as 400 years, compared to < 100 years of typical interplate (M~8) earthquakes. Along the Japan Trench, the recurrence intervals of M~8 interplate earthquakes have been estimated as several decades. However, studies of tsunami deposits indicate that very large tsunami, similar to the 2011 Tohoku earthquake (M~9) recurred with an interval of several hundred years, and the most recent one was the 869 Jogan earthquake. Along the Sagami Trough near Tokyo, two great Kanto earthquakes occurred in 1923 and 1703, but the size and distribution of associated coastal uplift and tsunami heights were different. Antepenultimate Kanto earthquake has been identified as that in 1293 from a tsunami deposit study, but a recent study of historical documents suggests one in 1495. Along the Nankai Trough, historical documents indicate that the recurrence interval of great earthquakes is approximately 100 years, but the tsunami deposits at some sites are found from selected earthquakes, suggesting that size of recurrent earthquakes are variable. Such variability makes it difficult to apply a simple characteristic earthquake model for the long-term forecast of large earthquakes.

Joint Inter-Association Symposium

JP05a - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-2088

Historical mega-tsunamis in the World Ocean and their implication for coastal hazard assessment

V. Gusiakov[1], *P. Dunbar*[2], *L. Kong*[3]
[1]*Institute of Computational Mathematics and Mathematical Geophysics SD RAS, Department of Geophysics, Novosibirsk, Russia*
[2]*NOAA National Geophysical Data Center, Solid Earh Geophysics, Boulder, USA*
[3]*UNESCO/IOC-NOAA- International Tsunami Information Center, Tsunami, Honolulu, USA*

Tsunamis have inflicted death and destruction on the coastlines of the world throughout history. The occurrence of tsunamis and the resulting effects have been collected and studied as far back as the second million B.C. The knowledge gained from cataloging and examining these events has led to significant changes in our understanding of tsunamis, tsunami sources, and methods to mitigate the effects of tsunamis. The most significant, not surprisingly, are the rare but most devastating events, such as the 2011 Tohoku, Japan and the 2004 Sumatra, Indonesia earthquakes and tsunamis. These mega-tsunamis are the strongest tsunamigenic events of tectonic origin that are characterized by run-up heights up to 40-50 m measured along a considerable part of the coastline. One of the most important features of mega-tsunamis is their ability to cross the entire oceanic basin and to cause significant damage on the opposite shoreline. This ability is a result of several factors, the main one being an increased directivity of energy radiation by an extended earthquake source and increased wavelengths as compared to regional and local tsunamis. Mega-tsunamis represent only a small fraction of all known historical tsunamis, however they are responsible for more than half the total tsunami fatalities and a considerable part of the overall tsunami damage. This talk presents a list of the most significant tsunami events identified so far in historical catalogs with their basic source parameters, near-field and far-field impact effects and their generation and propagation features. We also discuss the problem of the long-term tsunami hazard assessment when the occurrence of mega-tsunamis is taken into account.

Joint Inter-Association Symposium

JP05a - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4638

Pacific tsunami warning system: A half-century of protecting the Pacific 1965-2015, historical commemorative book

L. Kong[1], *P. Dunbar*[2], *N. Arcos*[1]
[1]*UNESCO/IOC-NOAA, International Tsunami Information Center, Honolulu, USA*
[2]*NOAA National Geophysical Data Center, Marine Geology and Geophysics, Boulder, USA*

Following the Pacific wide tsunami of 1960 that killed two thousand people in Chile and then, up to a day later, hundreds in Hawaii, Japan, and the Philippines, concerned countries met to discuss and draft the requirements for an international tsunami warning system. In 1965, the United Nations, through the Intergovernmental Oceanographic Commission of UNESCO, formed the International Coordination Group for the Tsunami Warning System in the Pacific (ICG/ITSU) to provide education and warnings to Pacific nations. The Tsunami Warning System in the Pacific is an example of how through international cooperation, the tsunami hazard impact has been mitigated by properly evaluating in real time potentially tsunamigenic earthquakes and by issuing timely informational bulletins and warnings. As we recognize the 50th anniversary of the ICG/ITSU, now renamed the Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System (ICG/PTWS), we should reflect on our progress and, using these accomplishments, extrapolate into the future. This book, which includes reflections from involved participants, a timeline of tsunamis and important events, a history of warning evolution, and a chronicle of scientific and technological development and innovation supporting warning and response, provides a foundation of activities and accomplishments upon which we can build the future. With 50 years of hindsight and countless lessons learned from dangerous tsunamis that have hit, and will continue to hit Pacific shores, the PTWS is poised to continue to lead in showcasing warning and mitigation best practices that save lives. We, the editors, will share highlights from this historical commemorative book.

Joint Inter-Association Symposium

JP05a - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4738

Tsunami warnings for distributed decision making

E. Bernard[1], *V. Titov*[1]
[1]*NOAA, Bellevue, USA*

As our global society moves from centralized decision making to distributed decision making, technologies will emerge that will revolutionize tsunami warnings. In the near future, it may be possible to provide individual warnings to each person in tsunami threatened areas anywhere in the world. Each individual, armed with appropriate information, will be able to decide how to escape immediate danger and how to recover from the aftermath of the tsunami. To plan for this "distributed decision making" world, the tsunami community must ensure that warning and educational products are easy to understand and represent best practices. Easy to understand products will probably be graphical to avoid translation problems. Best practices will emerge from technical and scientific standards established by the IUGG Tsunami Commission and other regional tsunami warning providers around the world.

Examples of easy to understand tsunami-warning products will be presented, including tsunami hazard maps, tsunami energy scale, real-time tsunami flooding estimates, and real-time current velocities in harbors. Appropriate use of these tsunami scientific products lead to greater resilience for tsunami threatened coastlines. A scientific infrastructure will be proposed to ensure that these products are both scientifically sound and represent today's best practices to protect the scientific integrity of the products as well as the safety of coastal residents. Criteria for easy to understand products will be presented.

Joint Inter-Association Symposium

JP05a - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4829

Tsunamis: bridging science, engineering and society

U. Kanoglu[1], *V. Titov*[2], *E. Bernard*[2], *C. Synolakis*[3]
[1]*Middle East Technical University, Department of Engineering Sciences, Ankara, Turkey*
[2]*National Oceanic and Atmospheric Administration,*
Pacific Marine Environmental Laboratory, Seattle, USA
[3]*University of Southern California, Viterbi School of Engineering, Los Angeles, USA*

There have been significant advances in tsunami science since the devastating 2004 Boxing Day tsunami. Yet, the 2011 Japan tsunami dramatically demonstrated that tsunamis continue to avoidably take lives and cause significant damage. Broadcasted live to a stunned world audience, the trail of destruction in 2011 in probably most tsunami ready nation underscores the difficulties of implementing practical advances in hazard mitigation.

The Philosophical Transactions A theme issue entitled ‘Tsunamis: Bridging Science, Engineering and Society’ examines lessons learnt from tsunamis over the last ten years, describes recent advances and state-of-the-art methodologies, outlined standards for warnings and design of critical structures, identifies vexing cross-disciplinary challenges and showstoppers. Mitigating tsunami impacts is a global problem and every nation needs to adopt best practices, ensuring the adoption of global standards and warnings, so everyone understands how to respond regardless of where they are. Global technical standards and uniform warnings are the best way to transfer tsunami science into society. The Fukushima accident is an unfortunate example, where had existing published guidelines been adopted in the reassessment of its safety done in 2010; the impact might have been avoided.

We present the summary and key findings of these multi-disciplinary studies that focus on coastal resilience, thus hopefully, reducing future losses and saving lives.

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Joint Inter-Association Symposium

JP05b - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-0428

Performance evaluation of the Indonesian tsunami early warning during a decade after the 2004 Indian Ocean Tsunami

A. Muhari[1], *F. Imamura*[2]
[1]*Ministry of Marine Affairs and Fisheries, Jakarta, Indonesia*
[2]*Tohoku University, International Research Institute of Disaster Science IRIDeS, Sendai, Japan*

We conducted performance evaluation of the Indonesian Tsunami Early Warning System (Ina-TEWS) by using post tsunami data and questionnaire surveys from eight tsunami events occurred from 2004 to 2014. These tsunami events cover the near- and far-field tsunami characteristics for comprehensive review. We took two downstream components of the end-to-end early warning concept, which are the dissemination of warning and the response from the community as the parameter of the evaluation. We obtain results show that first; to date the official warning is not correlated with the developed response capacity such as self-evacuation, which is mostly influenced by the existence of natural sign such as strong ground shaking and circumstances during the emergency. Secondly, we reveal that is not only a faster time in issuing a warning is necessary; the appropriate time to terminate the warning is also crucial to ensure the safety of the society. These two issues are crucial and need to be resolved for near future improvement.

Joint Inter-Association Symposium

JP05b - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-2320

A new algorithm for real-time near-field tsunami inundation forecast using a dense offshore tsunami observation network

N. YAMAMOTO[1]*, S. AOI*[1]*, K. HIRATA*[2]*, W. SUZUKI*[1]*, T. KUNUGI*[1]*,*
H. NAKAMURA[2]
[1]*National Research Institute for Earth Science and Disaster Prevention, Earthquake and Volcano Research Unit, Tsukuba, Japan*
[2]*National Research Institute for Earth Science and Disaster Prevention, Disaster Risk Research Unit, Tsukuba, Japan*

We started to develop a new algorithm for real-time tsunami inundation forecast using a dense offshore tsunami observation network. The most important concept on this algorithm is involving any type and/or form uncertainties in the tsunami forecast, which cannot be dealt with any of standard linear/nonlinear least square approaches. In this algorithm, we need to prepare a Tsunami Scenario Bank (TSB), which contains offshore tsunami waveforms at the stations and tsunami inundation area calculated from any possible tsunami sources. After tsunami occurrence, we then quickly select a range of several acceptable tsunami scenarios that can explain offshore observations by using multiple indices and appropriate thresholds. At the same time, possible tsunami inundation areas coupled with selected scenarios are forecasted.

Currently, we focus on near-field tsunamis occurring off the Pacific coast of Japan because the Seafloor Observation Network for Earthquakes and Tsunamis (S-net) will be ready soon (Kanazawa et al., 2012, JpGU; Uehira et al., 2014, AOGS). And we set up about 2000 tsunami scenarios prepared for a research project of nationwide Probabilistic Tsunami Hazard Assessment for Japan (Hirata et al., 2014, AGU). For selecting acceptable scenarios from the TSB, we defined three indices, correlation coefficient (R), geometric mean (S) and geometric standard deviation (s) between pseudo 'observed waveforms' (O) and calculated waveforms (C) (Yamamoto et al., 2014, AGU). In this study, we define two kinds of variance reductions, VRO = 1 - (sum of squared residual) / (sum of squared O) and VRC = 1 - (sum of squared residual) / (sum of squared C). The combination of several indices rather than any single index is probably promising to let us attain a robust tsunami forecast.

Joint Inter-Association Symposium

JP05b - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-2870

T3, a real-time tsunami forecasting tool for Australia

S. Allen[1], *J. Freeman*[1], *E. Schulz*[1]
[1]*Bureau of Meteorology, Centre for Australian Weather and Climate Research, Melbourne, Australia*

A cornerstone of the Joint Australian Tsunami Warning Centre's (JATWC) forecast system is the T2 tsunami scenario database. It comprises over 2000 pre-computed scenarios of tsunami propagation over a near-global domain. The database provides numerical forecast guidance that is input to the tsunami warning system.

At the time of T2's development, computational limitations required scenarios to be pre-computed and compiled into a database. However, advances in computer power, along with algorithm enhancements, permit (faster-than) real-time modeling of tsunami events. These advances will be utilised to develop JATWC's new numerical forecast system, T3.

T3 will be run in real-time as a key component of JATWC's operational tsunami warning system. This real-time computation will allow some of the assumptions and constraints required in T2 to be relaxed. For example, it will be possible to simulate a wider range of initial conditions than those available in the T2 scenario database, yet rapidly reduce to an optimal solution by comparison with real-time sea-level observations. This means T3 will produce forecasts with less uncertainly than those produced with T2.

This presentation will outline the computational advances that have made T3 possible. It will describe the news features of T3, particularly those that differ significantly from T2. The accuracy of T3 will be demonstrated using past tsunami events. Lastly, It will show how T3 fits into the JATWC warning system, as a replacement for T2.

Joint Inter-Association Symposium

JP05b - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4417

Real-time tsunami inundation forecasting and damage estimation method by fusion of real-time crustal deformation monitoring and high-performance computing

S. Koshimura[1], R. Hino[1], Y. Ohta[2], H. Kobayashi[3], A. Musa[4], Y. Murashima[5]
[1]Tohoku University, International Research Institute of Disaster Science, Sendai, Japan
[2]Tohoku University, Graduate School of Science, Sendai, Japan
[3]Tohoku University, Cyberscience Center, Sendai, Japan
[4]NEC Corporation, -, Tokyo, Japan
[5]KOKUSAI KOGYO CO.- LTD, Engineering Division, Tokyo, Japan

We established a new method of real-time tsunami inundation forecasting, damage estimation and mapping with use of advanced sensor networks and modern computing power. The method consists of fusion of real-time crustal deformation monitoring/fault model estimation, high-performance real-time tsunami propagation/inundation simulation with a vector supercomputer, and tsunami fragility curves for damage/loss estimation.

The method has recently accomplished “10-10-10 challenge”, to complete tsunami source determination in 10 minutes, tsunami inundation modeling in 10 minutes with 10 m grid resolution. The first response of the system is to identify the tsunami source model by applying RAPiD Algorithm (Ohta et al., 2012) to observed RTK-GPS time series at GEONET sites in Japan. After the tsunami source is determined, the system moves on to running tsunami propagation and inundation model, which was optimized on the vector supercomputer NEC SX-ACE installed at Tohoku University, to acquire the estimation of time series of tsunami at offshore/coastal tide gauges to determine tsunami travel and arrival time, extent of inundation zone, maximum flow depth distribution. Given the maximum flow depth distribution, the system performs GIS analysis to determine the numbers of exposed population and structures using census data, then estimates the numbers of potential death and damaged structures by applying tsunami fragility curve (Koshimura et al., 2013).

In 2015, the system starts trial operation in Kochi prefecture, one of at-risk coastal city against Nankai trough earthquake. In the trial operation, we verify the capability of the method as a new tsunami early warning and response system for stake holders and responders.

Joint Inter-Association Symposium

JP05b - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4515

Tsunami magnitude as measure of potential impact

V. Titov[1], *L. Tang*[2]
[1]*NOAA, PMEL, Seattle, USA*
[2]*NOAA- University of Washington, PMEL- JISAO, Seattle, USA*

Tsunami warnings that predict potential tsunami impact along coastlines, require a fast estimate of a tsunami magnitude. This requirement has been recognized since the beginning of tsunami research. Historically, earthquake magnitude has been used as a proxy of tsunami impact estimates. This proxy of tsunami impact carries significant uncertainties for quantitative tsunami impact estimation, since the ratio between the energy of an earthquake and resultant tsunami (averages around 0.1%) varies significantly from one earthquake to another.The works of Kajiura, Soloviev, Abe, Murty, and many others have discussed several scales for tsunami magnitude based on estimates of tsunami energy. Such estimates, were based on available tsunami measurements at coastal sea-level stations and carried significant uncertainties, due to the quality of tsunami signals at tide gages. The process of tsunami magnitude estimates, including collection of vast amount of available coastal sea-level data from affected coastlines, made it impractical to use these tsunami magnitude scales in tsunami warning operations. The uncertainties also make tsunami magnitudes difficult to use as a universal scale for tsunami research.In this work, we use modern tsunami measurement capabilities and forecast tools to create robust estimates of a tsunami magnitude that will quantify potential tsunami impacts. Such a scale will be useful for tsunami warning operations as a fast estimate for tsunami impact and for post-event research as a standard scale for tsunamis inter-comparison. We present a method for estimation of tsunami magnitude based on tsunami energy and apply this magnitude analysis for several historical events for inter-comparison with existing methods.

Joint Inter-Association Symposium

JP05b - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4922

Development of tsunami Green's function database based on linear dispersive-wave theory for real-time forecasting of near-field tsunamis

H. Tsushima[1], Y. Hayashi[1], T. Baba[2], K. Ando[3], T. Kato[4]
[1]Meteorological Res. Inst.- JMA, Seismology and Tsunami Research Department, Tsukuba, Japan
[2]University of Tokushima, Department of Civil and Environmental Engineering, Tokushima, Japan
[3]Japan Agency for Marine-Earth Science and Technology, Center for Earth Information Science and Technology, Kobe, Japan
[4]NEC Corporation, 1st Government and Public Solution Division, Tokyo, Japan

Real-time tsunami forecasting based on source inversion of offshore tsunami data is effective for update of tsunami early warnings. To accomplish the real-time analysis in a short time, in advance of an earthquake we prepare a database of the tsunami Green's functions that are responses to the unitary displacement of a sea-surface element (unit source) at observing points. For the construction of our present database, linear long-wave (LLW) approximation was used in the numerical simulation. However, recent offshore tsunami observations have demonstrated that the LLW approximation is sometimes invalid and the linear dispersive effect should be taken into account in tsunami modeling. If the effect is neglected in our source inversion, the accuracy of the resultant tsunami predictions should be degraded. In this study, we develop a database of Green's functions based on the linear dispersive-wave (DSP) simulations to improve the forecasting accuracy. A difficulty to make the DSP database is very long computation time. The DSP simulation takes much longer time than LLW one. In addition, we have to perform the simulation more than 1000 times, corresponding to the number of the unit sources. To reduce the computation time, we used tsunami-simulation code JAGURS [Baba et al., this meeting], which is optimized for the parallel computation in K computer (the Japanese supercomputer) by using OpenMP and MPI techniques. For more effective computation of many cases, we implemented a function that the tsunami simulations for more than 1000 source are performed in parallel once a user submits only one job. As the result of its application to the Nankai-trough region where there is 1059 sources, the whole calculation was finished in ~20 hours by using 4236 nodes of the K computer.

Joint Inter-Association Symposium

JP05c - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-0896

Tsunamis in straits: observations and modelling

A. Rabinovich[1,2], *I. Fine*[2], *R. Thomson*[2]
[1]*P.P.Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia*
[2]*Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney- BC, Canada*

An analysis of the 2010 Chilean and 2011 Tohoku tsunami records measured within Juan de Fuca Strait (JdF) indicates that the records have properties that distinguish them from those on the outer (Pacific) coast. JdF is a relatively wide (18-27 km) and deep (~200 m) channel of ~100 km length separating southern Vancouver Island, British Columbia (BC) and Washington State (WA). The tsunamis were measured by several BC and WA tide gauges located within the strait and on the oceanic coast and by open-ocean DART and NEPTUNE stations. We found that the outer spectra occupy a broad band of periods from 3 h to about 2 min, while the JdF spectra are limited to periods >6-15 min. A similar result occurs for tsunami waves in Alberni Inlet (AI), a long (~40 km) and narrow (1-2 km wide) fjord on the west coast of Vancouver Island. Here, the high-frequency tsunami energy rapidly decays with distance from entrance. We assume that JdF and AI efficiently transform the energy of arriving open-ocean waves, allowing the passage of most of the low-frequency energy but dampening the high-frequency energy. To validate this idea, we used a linear shallow-water numerical model similar to the TUNAMI model. The numerical results show the progressive low-frequency filtering and transformation of the longwave spectrum from the outer shelf to the heads of the strait and inlet.

Joint Inter-Association Symposium

JP05c - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-2078

Estimation of coastal tsunami heights from 60 submarine faults in the Sea of Japan

A. Gusman[1], *S. Murotani*[1], *K. Satake*[1]
[1]*The University of Tokyo, Earthquake Research Institute, Tokyo, Japan*

Several large (M>7.5) earthquakes occurred along the eastern margin of the Sea of Japan and caused tsunami damage in Japan as well as on Korean peninsula in the last two centuries. They were the 1993 Southwest Hokkaido (Mw 7.7), 1983 Japan Sea (Mw 7.7), 1940 Shakotan-oki (Mw 7.5), 1964 Niigata (Ms 7.5), and 1833 Shonai-oki (M 7.5) earthquakes. In order to assess possible future earthquakes and tsunamis, Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan recently identified 60 submarine active faults with lengths ranging from 24 to 162 km (corresponding moment magnitudes of 6.8 to 7.9).

Tsunami inundations in Aonae Bay, Okushiri Island, Japan on high-resolution bathymetry and topography data were simulated using the active faults. For small tsunamis (coastal tsunami heights < 4 m), the relationship between tsunami heights in the offshore (50 m depth) and at the coast may follow a linear regression line, whereas for larger tsunami the linear relationship may not hold. The regression line may give an amplification factor to roughly estimate coastal tsunami height from a tsunami numerical simulation result on a coarse grid system.

We computed offshore and coastal tsunami heights along the Japanese coasts from these 60 faults and identified faults that may possibly cause tsunami damage (coastal tsunami heights > 1 m) for 156 municipalities (cities and towns). Comparisons between offshore and coastal tsunami heights show that the ratios are vary from place to place, and seem to be controlled by the bathymetric slope.

Joint Inter-Association Symposium

JP05c - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-2616

Estimation of tsunami risk (including tides and storm surges) for the coasts of the Sea of Okhotsk

G. Shevchenko[1]
[1]*Institute of Marine Geology and Geophysics,*
Russian Academy of Sciences- Far East branch, Yuzhno-Sakhalinsk, Russia

Extreme sea levels arising from the combination of tides, storm surges, seasonal oscillations and tsunamis were estimated by the joint probability method for the coast of the Sea of Okhotsk and the Pacific coast of the Kuril Islands. The sea level observations at 10 coastal tide gauges were examined. The tidal heights at most stations are about 1.5 - 2 m, and only at Magadan they are much larger (about 5 m). Storm surges have the largest heights for the central Kuril Islands (Matua and Iturup islands), while at the North and South Kuril Islands the surge heights are the smallest. The recurrence of tsunami heights of various probabilities was estimated for each station. The influence of the tides and storm surges on the tsunami risk assessment for the Pacific coast was found to be relatively small. For the coast of the Sea of Okhotsk the contribution of tides and surges is essential, especially for the return periods less than 100 years. For longer return periods, the tsunamis play the major role in forming the extreme levels.

Joint Inter-Association Symposium

JP05c - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4180

A global tsunami model (GTM) for coordinated tsunami hazard and risk assessment

F. Løvholt[1], *C. Harbitz*[2], *J. Griffin*[3], *G. Davies*[4], *S. Lorito*[5], *R. Basili*[5], *J. Selva*[6], *M.A. Baptista*[7], *R. Omira*[7], *L. Matias*[8], *A. Babeyko*[9], *E. Geist*[10]
[1]*NGI, Offshore Energy, Oslo, Norway*
[2]*NGI, Natural Hazards, Oslo, Norway*
[3]*Geoscience Australia, Regional Development Section, Canberra, Australia*
[4]*Geoscience Australia, Community Safety and Earth Monitoring Division, Canberra, Australia*
[5]*Istituto Nazionale di Geofisica e Vulcanologia, Sismologia e Tettonofisica, Roma, Italy*
[6]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy*
[7]*Instituto Portugues do Mar e da Atmosfera, Divisao de Geofisica, Lisboa, Portugal*
[8]*Universidade de Lisboa, Instituto Dom Luiz- Faculdade de Ciências, Lisboa, Portugal*
[9]*Deutsches GeoForschungsZentrum - GFZ, Geodynamic Modeling, Potsdam, Germany*
[10]*USGS, Menlo Park, Menlo Park, USA*

The disasters caused by tsunamis in the last 10 years have highlighted the need for a thorough understanding of the global and regional tsunami hazard and risk. At present, the 2004 and 2011 tsunamis hint that their induced risk are dominated by large infrequent events with possibly long return periods. However, an in-depth understanding of how individual contributions from sources of different strength and frequency govern the hazard and risk is presently not clear. A first global analysis of tsunami hazard using earthquake sources was conducted in 2008 on behalf of the UN-ISDR Global Assessment Report (GAR). Recently, this initiative has resulted in the first, fully probabilistic global tsunami hazard assessment. Economic loss calculations based on building fragility curves largely derived from recent major tsunamis have also been included to assess the risk. Still, this complex assessment is premature. Further efforts are needed, requiring joint expertise covering a wide range of topics such as the understanding of sources, hydrodynamics, probability and statistics, as well as vulnerability and exposure. Therefore, there is a dire need for a joint interdisciplinary effort delivering data and tools that may help decision makers in assessing their tsunami hazard and risk. To this end, we propose to establish a Global Tsunami Model (GTM) that will

emphasize tsunami hazard and risk analysis on a global scale.The GTM will be based on the initial work in GAR, but should eventually involve a broader community. The motivation, the needs, and the possible contributors for such a GTM will be discussed.

Joint Inter-Association Symposium

JP05c - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4520

Update of the U.S. states and territories national tsunami hazard assessment: Historical record and sources for waves

P. Dunbar[1], *C. Weaver*[2]
[1]*NOAA / National Geophysical Data Center, Marine Geology and Geophysics, Boulder, USA*
[2]*U.S. Geological Survey, Pacific Region, Seattle, USA*

Tsunamis are infrequent high impact events that can cause a considerable number of fatalities, inflict major damage, and cause significant economic loss to large sections of the U.S. coastlines. Because of the large coastal area affected, it is imperative that the U.S. understand the tsunami threat to its States and territories, and to identify coastal areas that face the greatest tsunami risk. The first step in developing these plans is an assessment of hazard. NOAA's National Geophysical Data Center (NGDC) catalogs information on global historic tsunamis. Since earthquakes or earthquake-generated landslides caused more than 90% of the confirmed tsunamis in the NGDC tsunami database and the U.S. Geological Survey (USGS) conducts research on earthquake hazards facing all of the U.S.; in 2008 NGDC and USGS partnered together to conduct the first tsunami hazard assessment for the U.S. states and its territories. Since that time, there have been a number of significant tsunamis, including the 2009 Samoa, the 2010 Chile, and 2011 Japan tsunami events. This report updates the 2008 assessment by incorporating both the new tsunami inundation data recorded through 2014 and incorporating studies completed since the earlier report. The two most critical studies considered potential tsunami sources possibly affecting the Gulf Coast and the Atlantic Coast. The recent Chile and Japan tsunamis illustrate the necessity of understanding the entire hazard and risk. This report is intended to be an overview of the hazard down to the State level and is an initial step towards a national tsunami risk assessment. We also discuss current efforts on the U.S. west coast to move to a probabilistic tsunami hazard assessment and to identify the exposure and vulnerability to tsunamis.

Joint Inter-Association Symposium

JP05c - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-5743

Probabilistic tsunami design maps for US pacific coastlines

Y. Wei[1], G. Chock[2], H. Zhou[1], H.K. Thio[3], V. Titov[4]
[1]National Oceanic & Atmospheric Administration NOAA & University of Washington, Pacific Marine Environmental Laboratory & JISAO, Seattle, USA
[2]Martin & Chock Inc., Martin & Chock Inc., Honolulu, USA
[3]AECOM, AECOM, Los Angeles, USA
[4]National Oceanic & Atmospheric Administration NOAA,
Pacific Marine Environmental Laboratory, Seattle, USA

National standards of engineering design for tsunami effects do not currently exist in the U.S.. A significant risk posed by potential tsunami impact is mostly ignored in engineering design. The American Society of Civil Engineers (ASCE) 7 is completing the 2016 edition of ASCE/SEI 7 Standard, which includes the chapter on Tsunami Loads and Effects. This study use Probabilistic Tsunami Hazard Analysis (PTHA) technique to develops tsunami design maps of 2,500-year probabilistic tsunami inundation for Alaska, Washington, Oregon, California, and Hawaii for use with the ASCE design provisions. These new maps define coastal zones where critical structures will be designed for tsunami resistance to increase community resilience. We demonstrate methodology and procedures used to produce these PTHA maps. For maritime safety planning, we further extend the tsunami hazard maps to provide PTHA tsunami currents offshore and onshore.

Most of existing tsunami inundation hazard maps in the U.S. are developed with deterministic methods. These methods use various techniques based on historical tsunami data and tectonic analysis of large subduction zones to develop one or several worst-case tsunami scenarios. Development of probabilistic tsunami design provides an opportunity for comparing PTHA maps with deterministic maps, and to assess the level of tsunami resilience these maps would provide for coastal communities at risk.

Joint Inter-Association Symposium

JP05d - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-1531

Understanding tsunami hazard and risk in lakes: the case of western Lake Geneva

C. Calpini[1], *G. Simpson*[1], *C. Frischknecht*[1], *S. Girardclos*[1,2]
[1]*Earth and Environmental Sciences, Earth Sciences, Genève, Switzerland*
[2]*Earth and Environmental Sciences, Institut des Sciences de l'Environnement, Genève, Switzerland*

Catastrophic events linked to tsunami waves, such as the Tohoku-Oki Tsunami (2011), have raised strong societal interest in understanding and assessing risk associated with these phenomena. However, killer waves are not only restricted to oceanic water bodies but can also occur in lakes.

This research focuses on tsunami risk assessment for the shores of Lake Geneva (France – Switzerland) region. Indeed, previous seismic and sedimentological studies have shown that at least six sublacustrine mass failures triggered tsunamis in Lake Geneva, during the last 4000 years. Numerical simulations of the most recent event (563 AD) show wave heights exceeding 8 meters at the end of the Western Lake.

Since this event, Lake Geneva region has become a major economic and urban area with most of its shore urbanized. However, no tsunami early warning system and little or no awareness of tsunami risk exist. It is therefore of prime importance to better understand the possible consequences of tsunamis in lakes.

The study is based on two step assessments: the hazard and the exposure carried out within a GIS environment, in order to identify sensitive locations in space. The hazard assessment has been carried out using a new physical tsunami wave model based on a Non-Oscillatory central differencing scheme. Output of this model are expressed in terms of wave height, propagation speed and inundation zone. Exposure considers the population, the buildings and the infrastructures at risk in the Western Lake Geneva region.

Our work shows that a tsunami on Lake Geneva could have disastrous consequences. This is mainly due to the combined effects of (1) short wave arrival times (2) significant exposure (3) little or no awareness of the tsunami risk and (4) the lack of an early warning system.

Joint Inter-Association Symposium

JP05d - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-2477

New insights on Tsunami Hazards in the Makran Subduction Zone, northwestern Indian Ocean

M. Heidarzadeh[1], *K. Satake*[1]
[1]*The University of Tokyo, Earthquake Research Institute, Tokyo, Japan*

We present recent findings on tsunami hazards in the Makran subduction zone (MSZ), NW Indian Ocean, based on the results of tsunami waveform analyses for two Makran tsunamis of 1945 and 2013. A re-analysis of the 27 November 1945 tsunami in the MSZ showed that the slip needs to be extended to deep waters around the depth of 3000 m in order to reproduce the observed tide gauge waveforms at Karachi and Mumbai. On the other hand, coastal uplift report at Ormara (Pakistan) implies that the source fault needs to be extended inland. In comparison to other existing fault models, our fault model is longer and includes a heterogeneous slip with larger maximum slip. The recent tsunami on 24 September 2013 in the Makran region was triggered by an inland Mw 7.7 earthquake. While the main shock and all aftershocks were located inland, a tsunami with a dominant period of around 12 min was recorded on tide gauges and a DART station. We examined different possible sources for this tsunami including a mud volcano, a mud/shale diapir, and a landslide/slump through numerical modeling. Only a submarine slump with a source dimension of 10-15 km and a thickness of around 100 m, located 60-70 km offshore Jiwani (Pakistan) at the water depth of around 2000 m, was able to reasonably reproduce the observed tsunami waveforms. In terms of tsunami hazards, analyses of the two tsunamis provide new insights: 1) large runup heights can be generated in the coastal areas due to slip in deep waters, and 2) even an inland earthquake may generate tsunamigenic submarine landslides.

Joint Inter-Association Symposium

JP05d - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-2604

Earthquake Scenario-Based Tsunami Wave Heights in the Eastern Mediterranean and Connected Seas

O. Necmioglu[1], *N.M. Ozel*[2]
[1]*Bogaziçi University - Kandilli Observatory and Earthquake Research Institute, Istanbul, Turkey*
[2]*Bogaziçi University - Kandilli Observatory and Earthquake Research Institute, Geophysics, Istanbul, Turkey*

This presentation is an update to the presentation made at the ITS 2013 on the characterization of earthquake sources in the Eastern Mediterranean and its Connected Seas for tsunami modeling. We have initiated an extensive modeling study to perform a deterministic Tsunami Hazard Analysis for the study area (30°N-48°N and 22°E-44°E) by assigning characteristic earthquake source parameters (strike, dip, rake, depth, Mwmax) as input parameters for the deterministic tsunami hazard modeling at each 0.5° x 0.5° size bin for 0-40 km depth (total of 310 bins) and for 40-100 km depth (total of 92 bins) from the harmonization of the available databases and previous studies. Tsunami simulations of 6h duration with a coarse (2 arc-min) grid resolution have been simulated at EC-JRC premises for Black Sea and Eastern and Central Mediterranean (30°N-41.5°N and 8°E-37°E) for each source defined using shallow water finite-difference SWAN code (Mader, 2004) for the magnitude range of 6.5 – Mwmax defined for that bin with a Mw increment of 0.1. Results show that not only the earthquakes resembling the well-known historical earthquakes such as AD 365 or AD 1303 in the Hellenic Arc, but also earthquakes with lower magnitudes do constitute to the tsunami hazard in the study area, as indicated also by historical information. A simplified tsunami hazard map is also presented. This work is partially funded by project ASTARTE - Assessment, Strategy And Risk Reduction for Tsunamis in Europe - FP7-ENV2013 6.4-3, Grant 603839.

Joint Inter-Association Symposium

JP05d - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-2770

Tsunami hazard assessment in the Augusta-Siracusa coastal area (eastern Sicily, Italy) through a worst-case scenario approach

S. Tinti[1]*, A. Armigliato*[1]*, G. Pagnoni*[1]*, F. Zaniboni*[1]*, M.A. Paparo*[1]
[1]*Dipartimento di Fisica e Astronomia- Università di Bologna, DIFA, Bologna, Italy*

Eastern Sicily is well known to be one of the areas most exposed to tsunami hazard and risk in Italy and in the whole Mediterranean basin. The complementary information coming from the catalogues of historical events and from the paleo-tsunami deposit analyses indicate that the coastal sector between Augusta and Siracusa was hit by tsunamis generated locally (1169, 1693 and 1908) as well as by remote sources (365, western Hellenic trench). Nowadays, the Augusta bay hosts one of the most important petrochemical poles in Italy and in Europe, and Siracusa is listed as UNESCO World Heritage Site since 2005. For these and other reasons, both towns and the coastal areas between them have been chosen as test sites in the framework of the project called ASTARTE – Assessment, STrategy And Risk Reduction for Tsunamis in Europe – FP7-ENV2013 6.4-3, Grant 603839. This contribution aims at assessing the tsunami hazard for these test sites through a worst-case scenario approach. The most tricky part of it is probably the definition of the sources, as none of the historical events cited before has been recognized a widely agreed-upon source. We take into account five different source areas, including local and remote ones and formulate sound hypotheses on a number of tsunamigenic earthquake faults and submarine landslides. For each of them, we run numerical simulations of tsunami propagation and run-up by means of the in-house finite-difference NLSW code called UBO-TSUFD, making used of a set of nested grids whose finer resolution is 40 m in correspondence with the Augusta and Siracusa basins. The final products consist in maps of maximum water elevation, maximum water column, maximum velocity and maximum momentum flux for the aggregate scenario, which are presented and discussed.

Joint Inter-Association Symposium

JP05d - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4972

Tsunami hazard analysis for Gulluk Bay Turkey

S. Acar[1], B. Aytore[1], U. Kanoglu[2], A.C. Yalciner[3]
[1]METU, Civil Engineering, Ankara, Turkey
[2]METU, Engineering Sciences, Ankara, Turkey
[3]Prof. Dr., CIvil Engineering, Ankara, Turkey

The deterministic and probabilistic tsunami hazard analysis is one of the primary issues for disaster management and the determination mitigation strategies. Güllük bay (Turkey) located in southern Aegean Sea is selected as the study region to evaluate the effects of probable tsunami waves in the region. The critical structures in Güllük bay are aquaculture facilities, commercial port, marinas, airport and small size water front structures at touristic centers. The seismic and non-seismic sources are processed using the available data. The estimated rupture parameters of seismic sources and dimensional parameters of non-seismic sources are used in simulations in deterministic approach. The seismic data based on seismic monitoring between 1950-2014 is used and the earthquake magnitudes which may occur in 100, 500, 1000 years return periods are computed statistically by extreme value analysis in probabilistic approach. The related rupture parameters have been determined due to the rupture parameters measured in past earthquakes in the region.

Tsunami simulations due to selected rupture parameters of different return periods are performed by using tsunami numerical code NAMI DANCE. The near shore tsunami parameters (maximums of water elevations, current velocities, momentum fluxes, discharge fluxes, flow depth) are computed. Simulation results for each tsunami scenario are compared, discussed and presented in regard to tsunami hazard analysis for Güllük bay.

Joint Inter-Association Symposium

JP05d - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-5361

Assessing probabilistic tsunami hazard due to submarine landslides in the Cook Strait canyon system

W. Power[1]*, J. Mountjoy*[2]*, E. Lane*[3]*, P. Stephane*[4]*, X. Wang*[5]
[1]*GNS Science, Natural Hazards, Lower Hutt, New Zealand*
[2]*NIWA, Marine Geology, Wellington, New Zealand*
[3]*NIWA, Hydrodynamics, Christchurch, New Zealand*
[4]*Université Pierre et Marie Curie, Centre National de la Recherche Scientifique, Paris, France*
[5]*GNS Science, Tectonophysics, Lower Hutt, New Zealand*

Tsunami generated by submarine landslides are recognised as an important hazard, and can occur in a variety of settings such as on continental slopes, volcanic slopes, and submerged canyons and fjords. While significant progress has been made in understanding tsunami generation processes on open slopes, the problem of tsunami generation by landslides within submarine canyons has received less attention. We examine the tsunami hazard posed by submarine landslides in the Cook Strait canyon system, near Wellington, New Zealand. Understanding the hazard posed by this source is important because of its proximity to a populated coast. We also highlight the differences between tsunami generation on open coasts and within canyons. Geotechnical and geological studies of the Cook Strait region demonstrate many large landslide scars in the consolidated material of the canyon walls. Scouring of the base of the canyon slopes by strong tidal currents is believed to play a role in bringing slopes to the point of failure, with most large failures expected to occur during earthquake shaking. We present computer simulations of landslide failures using simplified canyon geometries. These simulations were made using Gerris, an adaptive-grid fluid dynamics solver. The landslide and tsunami are modelled together as a coupled system. Information on the age and size of past landslides has been combined with scenario modelling to make a probabilistic assessment of the tsunami hazard.

Joint Inter-Association Symposium

JP05e - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-0663

A new source function of the 1964 Alaska tsunami based on the near-field numerical modeling and observations

E. Suleimani[1], *J.T. Freymueller*[1]
[1]*University of Alaska Fairbanks, Geophysical Institute, Fairbanks, USA*

Near-field observations of tsunami waves generated by the M_w9.2 1964 Alaska earthquake reveal a complex relationship between the tsunami wave field in the source area and regional coseismic slip in South-central Alaska. The documented times and amplitudes of first arrivals, measured runup heights and inundation areas along the coasts of the Kenai Peninsula and Kodiak Island suggest that secondary splay faults played an important role in generating destructive tsunami waves. Analysis of recently acquired seismic reflection data in western Prince William Sound confirms that several megathrust splay faults ruptured during the 1964 earthquake. We conduct a numerical modeling study to test a hypothesis that a significant amount of slip needs to be placed on intraplate splay faults, and to evaluate the extent of these faults in order to explain the coseismic displacements and near-field tsunami observations. Our newly revised coseismic deformation model of the 1964 earthquake suggests that the Patton Bay fault extends offshore to the boundary of plate coupling along the Kenai Peninsula coast derived from previous GPS and postseismic deformation studies. The results of tsunami numerical modeling in the Kodiak Island region demonstrate that the new coseismic deformation model provides a good estimate of slip on the megathrust in the Kodiak asperity, and confirm that it was an important feature of the 1964 tsunami generation mechanism. Our approach for discretization of the fault geometry and redistribution of slip contributes to specification of potential credible tsunami sources. They are used for tsunami hazard assessment in Alaska coastal communities located along the Aleutian megathrust, where modeling results are highly susceptible to the complexity of the tsunami source.

Joint Inter-Association Symposium

JP05e - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-0882

The current signal of the April 1, 2014 Chile tsunami as recorded in Crescent City, California

A. Admire[1], *G. Crawford*[2], *L. Dengler*[1]
[1]*Humboldt State University, Geology, Arcata, USA*
[2]*University of Ontario Institute of Technology, Faculty of Science, Oshawa, Canada*

Crescent City, California is known for amplifying tsunami signals. The tide gauge in Crescent City typically records the largest or near largest amplitudes for far-field sources from many areas of the Pacific. The harbor has suffered the greatest property loss of any North American site in the tsunami events of the past decade. To understand this amplification, it is important to know how the geometry of the harbor influences the natural frequency of water level and currents caused by the forcing of tides and weather events, and how these frequencies may be enhanced or suppressed by tsunamis. We installed Nortek Acoustic Doppler Profilers (ADPs) in Humboldt Bay, 90 km south of Crescent City, in 2009 and in Crescent City Harbor in 2014 to better understand the tsunami dynamics of California's north coast. The ADPs measure pressure variations and currents with a one-minute sampling interval. In Crescent City, the ADP is deployed near the navigational channel at a fixed depth of 2.8 m below MLLW, and is collocated with the NOAA tide gauge. Spectral analysis shows that in the absence of tsunami forcing, the site exhibits frequency peaks at 20, 10, 5.6 and 2.5 min in the water level record. We observe all but the shortest period in the ambient current signal. The Crescent City ADP recorded the April 1 Chile tsunami. After the tsunami onset, the 20 min period was enhanced while the shorter periods appeared to be suppressed. The signal persisted in Crescent City Harbor for more than 100 hrs in the water level record and approximately 60 hrs in the current record. When compared to tsunami signals recorded by the ADP in Humboldt Bay the water level and current behavior and frequency response are more complex at Crescent City, likely caused by the geometry of the harbor.

Joint Inter-Association Symposium

JP05e - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-1799

1755 Lisbon tsunami towards the French Atlantic coasts: propagation of uncertainties

E. Antoshchekova[1], *D. Imbert*[2], *Y. Richet*[3], *L. Bardet*[1], *C.M. Duluc*[1], *V. Rebour*[4]
[1]*Institut de Radioprotection et de Sûreté Nucléaire, PRP-DGE/SCAN/BEHRIG, Fontenay-aux-Roses, France*
[2]*CEA, DAM- DIF, Arpajon, France*
[3]*Institut de Radioprotection et de Sûreté Nucléaire, PSN-EXP/SNC, Fontenay-aux-Roses, France*
[4]*Institut de Radioprotection et de Sûreté Nucléaire, PRP-DGE/SCAN, Fontenay-aux-Roses, France*

The purpose of our study is a reevaluation of tsunami hazard for French Atlantic coastlines. In this region we face a moderate seismic hazard. Thus, tsunami risk from local seismic sources is low. Distant sources were identified but not quantified until recently in terms of effects towards these coastlines. The Azores-Gibraltar fracture zone is the source of the largest earthquakes and tsunamis in Western Europe. We focused this work on the 1755 Lisbon event which is the strongest tsunamigenic earthquake ever reported in this region. The recent numerical study shows for instance the maximum tsunami amplitudes of about 0.5 m-1 m in La Rochelle harbor and island of Ré. The recent historical researches reveal that France was touched by 1755 tsunami along the Atlantic coasts with runup until 2.5 m (http://www.tsunamis.fr). More, there are still large uncertainties concerning source location and focal mechanism. Hence, simple deterministic approach is not sufficient. The aim of this study is to investigate the uncertainties related to Lisbon tsunami. The investigated uncertainties are related either to the seismic source parameters, or to bathymetry and resolution of bathymetric grids. In each group the identified parameters has been ranked according to its influence on result variability. A process using a coupling of a parametric modeling environment Promethée (http://promethee.irsn.org/doku.php) and a tsunami simulation software based on shallow water equations. The propagation of uncertainties on the input parameters to the output parameters goes through a Monte-Carlo sampling techniques. This work is realized as part of the project TANDEM (**T**sunamis in the **A**tlantic and the English Cha**N**nel: **D**efinition of the **E**ffects through numerical **M**odeling).

Joint Inter-Association Symposium

JP05e - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-5210

Tsunami waveform inversion for the 2011 Tohoku Earthquake: Importance of dispersion and source kinematics

P. Cummins[1], *J. Hossen*[1], *J. Dettmer*[1]
[1]*Australian National University, Research School of Earth Sciences, Acton, Australia*

This presentation considers the importance of model parametrization, including dispersion, source dynamics, and source discretization, in tsunami source inversion. We implement single and multiple time window methodsfor dispersive and non-dispersive wave propagation to estimate source models for the tsunami generated by the 2011 Tohoku-Oki earthquake. The results show that tsunami source models can depend strongly on such model choices, in particular for high quality data available today from ocean bottom pressure and global positioning system gauges. We carry out several synthetic inversion tests to validate the method and assess the impact of including dispersion and source duration/rupture velocity in data predictions onthe inversion results. Although each of these effects have been considered separately in previous studies, we show that it is important to consider them together in order to obtain more meaningful inversion results. Our results suggest that the discretization of the source, the use of dispersive waves, and accounting for finite source duration (and variable rupture velocity) are all important factors in tsunami source inversion of large events such as the Tohoku earthquake, and in particular, when an extensive set of high quality tsunami waveform recordings are available. For the Tohoku event, a dispersive model with variable rupture velocity results in a profound improvementin waveform fits that justify the higher source complexity and provide a more realistic source model.

Joint Inter-Association Symposium

JP05e - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-5487

Losses due to historical tsunamis in the European-Mediterranean region

G.A. Papadopoulos[1], *G. Diakogianni*[1], *A. Fokaefs*[1], *A. Papageorgiou*[1],
I. Triantafyllou[1]
[1]*National Observatory of Athens, Institute of Geodynamics, Athens, Greece*

We have compiled a new tsunami catalogue covering the entire European and Mediterranean region from pre-historical times up to the present. The catalogue is of increased completeness and homogeneity with respect to previous ones containing more than 370 events with reliability assignment to all the events listed. In association to the catalogue, an inventory of tsunami impact was created with the main attributes being the numbers of people killed and injured, the damage to buildings, vessels, cultivated land and to other property, including also environmental tsunami impact. The tsunami impact was studied in space and time. In space, it was quantified and mapped in terms of tsunami intensity, in the 12-point Papadopoulos-Imamura scale, and impact zones were determined. The time distribution of the tsunami impact was examined for each one of the impact zones. It was found that the main impact comes from extreme, earthquake tsunamigenic events, such the ones of AD 365 in Crete, 551 in Lebanon, 1303 in Crete, 1755 in Lisbon. However, high impact may also occur from events of lower magnitude, such as the 1908 tsunami in Messina straits and the 1956 tsunami in the South Aegean, which underlines the strong dependence of the impact on the community exposure. Another important finding is that the cumulative impact of relatively moderate or even small, local tsunamis, produced by earthquakes, landslides or volcanic activity, is quite important and that such distributed tsunami impact should not be neglected in actions undertaken for the tsunami risk mitigation. This research is a contribution to the EU-FP7 tsunami research project ASTARTE (Assessment, Strategy And Risk Reduction for Tsunamis in Europe), grant agreement no: 603839, 2013-10-30.

Joint Inter-Association Symposium

JP05e - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-5565

Historical tsunamis in the Island volcanic complex of Thera (Santorini), Greece

I. Triantafyllou[1], *E. Nomikou*[2], *G.A. Papadopoulos*[3]
[1]*National Observatory of Athens, Insitute of Geodynamics, Athens, Greece*
[2]*University of Athens, Faculty of Geology and Geoenvironment, Athens, Greece*
[3]*National Observatory of Athens, Institute of Geodynamics, Athens, Greece*

The volcanic eruptions in the island complex of Thera (Santorini), including the extra-caldera submarine volcanic ediffice of Columbo, have taken a long historical record after the pre-historic giant Plinian eruption of 17th century BC, which generated the large so-called Minoan tsunami documented from tsunami sediment deposits and archaeological evidence in the eastern Mediterranean basin. Several post-Minoan historical eruptions were documented, the first being in 197 BC and the last occurring on AD 1950. Although some of them were associated with sea disturbances no clear evidence is available for tsunami generation. A characteristic exception was the AD 1649-1650 Kolumbo eruptive activity which during its paroxysmal phase generated a large, destructive tsunami that affected a large area of the South Aegean Sea in 30 September 1650. We have compiled a series of original documentary sources describing the Kolumbo eruptive activity of 1649-1650 and its associated phenomena. We found that a second, smaller tsunami was generated on December 1650, which is not included in the tsunami catalogues available. On the basis of the documentary sources the impact of the large 30 September 1650 tsunami was mapped with the use of GIS technology while the tsunami impact was quantified in the terms of tsunami intensity in 12-point scale. Our results are useful for studies aiming to better understand tsunami generation and organize mitigation of tsunami risk in the area. This research is a contribution to the EU-FP7 tsunami research project ASTARTE (Assessment, Strategy And Risk Reduction for Tsunamis in Europe), grant agreement no: 603839, 2013-10-30.

Joint Inter-Association Symposium

JP05f - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-3228

Generation of meteotsunamis in south-western Australia due to the passage of frontal systems

C. Pattiaratchi[1], *S. Wijeratne*[1], *A. Salehi*[1]
[1]*The University of Western Australia,*
School of Civil- Environmental and Mining Engineering & The UWA Oceans Instit ute, Nedlands, Australia

Meteotsunamis are water level oscillations with similar characteristics to tsunami waves generated by seismic activity but are generated by meteorological events, and in particular, moving pressure disturbances due to squalls, thunderstorms, frontal passages, and atmospheric gravity waves. In this presentation we examine meteotsunamis generated along south-west Australia generated by passage of frontal systems. The region is impacted anticyclones which move from west to east and cross the coast every 3-10 days throughout the year with ~30 mid-latitude depressions and associated frontal systems impacting the coast during the winter months. Previous studies have indicated that meteotsunamis are a regular occurrence with those generated during winter to passage of cold fronts. A meteotsunami event due to the passage of a cold front contributed to the highest ever water level recorded at Fremantle in 2012. Similarly an incident where a ship broke moorings and impacted on a railway bridge was attributed to a meteotsunami generated by a cold front in 2014. Analysis of local water level records for 2014 revealed that there were > 30 events which could be classified as meteotsunamis with the majority occurring during the winter months associated with the passage of cold fronts. Time-frequency diagrams indicated that during the passage of a cold front the whole spectrum is energised similar to those observed during seismic tsunamis. The meteotsunami events are compared with simultaneous meteorological data, including the magnitude of the pressure jumps, speed and direction and are examined to identify the dominant parameters responsible for the generation of meteotsunamis.

Joint Inter-Association Symposium

JP05f - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-3293

A widespread Mediterranean/Black Sea meteotsunami of 23-27 June 2014: Observations and assessment of atmospheric processes

J. Sepic[1]*, I. Vilibic*[1]*, A. Rabinovich*[2]*, S. Monserrat*[3]
[1]*Institute of Oceanography and Fisheries, Physical Oceanography Laboratory, Split, Croatia*
[2]*P. P. Shirshov Institute of Oceanology, Tsunami laboratory, Moscow, Russia*
[3]*University of the Balearic Islands, Department of Physics, Palma de Mallorca, Spain*

A number of destructive tsunami like events occurred in the Mediterranean and Black Sea regions during the period of 23 to 27 June 2014. First location to be struck was Ciutadella Harbour (the Balearic Islands, Spain), where 1-m high oscillations were observed on 23 June. Two days later (25 June), four bays in the Adriatic Sea were hit by tsunami waves with wave-heights of up to 3 m, and, on the same day, a phenomenon locally known as 'marrubbio' occurred on the western coast of Sicily: a strong tidal bore with wave heights of >1.5 m propagated inside the Mazara River inlet, damaging moored vessels. Finally, at the midday of 27 June, a sudden tsunami-like wave swept beaches in Odessa, the Black Sea (Ukraine), injuring a number of people. All of the events were correlated and found to be associated with abrupt air pressure changes of ~2 hPa/5 min.

A comprehensive in-depth study was carried out to determine key elements, including coverage, duration, intensity and source mechanism of the observed events. Atmospheric surface observations, upper air sounding data, satellite imaginary, reanalysis models, and tide gauge data were examined, and ocean numerical models were applied to simulate the events and reproduce their physical parameters. A unique meteotsunamigenic synoptic pattern was found propagating eastward over South Europe in accordance with onset times of the events. The observed pattern supported the generation and propagation of ducted atmospheric gravity waves, which resonantly excited sea level oscillations throughout the Mediterranean and the Black Sea. The dependence of sea level response to a number of parameters, including topography, bathymetry, and propagation parameters of atmospheric gravity waves was determined and investigated.

Joint Inter-Association Symposium

JP05f - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-3359

A new technique for tsunami numerical simulation using tsunami observations in a source region as an input

Y. Tanioka[1]
[1]*Hokkaido University, Institute of Seismology and Volcanology, Sapporo, Japan*

After the 2011 devastating Tohoku-oki tsunami, improvement of tsunami warning system is one of key issues in Japan. Japanese government is decided to install 125 ocean bottom pressure sensors and seismometers with a cable system along the Japan and Kurile trench. More than 50 sensors have already been installed off Boso to Sanriku. We should take an advantage using those data for real-time tsunami forecast.
Although the tsunami is generated by coseismic deformation due to a large earthquake, sensors on the top of tsunami source area do not observe a large vertical coseismic deformation. They observes a tsunami wave when it starts to propagate. In this paper, a new technique, which uses the observations at a network of pressure sensors on the tsunami source area as an input to compute the tsunami, is presented.
In this technique, a time derivative of observed heights at sensors are used as an input to compute the tsunami. Actual tsunami heights at the sensors on the source area is difficult to know immediately because the cosismic vertical deformation is unknown. However, we observe directly the time derivative of tsunami heights at the sensors.
Equations of finite difference schemes using linear long wave equations with a staggered grid system are transformed. So, time derivatives of tsunami heights at each grid are used as inputs. Then we can numerically compute a tsunami using a traditional finite difference technique. The technique was tested using the synthetic tsunami waveforms computed using 5 minutes grid system off Tohoku. Time derivatives of tsunami heights in 30 X 30 grids are used as an input to compute tsunami instead of coseismic deformation or ocean surface deformation. The results may be good enough for tsunami forecast.

Joint Inter-Association Symposium

JP05f - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-3593

Landslide on the eastern slope of Sakhalin Island as a possible tsunami source

E. Kulikov[1], *A. Ivanova*[1], *I. Fine*[2], *B. Baranov*[1]
[1]*P.P.Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia*
[2]*Institute of Ocean Sciences, Department of Fishery and Oceans, Sidney, Canada*

During marine research expedition provided in the frame of the Japanese-Korean–Russian Project, Sakhalin Slope Gas Hydrates (SSGH), a large (of about 4 km^3) submarine landslide located in the central part of the eastern slope of Sakhalin Island was found and mapped. The age of the landslide is estimated to be less than 300 years. Underwater slope failures of such magnitude could certainly induce a strong tsunami. Based on the sediment mass distribution, we estimated the initial position of the slide body of intricate shape with approximate dimension of 6*7 km and mean thickness ~80 m. A modified and corrected version of the viscous slide model of Jiang and LeBlond (1994) was used to numerically simulate the slide-generated tsunami and to estimate the maximum tsunami wave amplitudes along the coast of Sakhalin Island. It was shown that such landslide and associated tsunami is a real threat for coastal infrastructure and gas/oil pipelines located in this region.

Joint Inter-Association Symposium

JP05f - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4651

Long-term drift characteristics of ocean-bottom pressure sensors of DONET

H. Matsumoto[1], E. Araki[1], K. Kawaguchi[1], K. Ariyoshi[2]
[1]JAMSTEC, R&D Center for Earthquake and Tsunami, Yokosuka, Japan
[2]JAMSTEC, R&D Center for Earthquake and Tsunami, Yokohama, Japan

DONET, i.e., the dense ocean-floor network system for earthquakes and tsunamis has started its operation in the Nankai Trough, SW Japan in the early of 2010. DONET in 20 observatories consists of various geophysical sensors such as broadband seismometer, seismic accelerometer, tsunami meter, and so on. The present study focuses on pressure sensors being used as tsunami meters measuring hydraulic pressure change. Pressure sensors specify their performance for both hysteresis and repeatability, however there is no specification about the long-term sensor's stability. It has been long known that pressure sensor appears sensor's drift with its operation time. We processed the acquired data in order to evaluate the sensor's drift since deploying into the deep-sea by removing tide component, which indicates that the sensor's drift is lasting after the deployment. Assuming that the pressure sensor's drift is dominated by the exponential trend followed by the linear trend, our drift fitting suggests two-thirds DONET pressure sensors are still on-going at the initial exponential drift stage. Each science node connects with four observatories nearby in DONET, the pressure deviations from four averaged records make it possible to derive more accurate long-term sensor's drift. Thus processed pressure sensor's drift rate has been confirmed to be 5 hPa per year in the current stage. Our results contribute to the quantitative interpretation for interplate coupling along the subducting plate boundaries.

Joint Inter-Association Symposium

JP05f - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4865

The influence of sediment source, inundation path, and deposition site on tsunami deposit characteristics

Y. Nishimura[1], *Y. Nakamura*[1]
[1]*Institute of Seismology and Volcanology, Hokkaido University, Sapporo, Japan*

Spatial distribution and sedimentary features of tsunami deposits are controlled by environmental settings where erosion and deposition occurred by the tsunami. In coastal wetland at cold districts, a local topographic high is created where grasses are denser, which is called tussocks or Yachibouzu in Japanese. We studied sandy paleotsunami deposits that thickened and thinned in response to the vegetation-induced microtopography in such wetland in Hokkaido, northern Japan, where large tsunamis caused by earthquakes along the Kuril trench are known to have impacted repeatedly. The upper boundaries of these deposits were relatively flat but the lower ones varied with a wavelength of approximately of 50cm to 1m. These wavelengths are similar to the microtopography created in the present wetland, causing an uneven lower boundary. The spatial variation in grain size is also affected by the original surface undulation: the grain size characteristics of the deposits on the seaward and landward sides of a buried tussock show the different pattern. On the other hand, the thickness and grain size pattern is quite different from paleotsunami deposits formed on flat, non-vegetated surfaces, which typical varies in thickness from 2 to 10cm and have a sheet-like geometry without substantial variation in grain size. These are commonly observed for tsunami deposits older than the10th century when the area was not cold enough to develop tussocks. This is a good example of how the features of tsunami deposits are controlled by local environmental settings at the time the tsunami impact the coastal area.

Joint Inter-Association Symposium

JP05g - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-1357

Assessment of Beidou/GPS combined precise positioning and its potential contribution to tsunami early warning in South China Sea

K. Chen[1], *A. Babeyko*[1], *N. Zamora*[1], *M. Ge*[2]
[1]*German Research Centre for GeosciencesGFZ, section 2.5, Potsdam, Germany*
[2]*German Research Centre for GeosciencesGFZ, section 1.1, Potsdam, Germany*

Around the end of 2012, China has completed the constellation of the regional Beidou Navigation Satellite System (BDS) and the system is running operationally since then. Due to the similar signal structures and frequencies compared with Global Positioning System (GPS), BDS provides a good opportunity to investigate the impact of multi-GNSS capacity on real-time precise positioning in terms of accuracy and reliability.

South China Sea (SCS) has been identified as a region of potential tsunami hazard because of the Manila subduction zone. Despite the fact, that no earthquake higher than Mw7.6 has occurred in this region during last years, events of higher magnitudes cannot be excluded which could expose SCS to the tsunami risk. The devastating Great Sumatra 2004 and Tohoku 2011 earthquakes and following tsunamis have reminded us the imperfection of existing Tsunami Early Warning Systems(TEWS). For these tragedies, it was confirmed that saturation and tilt of traditional seismic instruments which caused the underestimate of earthquake magnitude in the very first minutes were mainly to blame. Since GNSS measures arbitrary displacements in almost real-time, in-cooperating continuous GNSS-arrays into TEWS is now an active area of research.

In this study, on one hand, we concentrated on precise positioning using BDS, BDS/GPS observations.Improvement in integer ambiguity resolution, convergence, accuracy and reliability by the integrating BDS will be investigate. One the other hand, we use numerical simulation technique to assess the potential of combined positioning for TEWS in SCS. We suggest deployment of a real-time BDS/GPS coastal network at the Luzon Island. Such a network, if established, will effectively contribute to fast source inversion at the Manila trench.

Joint Inter-Association Symposium

JP05g - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-3957

NOAA/NGDC global water-level data in support of tsunami research

G. Mungov[1]*, K. Stroker*[1]*, A. Sweeney*[1]*, M. Eblé*[2]*, R. Bouchard*[3]
[1]*NOAA National Geophysical Data Center, Marine Geology and Geophysics, Boulder- CO, USA*
[2]*NOAA Pacific Marine Environmental Laboratory,*
National Center for Tsunami Reserch, Seattle- WA, USA
[3]*NOAA National Data Buoy Center, Engineering Branch,*
Stennis Space Center- MS, USA

The National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDC) is responsible for quality-controlled, high-resolution water level data stewardship in support of informed decisions to minimize tsunami impact to coastal communities. Applications of these data include, but are not limited to, tsunami and storm-surge inundation, open- and coastal-ocean dynamic modeling, sea-level change, and climate variability. As the World Data Service for Geophysics, NGDC processes, archives, and distributes high-resolution (15-second) bottom pressure recorder data and associated run-ups observed during global historic tsunami events, including data recorded by Deep-ocean Assessment and Reporting of Tsunami (DART®) pressure gauges, coastal tide-gauges, and historic marigraphs, as well as bathymetries and data observed during other relevant hazards. Since 2008, NGDC has archived and served as stewards for coastal tide-gauge data collected by both the NOAA National Ocean Service (NOS) and NOAA's two Tsunami Warning Centers (TWCs). The NGDC data repository is maintained in close collaboration with NOAA's National Data Buoy Center and NOAA's Pacific Marine Environmental Laboratory. Here, we present an overview of the NGDC database, provide summary information on data availability, data resolution, data processing methodology, and variations in data quality within different geographic regions for several recent tsunami events. We provide a description of the data products subsequently distributed by NGDC: DART® bottom pressure internally recorded 15-second and 1-minute real-time data, and 1-minute and 15-second coastal tide-gauge data, segments with recorded tsunamis. A brief description of NGDC tsunami event web pages is also presented.

Joint Inter-Association Symposium

JP05g - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4567

Comparison of GPS based and DART based tsunami measurement systems

M. Lavrentiev[1], *A. Romanenko*[1], *E. Goriounov*[1]
[1]*Novosibirsk State University, Information Technologies, Novosibirsk, Russia*

There are a number of approaches to evaluate the initial see-face disturbance (using knowledge about the trench geo structure, satellite imaging, etc.). One of perspective approaches is to recalculate tsunami wave profiles, recorded by deep-ocean stations like DART buoys or GPS equipment, in terms of initial sea surface displacement.

Questions of performance optimization of the so-called preliminary calculation strategy is discussed. This approach (proposed by V. Titov) suggests that the targeted subduction zone is covered by a number rectangular “unit sources” 50x100 km. Wave propagation from each unit source, caused by the unified shape (typical for the given subduction zone), is calculated in advance other the entire aquatoria. After real event the wave profile, measure at certain sensor, is approximated as linear combination of model signals from the above unit sources, calculated at the same point. Method was proved to be rather accurate. However, it takes valuable time to recover initial displacement at tsunami source in case of larger zone of disturbance (e.g. about 20 minutes for processing tsunami epicenter covered with six unit-sources).

Based on numerical experiments we compare two sensor networks (one based on deep-ocean pressure recorders, like DART buoys, and GPS-based surface sensors) in view of time, required to measure the tsunami wave. Automated fast algorithm for the tidal component filtering is discussed as well.

The target goal is to achieve performance of 12-15 minutes to calculate the tsunami wave parameters at 2000x2000 km water area.

Joint Inter-Association Symposium

JP05g - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-5261

From Sumatra 2004 to Tuhoku-Oki 2011: what we learn about Tsunami detection by ionospheric sounding.

G. Occhipinti[1], *L. Rolland*[2], *S. Watada*[3], *P. Coisson*[4], *P. Lognonné*[1], *H. Hebert*[5], *J. Makela*[6]
[1]*Institut de Physique du Globe de Paris, Planetology and Space Science, Paris, France*
[2]*Geoazur- Nice, Dynamique des Failles et des Séismes, Nice, France*
[3]*Earthquake Research Institute, Ocean Hemisphere Research Center, Tokyo, Japan*
[4]*Institut de Physique du Globe de Paris, Geomagnetisme, Paris, France*
[5]*Commissariat Energie Atomique CEA, DASE, Paris, France*
[6]*University of Illinois, DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, Urbana, USA*

The recent tsunamigenic Tohoku earthquake (2011) strongly affirms, again, after the 26 December 2004, the necessity to open new paradigms in oceanic monitoring. Ionospheric anomalies related to the Sumatra tsunami (e.g., Occhipinti et al. 2006) demonstrated that ionosphere is sensitive to earthquake and tsunami propagation. Observations supported by modelling proved that tsunamigenic ionospheric anomalies are deterministic and reproducible via the ocean/atmosphere/ionosphere coupling (Occhipinti et al., 2008). Tsunami signature in the ionosphere is routinely detected, we show here perturbations of total electron content (TEC) measured by GPS and following tsunamigenic eartquakes from 2004 to 2010 (Rolland et al. 2010, Occhipinti et al., 2013), nominally, Sumatra (26 December, 2004 and 12 September, 2007), Chile (14 November, 2007), Samoa (29 September, 2009) and Tohoku-Oki (11 Mars, 2011). The Tohoku-Oki event has been measured by GPS/TEC observations close to the epicenter with the dense GEONET network, as well as by Airglow camera in the far-field clearly showing the ionospheric tsunami signature over Hawaii (Occhipinti et al., 2011). Based on the observations close to the epicenter, mainly performed by GPS networks located in Sumatra, Chile and Japan, we highlight the TEC perturbation observed within the first hour after the seismic rupture. This perturbation contains informations about the ground displacement, as well as the consequent sea surface displacement resulting in the tsunami. In this talk we present all this new tsunami observations in the ionosphere and we discuss, under the light of modelling, the potential role of ionospheric sounding in the oceanic monitoring and future tsunami warning system. All ref. @ www.ipgp.fr/~ninto

Joint Inter-Association Symposium

JP05g - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-5309

Mapping palaeotsunami inundation and finding recurrence interval using ground penetrating radar and optically stimulated luminescence

R. Premasiri[1], P. Styles[2], V. Shrira[3], J.L. Schwenninger[4], N. Cassidy[5]
[1]Moratuwa University, Faculty of Engineering, Colombo, Sri Lanka
[2]Keele University, School of Geography- Geology and the Environment, Newcastle-under-Lyme, United Kingdom
[3]Keele University, Department of Mathematics, Newcastle-under-Lyme, United Kingdom
[4]University of Oxford, School of Archaeology, Oxford, United Kingdom
[5]Keele University, School of Geography- Geology and the Environment, Newcastle-under-Lyme, United Kingdom

Reconstruction of magnitudes and dates of past events is a promising route towards evaluation and, hence, mitigation of tsunami hazard. To this end coastal sediments deposited by tsunamis (tsunamites) are intensively studied. Of the three key elements needed for palaeotsunami reconstruction (identification, dating and magnitude determination) the latter remains the most difficult. There is no established method of estimating tsunami amplitude or extent of inundation exists. By analysing tsunamites from Sri Lanka identified using sedimentological and paleontological characteristics, we show that their dielectric properties differ significantly from those of surrounding sediments. This allows us to use ground penetrating radar (GPR) to trace their extent and morphology. In this pilot study we used GPR in two locations to trace four major palaeotsunamis for at least 400m inland (constrained by inaccessible security zones). We assume the subsurface extent of tsunamites (not available without extensive excavation) to be a good proxy for inundation. The deposits were dated using Optically Stimulated Luminescence (OSL), yielding ages of circa 130, 2200, and 3200B.P. GPR strongly indicates deeper, older events, not yet been sampled and dated. This non-invasive method of GPR/OSL-based reconstruction of palaeotsunamis enables mapping of tsunami inundation and estimation of recurrence for any sandy coast with identifiable tsunamigenic deposits.

Joint Inter-Association Symposium

JP05g - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-5334

On the tsunami-generated electromagnetic fields: Its properties and application to tsunami early warning

H. Toh[1], *T. Minami*[1], *I. Kawashima*[1]
[1]*Kyoto University, Earth and Planetary Sciences- Graduate School of Science, Kyoto, Japan*

It has been found that tsunamis generate detectable electromagnetic (EM) fields (Toh et al., 2011). This is a necessary result from coupling of particle motions, v, of the electrically conducting seawater with the weak but significant geomagnetic main field, F. The primary electromotive force is generated by the Lorenz force, v x F, to form source electric currents that propagate across the ocean with tsunami wave fronts. The secondary magnetic field can be created not only by the source currents but also by induced electric fields in the ocean because tsunami phase velocities are too fast to neglect the self-induction effect of the created magnetic field.

In 2006, 2007 and 2011, the tsunami-generated EM fields were successfully recorded by a seafloor EM station installed in the northwest Pacific basin. The data show significant variations in the vector geomagnetic field as well as the horizontal geoelectric field well after the seafloor station's tiltmeter ceased recording ground motions caused by seismic waves. Judging from the epicentral distances of the three tsunamigenic earthquakes to the seafloor station, all the EM variations were found to coincide with the arrivals of not seismic but tsunami waves, which made negligible tilts of the seafloor station.

Here we report properties of the tsunami-generated EM fields observed at the time of the three tsunami events. It was found that the tsunami-generated vertical magnetic component is a proxy of the tsunami wave height with 10- to 90-degree phase leads to the maximum wave height. Furthermore, the tsunami-generated horizontal magnetic components found to emerge well before the tsunami arrivals because of the induced electric field in front of the first tsunami wave. These properties are of use to tsunami early warning.

Joint Inter-Association Symposium

JP05h - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-0512

Physical modelling of tsunami generation and propagation in a large-scale experimental facility

I. Didenkulova[1], *S. Schimmels*[2], *V. Sriram*[3]
[1]*Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Applied Mathematics, Nizhny Novgorod, Russia*
[2]*Forschungszentrum Küste, FZK, Hannover, Germany*
[3]*Indian Institute of Technology Madras, Department of Ocean Engineering, Chennai, India*

In this paper we study very long, i.e. real tsunami-like wave generation in a large-scale wave flume using a piston type wave maker. Waves of periods between 30 s and more than 100 s were generated at 1 m water depth using two different approaches: (i) deriving the wave board motion directly by integration of the water surface elevation, composed of a different number of solitons (sech2 waves) and (ii) using an iterative self correcting method (SCM).The importance of very long wave generation instead of solitary waves and the necessity for large-scale testing facilitiesis is discussed. Results from GWK experiments are presented. They include single pulses (elongated solitons), N-waves and real tsunami records, either approximated as a combination of solitons or applying the SCM to the time series directly.The possibility to study propagation, shoaling and run-up of these waves over a slope in a 300-meter long large wave flume (GWK), Hannover is also discussed. Experimental data of long wave propagation in the flume are compared with numerical simulations performed within the fully nonlinear potential flow theory and KdV equations. Shoaling and run-up of waves on different mild slopes is studied hypothetically using nonlinear shallow water theory. The paper ends with the conclusions about the feasibility of using large scale experimental facility (e.g. GWK) to study tsunami wave propagation and run-up.

Joint Inter-Association Symposium

JP05h - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-1335

Observational support for the IPRC model simulations of marine debris transport from the 2011 Japan tsunami

J. Hafner[1], *N. Maximenko*[1], *G. Speidel*[1]
[1]*University of Hawaii at Manoa, IPRC/SOEST, Honolulu, USA*

Marine debris is recognized as an increasing threat to the environment. Yet, our knowledge of marine debris impacts, transport, and dynamics is still incomplete. This study is based on simulation of marine debris movement from the 2011 tsunami in Japan across the North Pacific Ocean.The IPRC's SCUD model of ocean surface currents, based on trajectories of real drifting buoys, is employed. The model is forced by satellite-observed surface winds and sea level data. The resulting diagnosed currents are applied to calculate the motion of the floating tsunami debris. The direct effect of wind is included to account for transport differences depending upon debris-shape and buoyancy.Model tracer maps provide comprehensive visualization of debris advection, dispersion, and wind-induced sorting. Because of the scarce and fragmentary observations and unknown initial debris amount and composition, direct model validation is not possible. However, the timelines of tsunami debris arrivals, reported from different segments of the US/Canada West Coast and from Hawaii, are consistent with the model solution. Differences between compositions of debris in different areas are also consistent with the model windage parameter.In our presentation, we will discuss model applications to identify tsunami debris aggregation areas, its fate, threat to navigation, and cross-ocean pathways for potentially dangerous alien species.

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IUGG-2333

Detecting tsunami inside the source region by ocean-bottom pressure: a theoretical study

T. Saito[1]
[1]*National Research Institute for Earth Science and Disaster Prevention, Earthquake and Volcano Research Unit, Tsukuba, Japan*

After the 2011 Tohoku-Oki earthquake, a new tsunami observation project started offshore northeastern Japan, in which ~150 ocean-bottom pressure gauges are to be deployed across the source area of tsunamigenic earthquakes that could possibly occur in future. This nearfield observation is totally different from the traditional ones that detect tsunami distant from its source region. Since tsunami records inside the focal area are significantly contaminated by ocean-acoustic wave and dynamic/static sea-bottom deformation, we cannot correctly estimate the tsunami source if conventional methods are directly used in analyzing these records. In order to clarify the contributions of the acoustic wave and sea-bottom dynamics on the tsunami records, this study numerically simulated the tsunami generation from the earthquake rupture inside the elastic earth including the coupling effects between fluid ocean and elastic earth medium. Past studies employed a simple relation p = rho a h between the sea-bottom pressure and the sea-bottom motion for interpreting ocean-bottom pressure records (e.g. Filloux 1982 GRL), where p is the pressure generated by dynamic sea-bottom deformation, a is the acceleration of the sea bottom, rho is the water density, and h is the sea depth. However, our simulation results proved that this relation cannot always be valid but needs to be extended by using an analytical solution of an incompressible fluid theory (Saito 2013 EPS). We found that a spatial filtering of tanh (kh)/ kh in the wavenumber domain k reproduced the simulation results better than the simple relation in the past studies.

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IUGG-5139

Tsunami debris boats forge Japan – US connection and foster tsunami education efforts

L. Dengler[1], *A. Miller*[2]
[1]*Humboldt State University, Geology, Arcata, USA*
[2]*City of Rikuzentakata, Public Information, Rikuzentakata, Japan*

An estimated 1.5 million tons of debris were caught the Pacific-wide gyre system following the March 2011 tsunami. Debris began arriving on the West Coast of North America in spring 2012 and more than 2000 possible tsunami debris sightings have been reported to NOAA's tsunami debris web site since then. About fifty items have been verified as tsunami debris including two boats that landed on California's North Coast. In April 2013 a boat belonging to a high school in Rikuzentakata beached in Crescent City. Through the efforts of a group of California High School students, diplomatic efforts, and donations, the boat was returned to Japan in October 2014. The boat has become a celebrity in both the United States and Japan, featured in a Facebook film and now housed in Tokyo's National Museum. It has forged student exchanges and a sister school relationship between the high schools and communications between the two tsunami-vulnerable cities. A second boat landed about 60 km south of Crescent City in June 2014. It was linked to Miyagi Prefecture and is now being used by the Redwood Coast Tsunami Work Group as education tool to increase understanding of earthquakes, tsunamis, ocean currents and debris and an understanding of our cross-Pacific linkages. Both boats are functioning as "social objects". Social media marketing researchers have identified social objects as items that spark a common chord in people and make them want to interact with others and facilitate "milling", an essential first step in taking preparedness actions.

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IUGG-5339

Earthquake-generated tsunami modelling through a pre-calculated database of uniformly-spaced elementary sources: validation and potential applications for the Mediterranean Sea

R. Tonini[1], *I. Molinari*[1], *S. Lorito*[1], *A. Piatanesi*[1], *F. Romano*[1], *D. Melini*[1], *J.M. Gonzalez Vida*[2], *J. Macias*[3], *M. Castro*[3], *M. de la Asuncion*[3]
[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Roma 1, Roma, Italy*
[2]*Universidad de Málaga, Dpto. Matemática Aplicada, Malaga, Spain*
[3]*Universidad de Málaga, Dpto. Análisis Matemático- Facultad de Ciencias, Malaga, Spain*

Databases of pre-calculated tsunami waveforms can represent a useful platform for several applications, such as real-time tsunami forecast, probabilistic tsunami hazard assessments, and inversion for the tsunami source. The effectiveness of the results of these applications depends on how these databases have been designed in order to avoid biases and minimize the introduced uncertainty. Here we present and discuss the reliability of a database of pre-calculated tsunami waveforms developed for the Mediterranean Sea. We select ~13,000 forecast points (i.e., tsunami receivers) equally spaced (~2 km) along the 50 metres isobaths. For each of them, we store the waveforms obtained from the propagation of a large set (~53,000) of uniformly-spaced (~7 km) elementary sources. These elementary sources are represented by Gaussian-shaped initial conditions (sigma=4 km) which have been properly set in order to reproduce by linear superposition any tsunami initial condition generated by earthquakes with Mw >= 6.5, and hence the tsunami waveforms and maxima at the forecast points. Tsunami propagation is modelled with HySEA, a GPU finite volumes solver for the shallow water equations developed by EDANYA group at University of Malaga. The database will be used by Italian candidate Tsunami Service Provider based at the 24/7 monitoring room at INGV in Rome, in the framework of the NEAMTWS, and for the Italian hazard map for earthquake-generated tsunamis. The overall procedure is tested by comparing its results with the ones obtained for a set of tsunami scenarios conveniently selected to explore the limits of this approach and quantify the introduced uncertainty.The research is funded by the Italian flagship project RITMARE and by the EU project ASTARTE (FP7-ENV2013 6.4-3, Grant 603839).

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IUGG-5426

Unusual amplification of tsunami waves in Seaquake Inlet

I. Fine[1], *J. Cherniawsky*[1], *E. Kulikov*[2]
[1]*Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, Canada*
[2]*P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia*

According to the post-tsunami surveys carried out after the 2012 Haida Gwaii earthquake (Leonard and Bednarski, 2014), tsunami wave run-up heights inside Seaquake Inlet on the west coast of Moresby Island, were up to 13 m high. Such relatively large run-up is way above the other run-up measurements on this coast. To verify that this feature is related to the specific properties of the inlet, an autonomous bottom pressure recorder was deployed inside the inlet during the winter and spring of 2013/2014. The observed background noise inside the inlet showed strong resonance in the tsunami frequency band. This instrument also clearly recorded the 01 April 2014 northern Chilean tsunami, with a maximum wave height of more than 40 cm, significantly higher than recorded by any other coastal tide gauge within a 1000-km distance, which can only be attributed to resonant characteristics of the inlet. These were estimated using a special numerical technique, which showed that the response of the inlet to the incoming waves is determined by its main fundamental mode, with very high amplification at or near its resonance frequency. Additional numerical experiments were carried out to estimate contributions to the high amplification from various geometrical factors, such as the inlet shape, its depth profile, or the influence of the nearby shelf. These experiments have demonstrated that the two-dimensional effects also play a significant role in the unusual resonant properties of this inlet.

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JP05i - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-2382

Uncertainty on seismic sources and bathymetry for tsunami modelling

D. Imbert[1], E. Antoshchenkova[2], A. Gailler[1], H. Hébert[1]
[1]CEA, DAM/DIF, ARPAJON CEDEX, France
[2]IRSN, PRP-DGE, FONTENAY-AUX-ROSES CEDEX, France

We show and quantify connections between the uncertainty on specific geological parameters of the generation process of tsunamis, numerical bathymetric parameters and the inundation hazard due to tsunamis. Our work is part of the French project TANDEM which aim is to provide guidance for Tsunami risk assessment on the Atlantic Ocean coastlines. Within this framework, we couple our software (Calypso), which models tsunamis due to earthquakes, and the Promethee software (http://promethee.irsn.org), which propagates uncertainty through numerical models. On one hand, Calypso uses Okada's analytic formulation to model the water surface deformation due to earthquakes in order to generate the tsunami. Then, either the shallow water equations, or Boussinesq equations, are discretized using the finite difference method to propagate the tsunami towards the coast. On the other hand, Promethee is used to propagate sources of uncertainties through the physical model and to perform a global sensitivity analysis. To do so, it runs and analyses a large number of simulations while changing parameters to examine all possible scenarios of the tsunami propagation. We present a preliminary uncertainty analysis of Okada's model parameters such as location, dimensions, orientation of the rupture zone, or shear modulus. We also quantify the effects of the numerical (x,y) and topographic (z) precision of bathymetric grids on the uncertainty of relevant output data for the tsunami warning such as synthetic gages recordings or the maximum water height at the coast. Our study reveals the importance to take into account the uncertainty when estimating the tsunami hazard.

Joint Inter-Association Symposium

JP05i - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-3725

Development of multifunction simulation code for an understanding of comprehensive tsunami phenomena

T. Baba[1], *K. Ando*[2], *T. Kato*[3], *A. Sebastien*[4], *P. Cummins*[5], *H. Tsushima*[6], *Y. Hayashi*[7]
[1]*The University of Tokushima, Tokushima, Japan*
[2]*JAMSTEC, CEIST, Kobe, Japan*
[3]*NEC, -, Tokyo, Japan*
[4]*ANU, Research School of Earth Science, Canberra, Australia*
[5]*ANU, Research School of Earth Sciences, Canberra, Australia*
[6]*MRI, Seismology and Tsunami Research Department, Tsukuba, Japan*
[7]*MRI, Seismology and Tsunami Research Departmen, Tsukuba, Japan*

The shallow water model used in general tsunami simulation does not include dispersive effects, such as frequency dispersion apparent in the far-field and undular bore formation near the coast. The tsunami travel time and the first withdrawal recorded at far-field stations can also not be predicted well with the simple shallow water model. However, these phenomena were clearly observed during the 2010 Maule, Chile (M8.8) and the 2011 Tohoku, Japan (M9.0) tsunamis. Dispersion can be modelled with the Boussinesq model. The arrival time and the first withdrawal can be modelled by considering deformation of the earth due to tsunami loading and sea water density stratification. Therefore, we are developing a multifunction numerical code called JAGURS that can simultaneously simulate these tsunami phenomena. These incur a huge computational cost, so we applied a hybrid parallelized technique using OpenMP and MPI. At writing of this abstract, our new code includes functions to solve the linear or nonlinear shallow water equations, the linear or nonlinear Boussinesq equations with a nesting algorithm, in the spherical or Cartesian coordinates. These were validated with a flume tank experiment and the 2011 Tohoku tsunami. We will continue the development to include the elastic loading and sea water density stratification effects.

Joint Inter-Association Symposium

JP05i - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-4873

Investigation of tsunami hydrodynamic parameters and preparation of inundation maps in gocek, Turkey by 2D and 3D numerical modeling

C. OZER SOZDINLER[1], N. MERAL OZEL[1], T. ARIKAWA[2], O. NECMIOGLU[1], A.C. YALCINER[3], A. ZAYTSEV[4], T. TOMITA[2]
[1]BOGAZICI UNIVERSITY KANDILLI OBSERVATORY AND EARTHQUAKE RESEARCH INSTITUTE, DEPARTMENT OF GEOPHYSICS, ISTANBUL, Turkey
[2]Port and Airport Research Institute, Port and Airport Research Institute, YOKOSUKA, Japan
[3]MIDDLE EAST TECHNICAL UNIVERSITY- OCEAN ENGINEERING RESEARCH CENTER, DEPARTMENT OF CIVIL ENGINEERING, ANKARA, Turkey
[4]Far Eastern Branch of Russian Academy of Sciences,
Special Research Bureau for Automation of Marine Researches, Uzhno-Sakhalinsk Gorkiy, Russia

Eastern Mediterranean has been suffering from destructive earthquakes and tsunamis throughout history in which the evidences and seismic activities necessitate the investigation and monitoring of earthquake and tsunami hazard, and the preparation of mitigation strategies and national resilience plans in Turkey. For this purpose, Kandilli Observatory and Earthquake Research Institute is acting as Regional Earthquake and Tsunami Warning Center in the form of Candidate Tsunami Watch Provider since July 1, 2012 in the framework of ICG/NEAMTWS. One of the activities of this center is the preparation of tsunami inundation maps at coastal locations with high population, touristic and industrial activities or national priority, called Tsunami Forecast Points (TFP).

Gocek town, as one of the TFPs and very popular touristic destination especially for yachtsmen, is selected in this study for the tsunami modeling by using high resolution bathymetric and topographic data with less than 4m grid size including detailly digitized coastline, sea and land structures and earthquake catalogs and historical records as tsunami sources. The tsunami analyses are performed by the numerical codes NAMIDANCE and STOC-CADMAS for the calculations of tsunami hydrodynamic parameters such as wave amplitude, current velocity, flow depth and inundation distance. Froude numbers as tsunami damage indicators and the directions of current velocities inside marinas are solved by NAMIDANCE while STOC-CADMAS determines the tsunami pressure exerted onto the structures with three-dimensional and non-hydrostatic approaches. The results are then used to determine the tsunami inundation and structural resilience and establish the

tsunami preparedness and mitigation plans, accordingly.

Joint Inter-Association Symposium

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IUGG-5058

Experiment on morphology change caused by tsunami intrusion into lake

Y. Mitobe[1], K. Imai[2], Y. Hirakawa[3], T. Takahashi[4]
[1]Tohoku University, Department of Civil and Environmental Engineering, Sendai, Japan
[2]Tohoku University, International Research Institute of Disaster Science, Sendai, Japan
[3]Tohoku University, School of Engineering, Sendai, Japan
[4]Kansai University, Faculty of Safty Science, Takatsuki, Japan

Characteristics of morphology change induced by tsunamis needs to be understood well for the effective use of tsunami deposits to extract information on historical tsunami events. In this study, morphology change in lakes caused by tsunami intrusion is discussed through a hydraulic model experiment. In a horizontal channel of 17 m length, 0.2 mm sand is put behind a fixed mound of 15 cm height with the front slope of 1/30. Still water depth on the sand bed is set to be 2.5 cm as a 1/100 model of a lake. Temporal variation of bed shapes behind the mound under dam-break flow is extracted from video images recorded by a high-speed camera. And three dimensional bed shapes before and after the experiment are measured by an image measurement technique to get horizontal distributions of bed level change. In this technique, object surfaces under color dot illumination from a PC projector are recorded by a digital camera, and three-dimensional coordinates of the color dots reflected on the surfaces are determined with geometrical relationship between the camera and the projector. Rapid development of scour behind the mound was caused by the dam-break flow in all cases. While the erosion was limited in the area near the mound only, deposition was observed in wider area behind the scour. With higher wave condition, the scour behind the mound was deeper and wider. While the deposition area behind the scour was also wider with the higher waves, maximum thickness of the deposit layer was almost constant for the 3 different wave conditions.

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IUGG-5594

Analytical modeling of nonlinear evolution of long-waves

B. Aydin[1], *U. Kanoglu*[2]
[1]*Adana Science and Technology University, Department of Civil Engineering, Adana, Turkey*
[2]*Middle East Technical University, Department of Engineering Sciences, Ankara, Turkey*

We present an initial-boundary value problem formulation for the solution of the nonlinear shallow-water wave (NSW) equations. We transform the nonlinear equations into a linear problem by using the Carrier-Greenspan transformation. Then, we obtain the solution through the separation of variables method rather than integral transform techniques, which is the usual practice (Carrier et al., J Fluid Mech 2003; Kanoglu, J Fluid Mech 2004). This formulation allows the use of any physically realistic initial waveform, with and without initial velocity. We consider propagation of different incident wave profiles over a sloping beach, such as solitary waves and N-waves. Comparison of the results of our model with the existing integral transform solutions (Carrier et al., 2003; Tinti and Tonini, J Fluid Mech 2005; Kanoglu and Synolakis, Phys Rev Lett 2006) demonstrates its versatility.

We then consider the forced NSW equations to model underwater landslides. We introduce approximations to the governing equations, as the forced equations cannot be transformed into a linear governing equation exactly. We solve the resultant equation using both integral transform and separation of variables techniques. We compare our solution with the linear analytical and nonlinear numerical results of Liu et al. (J Fluid Mech 2003) for a deforming Gaussian disturbance on the ocean floor and determine the ranges of different parameters for which the approximate nonlinear theory is valid.

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Joint Inter-Association Symposium

JP05i - JP5 Tsunamis (IAPSO, IASPEI)

IUGG-5762

Caribe wave/lantex caribbean and adjacent regions tsunami exercises

C. von Hillebrandt-Andrade[1],
. CARIBE EWS CARIBE WAVE/LANTEX 2015 Task Team[2]
[1]*NOAA NWS, Caribbean Tsunami Warning Program, Mayaguez, USA*
[2]*UNESCO IOC, Tsunami Unit, Paris, France*

Over 75 tsunamis have been documented in the Caribbean and Adjacent Regions over the past 500 years. While most have been generated by local earthquakes, distant tsunamis also occur. For example, waves from the 1755 Lisbon tsunami were also observed in the Caribbean. Since 1500, at least 4484 people are reported to have perished in these killer waves. The most recent devastating tsunami occurred in 1946 in Dominican Republic; almost 2000 were reported to have died. With the explosive increase in residents, tourists, infrastructure, and economic activity along the coasts, the potential for human and economic loss is enormous. It has been estimated that on any day, upwards of more than 500,000 people could be in harm’s way just along the beaches, with hundreds of thousands more working and living in the tsunamis hazard zones.

Given the relative infrequency of tsunamis, exercises are a valuable tool to test communications, evaluate preparedness and raise awareness. Exercises are conducted under the framework of the UNESCO IOC Intergovernmental Coordination Group for the Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions (ICG CARIBE EWS) and the US National Tsunami Hazard Mitigation Program. On March 25, 2015 the fourth CARIBE WAVE/LANTEX regional tsunami exercise will take place. The CARIBE WAVE/LANTEX 15 scenario will simulate a tsunami generated by a magnitude 8.5 earthquake originating off the Caribbean coast of Panama. For the exercise messages are issued by the US tsunami warning centers to nationally designated Tsunami Warning Focal Points for their evaluation and in some cases, further dissemination. To obtain feedback an online survey is conducted. The results of the past exercises will be presented.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-001

Project GENSAI: A practical application of children's disaster education at school

M. Yasuda[1], *I. Fumihiko*[1], *A. Suppasri*[1], *R. Nouchi*[2], *D. Nguyen*[1]
[1]*Tohoku University, International Research Institute of Disaster Science, Sendai, Japan*
[2]*Tohoku University, nternational Research Institute of Disaster Science, Sendai, Japan*

Children and senior citizens often constitute a significant percentage of casualities in large scale disasters, due to their limited survival capabilities. The Practical Education Program for Improving Response Capabilities, has been proposed by Yasuda et al (2013) at the International Tsunami Symposium in 2013. This program focuses in improving survival capabilities among children via education programs, due to their higher curiosity and faster knowledge absorption which leads to improved disaster response.

In order to survive from disasters and recover, it is imperative to maintain "GENSAI", the Japanese term for disaster reduction and quick recovery. Keeping in mind that larger scale disasters is accompanied by potentially diminished government assistance, the project seeks to improve disaster self-resiliency through the development of survival capabilities. This project includes several educational workshops for children at the higher grade levels of elementary schools, due to their stronger background and interest in science.

The workshop included the participation of nearly 4,000 students from 70 schools in thirteen countries. During the workshop, children were to strategize their post disaster plans utilizing hazard maps and evacuation drills. A survey was conducted before and after the class in order to measure a change in GENSAI awareness among the students. For instance, we discovered that the number of students who discuss disaster awareness and response with their parents increased from 89.6% to 99.3%. If GENSAI awareness is improved for children, they can lead their parents and improve disaster awareness among the entire community.

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JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-002

Comparison of building damage caused by the 2011 Tohoku earthquake tsunami and the 2013 Super Typhoon Haiyan storm surge

A. Suppasri[1], N. Leelawat[2], I. Charvet[3,4], C. Yi[1], F. Imamura[1]
[1]Tohoku University, International Research Institute of Disaster Science IRIDeS, Sendai, Japan
[2]Tokyo Institute of Technology, Department of Industrial Engineering and Management, Tokyo, Japan
[3]Risk Management Solutions, Catastrophe Risk, London, United Kingdom
[4]University College London, Earthquake and People Interaction Centre, London, United Kingdom

Building damage assessment is one of the important issues for coastal management against coastal hazards, i.e. tsunamis and storm surges. This study presents analysis results of building damage data in case of the two major coastal disasters recently, tsunami induced by the 2011 Tohoku earthquake and storm surge by the 2013 typhoon Haiyan. Damage data by the tsunami in Japan was collected from field surveys and includes flow depth, building material, number of stories and occupancy type for about 250,000 buildings. Numerical simulations were conducted to obtain characteristic tsunami measures such as flow velocity. These data were analysed using advanced statistical methods to create fragility functions. The effect of floating debris was also considered by using a binary indicator of debris impact based on the proximity of a structure from a debris source. For the storm surge, we obtained detailed damage data of 166 school buildings in 39 schools from Tananuan municipality, the Philippines. The data contain building area and percentage of damage to roof, ceiling, window, door and wall for each building. The data was then overlaid on the storm surge inundation map created by field surveys and obtain the distance of each building from the sea. The percentage of damage and distance from the sea were plotted in order to compare the damage between the buildings inside and outside the storm surge inundation zone (i.e. wind only vs. wind and surge). Damage from Haiyan is compared to tsunami damage results normalizing the damage scale and comparing damage probabilities. The results bring cross-interdisciplinary benefits not only to coastal engineers to understand the different damage but also to decision makers to decide the no-build zones in case of integrated coastal hazards.

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JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-003

The method for a rough tsunami height estimation based on a ray approach

A. Marchuk[1]
[1]*Institute of Computational Mathematics and Mathematical Geophysics, Tsunami laboratory, Novosibirsk, Russia*

The way-ray approach to tsunami propagation problems assumes the wave energy conservation inside a wave-ray tube (a space between two neighboring wave rays). The method for a wavefront kinematics computation with estimating a tsunami height based on this approach has been developed and tested. The moving tsunami wavefront being built by the orthogonal advance of a limited number of points is located along the wavefront line. Precise algorithms for determining the direction of these points movement and an addition of new ones have been proposed. This method was tested in an area with parabolic and sloping bottom topography. The obtained result of wave front propagation was compared to exact analytical solutions which are obtained for such depth models. The method proposed makes possible to compute not only tsunami travel times but wave rays as well. Tsunami amplitudes can be estimated by the wave-ray divergence and a change in a depth along the wave route. The wave amplitude estimation was tested against the exact solution and the result of the shallow-water numerical modeling of tsunami propagation using the MOST software. A difference in the results between the two methods in the area with a slope-like bathymetry does not exceed a few percent. The main advantages of the method proposed are its rapidness and low computer costs.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-004

Adriatic meteotsunami events of 25-26 June 2014: observations, numerical modelling and assessment of atmospheric processes

J. Sepic[1], I. Vilibic[1], I. Medjugorac[2], M. Telisman-Prtenjak[2], I. Janekovic[3], N. Dunic[1]
[1]Institute of Oceanography and Fisheries, Physical Oceanography Laboratory, Split, Croatia
[2]Andrija Mohorovicic Geophysical Institute, N/A, Zagreb, Croatia
[3]Rudjer Bokovic Institute, Division for Marine and Environmental Research, Zagreb, Croatia

A series of destructive meteorological tsunamis struck several regions in the Mediterranean and the Black Sea during the period of 23 to 27 June 2014. One of the affected areas was the Adriatic Sea. During morning and afternoon hours of 25 June, four bays in the middle Adriatic were hit by tsunami-like waves with maximum observed wave-heights up to 3 m. The waves were accompanied by strong destructive currents with eyewitnessed velocities up to 5 m/s. One day later, on 26 June, slightly weaker tsunami-like waves with wave heights up to 1 m were observed in two bays in the middle Adriatic as well.

During the period a number of individual air pressure perturbations were recorded over the middle Adriatic area. Pressure oscillations were characterized by: abrupt air pressure changes > 1 hPa/5 min, limited cross-propagation dimensions (~20 - 40 km), and speeds of propagation of 30-40 m/s. Passage of air pressure oscillations over affected bays coincided with onset times of tsunami-like waves, supporting that these events were indeed meteotsunamis. Deeper analysis of general synoptic conditions, radio sounding data, satellite images and outputs of atmospheric numerical models suggested that observed air pressure oscillations were ducted atmospheric gravity waves.

High-frequency sea level oscillations with wave heights up to 60 cm were recorded at numerous tide-gauge stations at the western and eastern coast of the middle and south Adriatic region, coincident to times of the observed meteotsunami events. Significant amount of available tide gauge data along with detailed eyewitnesses reports, and use of numerical ocean model, allowed for a detailed study of generation, propagation and amplification of meteotsunami waves in the Adriatic Sea.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-005

Numerical simulating an initial tsunami waveform by the sea-level data inversion for Solomon Islands tsunami of 6th February 2013

T. Voronina[1], *A. Romanenko*[2]
[1]*Institute of Computational Mathematics& Mathematical Geophysics of SB RAS, Novosibirsk, Russia*
[2]*Novosibirsk State University, Information Technologies, Novosibirsk, Russia*

One of the major issues of the tsunami modeling is gaining some insight into a tsunami source.

The inverse problem to infer the initial water displacement in the tsunami source area using water level records is the so-called ill-posed problem. The developed numerical inversion technique based on the least square inversion and a truncated SVD approach is here described. The tsunami wave propagation is considered within the scope of the linear shallow-water theory. The quality of the inversion is evaluated by relative errors of the tsunami source reconstruction The solution obtained is a projection of the exact solution onto a linear span of the r first right singular vectors corresponding to the largest singular values of a compact operator of the direct problem. Thus, the method presented allows one to control the instability of the numerical solution and to obtain an acceptable result in spite of the ill- posedness of the problem. The number r depends on the rate of decreasing a singular spectrum of the resulting matrix, which is tightly bounded with the parameters of the observational system. Hence, analyzing the singular spectrum of the matrix obtained during numerical calculations one can estimate the future inversion by a certain observational system that will allow offering more effective disposition for the recorders by precomputations. Results of numerical experiments are presented in the case study of Solomon Islands tsunami of 6th February 2013.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-006

A simple method for estimating the tsunami inundation depth at the front of RC building with aperture

H. Matsutomi[1], *N. Ono*[1]
[1]*Akita University, Civil and Environmental Engineering, Akita, Japan*

A simple method using the incident tsunami inundation depth h_i and velocity u_i is developed for estimating the inundation depth h at the front of a solitary wide RC building with aperture. When the inundation depth is estimated, it can be possible to make a rough estimate of the horizontal and vertical tsunami fluid forces on the RC building. The energy loss coefficient ζ of the wide sense, newly defined in the developed method, is examined through comparison of the inundation depth with that estimated by Stoker theory (1957) for the aperture ratio O_p=0 and its expanded theory for $O_p \neq 0$ developed in this study under the assumptions of quasi-steadiness and hydrostatic pressure. The validity of the method is examined through comparison of the inundation depth with that experimentally obtained by Togashi et al. (1983), Matsutomi et al. (2013), Arikawa & Oie (2014), Kato et al. (2014), and it is confirmed that the method is valid and useful. Effects of the incident Froude number F_{ri}, aperture ratio O_p of the building, synthetic friction factor f on the inundation depth are discussed. In addition, the moving-overturning condition of RC building with aperture in Japan is discussed, using the estimated inundation depth and the moving-overturning data of RC building collected by Matsutomi et al. (2012) at the time of the 2011 Off the Pacific Coast of Tohoku Earthquake Tsunami.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-007

Bayesian tsunami source inversion of the 2014 Pisagua earthquake off Northern Chile

T. Takagawa[1], *T. Baba*[2], *H. Tsushima*[3], *Y. Hayashi*[3], *C. Gómez*[4], *P. Catalán*[5]
[1]*Port and Airport Research Institute, Asia-Pacific Center for Coastal Disaster Research, Yokosuka, Japan*
[2]*The University of Tokushima, Civil and Environmental Engineering, Tokushima, Japan*
[3]*Japan Meteorological Research Institute, The 1st Laboratory- Seismology and Volcanology Research Department, Tsukuba, Japan*
[4]*Servicio Hidrográfico y Oceanográfico de la Armada, Oceanography Department, Valparaiso, Chile*
[5]*Universidad Tecnica Federicco Santa Maria, Civil Engineering, Valparaíso, Chile*

On 1st April, an Mw 8.1 earthquake ruptured offshore northern Chile, near Pisagua. The ruptured area was located in a seismic gap called "Northern Chile gap", which had been expected as a potential risk of extremely large earthquake. However, the earthquake is much smaller than the expected maximum. It is important to reveal the area and the heterogeneity of the seismic rupture in order to access the remaining risk of earthquake and tsunami in this region. We therefore carried out an inversion analysis of tsunami waveforms in this event. Observed waveforms we used in the analysis were recorded by offshore Dart buoys and tide gauges along Chilean and Peruvian coasts. They include not only tsunami component but also tide and base shift by seismic crustal deformation. We extracted tide and base shift components by harmonic analysis. The base shift of –29 cm, –9 cm, and –6 cm was estimated at Pisagua, Iquique, and Patache, respectively. Remaining waveforms after removing tide and base shift components were used for further analysis of tsunami source. In our inversion, tsunami waveforms are expressed by linear combination of Green's functions. The functions were calculated by numerical simulation on the basis of finite differential equations with linear long wave approximation. Delay effects of tsunami propagation by water compressibility and earth elasticity were considered. In the simulation, we used the bathymetry data compiled by the Hydrographic and Oceanographic Service of the Chilean Navy. As a result of our analysis, sea surface rise with 170 km length and 60 km width was estimated off of Pisagua. The distribution corresponds well with the distribution of aftershocks. The maximum rise was estimated at 1 m.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-008

This is my abstract title "The development of Augmented Reality visualization technology for tsunami risks with a camera-embedded eyeglass"

C. Kameda[1]*, T. Takahashi*[1]
[1]*Kansai University, Safety Science, Osaka, Japan*

Tsunami research is progressing day by day. However, actually these findings can't be utilized completely in tsunami disaster reduction. That becomes apparent in Tohoku earthquake in 2011. In this disaster, the central and local governments could not grasp the situation of damage, so their disaster responses were hindered right after the disaster. It will also be likely to lead to same result in Nankai Trough. To utilize the findings of tsunami research in disaster reduction, visualizing of complicated tsunami scenarios is important. In this research, we developed a visualization technology of tsunami risks by using Augmented Reality (AR) technology. AR is a new technology to project Computer Graphics (CG) on actual world. We applied this technology and replicated ground, water region, road, building and tsunami prediction result of Kobe City. In this prediction result, tsunami propagation and inundation were carried out with minimum grid size of 2 meters for the Nankai Trough Tsunami. And this visualization is using a glass with camera and actual detailed urban model was created in front of our eyes. And it enabled to grasp viscerally a tsunami propagation process and the situation that tsunami hit the city from various angles. Further, if we use this in disaster map exercise, we can share the information with several people and discuss it with them. This might be expected to be able to use effectively on disaster reduction.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-009

A new physical flume of tsunami-inundation flow; Large-scale Tsunami Physical Simulator

M. Matsuyama[1], *N. Kihara*[1]
[1]*Central Research Institute of Electric Power Industry,*
Civil Engineering Research Laboratory, Abiko-shi, Japan

In the fragility assessment of a structure in tsunami inundation area, both load due to tsunami flow and impact due to tsunami debris must be predicted. For these predictions, numerical approaches are in general used. On the other hand, for the investigation of the predominant failure mode of the structure or the development/verification of the numerical approaches, large-scale experiments for the fragility against tsunami are helpful. Tsunami fragility experiments have been carried out by using hydraulic flumes.

A new physical flume of the tsunami-inundation flow, the Large-scale Tsunami Physical Simulator, was installed in CRIEPI, Japan. In the flume, high and long tsunami inundation flow, with flow depth of over 2 m and duration of 60 s, can be reproduced. This flume is composed of a head tank, a control unit, a test section, and a water storage. The maximum water volume and depth of the head tank are 650 ton and 6.5 m. The control unit is the rectangular close channel. The test section is the open channel with 20 m length, 4 m width and 2.5 m height. Eight valves are mounted across eight pipes, respectively, which connect between the head tank and the control unit. A radial gate and a moving weir are installed between the control unit and the test section, and between the test section and the water storage. In order to control the tsunami-inundation flow in the test section, aperture of the eight valves, and the heights of the radial gate and the weir are computer-controlled simultaneously.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-010

Tsunami numerical simulation and application of fragility curves for building damage estimation in Iquique, Chile

E. Mas[1], L. Urra[2], B. Adriano[3], R. Aranguiz[2], S. Koshimura[1], Y. Yagi[4],
T. Takahashi[5], R. Cienfuegos[6], T. Takashi[7]
[1]Tohoku University, International Research Institute of Disaster Science, Sendai, Japan
[2]Universidad Catolica de la Santisima Concepcion,
Department of Civil Engineering, Concepcion, Chile
[3]Tohoku University, Graduate School of Engineering, Sendai, Japan
[4]University of Tsukuba, Faculty of Life and Environmental Sciences, Tsukuba, Japan
[5]Kansai University, Faculty of Safety Science, Osaka, Japan
[6]Pontificia Universidad Catolica de Chile,
Departamento de Ingenieria Hidraulica y Ambiental, Santiago de Chile, Chile
[7]Port and Airport Research Institute, Asia-
Pacific Center for Coastal Disaster Research, Yokosuka, Japan

On April 1, 2014 a magnitude Mw8.2 earthquake struck off the coast of Chile, 95km northwest of Iquique city, triggering a tsunami reported with a maximum tsunami height of 4 meters. It has been suggested that this event has released at most 20% of the seismic gap along the 1877 (~Mw8.5) rupture zone. Therefore, most of the historical gap remains unbroken and hazardous. Iquique is a port city in the north of Chile, capital to the administrative region of Tarapaca and home to approximately 100,000 people living in tsunami-prone areas. In light of recent events, it is necessary to evaluate the remaining risks for a major city of the northern Chile. Therefore, we have conducted a series of tsunami numerical simulation with various seismic scenarios to grasp the tsunami risk to Iquique city. In addition, for each scenario, tsunami fragility curves were applied to estimate the number of structure with high probability of damage due to the tsunami impact. A large number of structures resulted with high probability of damage for the largest mega earthquake scenario (Mw9.0), however due to a limited inundation for scenarios of Mw8.8 and Mw8.9, the damage estimation resulted considerably lower. Nevertheless it was confirmed that the northern area of Iquique, the ZOFRI tax free zone, remains one of the highly vulnerable areas in the city.

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JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-011

A detail study of the Chilean tsunami of April 1st 2014 recorded in French Polynesia.

A. Jamelot[1]*, D. Reymond*[1]
[1]*CEA, LDG Tahiti / CPPT, Papeete, French Polynesia*

On the 1th April 2014, an earthquake with magnitude of 8.1 occurred near Iquique, Chile. The French Polynesia Tsunami Warning System (CPPT) , located on Tahiti, notified French Polynesia authorities through tsunami watch bulletin for Marquesas islands only.

Using the preliminary focal mechanisms obtained at the CPPT with the PDFM2 method and W-Phase inversion, our tsunami height forecast tools estimated a maximum height of 1.4 m for Marquesas islands whereas less than 0.3 m were expected in the others archipelagos of French Polynesia.

Indeed, when major earthquakes occurring in the Nazca subduction zone have magnitudes such large, historical tsunami events as for example 2010 Maule tsunami showed that the most concerned islands in French Polynesia are the Marquesas Islands that are not protected by coral reefs with gentle slopes and large bays.

As the tsunami arrived over the Marquesas during the night we have very few testimonies of the potential impact on the shoreline however the two tide-gauges of the archipelago (in Hiva-Oa and Nuku-Hiva) have recorded clearly the tsunami signal with a maximum height of 0.60 m.

In the post-warning context we noticed an over-estimation of the tide-gage of Nuku-Hiva by a factor 2 while the first waves of Hiva-Oa 's tide gage were strangely well predicted (Hiva-Oa is about 150 km SE of Nuku-Hiva).

In this context, the associated tsunami has been modelled over Pacific ocean until Marquesas islands using multiple grids with different sizes to search for a better understanding of the sources parameters to fit all the French Polynesian tide gages observations.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-012

This is my abstract title : Hydraulic experiment and numerical calculation for drifting multiple vessel by tsunami

S. HEO[1]*, Y. shigihara*[2]
[1]*National Defense Academy- Japan, paku-haitsu N-201, yokosuka-si, Japan*
[2]*National Defense Academy- Japan, 1-10-20, yokosuka-si, Japan*

The 2011 earthquake Tsunami off the Pacific coast of Tohoku, in East Japan, caused over more than 20,000 casualties or missing and have resulted a huge amount of damage cost which is estimated up to more than 1.3 hundred billion dollars. We believe that the damage was caused not only by the earthquake and resulting tsunami itself but has expanded due to the drifting vessels, vehicles, and containers which were caused by the strong flow of force from the tsunami.

Advanced research have shown drifting models of timber and vessels caused by tsunami and such models were reviewed to be utilized for evaluating the source of damage resulted from the tsunami. However, the accuracy of the drift model is still insufficient and the effective method has not been fully established.

Therefore, in this study, we have performed hydraulic experiment of a number of vessels drifting due to tsunami on harbor and have viewed on the mechanism which affects the drift phenomenon. Also we have verified the accuracy of the numerical model by conducting a reproduction calculation of the experiment on the numerical model through the rigid model based on the rotation and the collision of the drifting object.

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JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-013

A laboratory experiment on the incipient motion of boulders transported by tsunamis

L. Bressan[1], M. Guerrero[2], V. Petruzzelli[3], S. Tinti[4]
[1]Dipartimento di Fisica e Asttronomia- Università di Bologna, DIFA, Bologna, Italy
[2]Laboratorio di Ingegneria Idraulica- DICAM- Università di Bologna, LIDR, Bologna, Italy
[3]Centro Interdipartimentale di Ricerca Industriale Edilizia e Costruzioni- Università di Bologna, CIRI Edilizia e Costruzioni, Bologna, Italy
[4]Dipartimento di Fisica e Astronomia- Università di Bologna, DIFA, Bologna, Italy

The scientific debate on the transport of boulders by tsunamis is a very actual topic, testified by the large amount of scientific literature on boulders transported onshore by high-energy events, such as tsunamis or storms. In order to get experimental data on boulder transport by tsunamis, a laboratory experiment was carried out at the Hydraulic Engineering Laboratory (LIDR) of the University of Bologna, Italy, on a 11 m long and 0.5 m wide flume. The goal of this experiment is to study the flow conditions of the incipient motion for boulders, i.e. to relate the flow characteristics that initiates the boulder movement with the characteristics of the boulders, i.e. weight, geometry and orientation.

The tsunami wave is simulated with a dam-break generation, by suddenly opening the gate at flume edge that releases the water volume. Boulders are located on the opposite edge, on a 1:10 slope that rises after a central flat area. The channel is equipped with a high frequency camera pointing to the initial boulder position, with a Doppler ultrasound velocimeter (DOP), next to the boulder initial location, to measure the water velocity and with resistive level sensors to measure the bore passage at different distances from the gate. The images provided by the HF camera record the impact of the flow with the boulder and the initial movement of the boulder, and they can be used to further extract the velocity and the depth of the flow. Laboratory tests have been carried out by varying both the boulder characteristics and the flow conditions, i.e. with boulders of different weight, dimension, and orientation, and by varying the initial conditions (i.e. the water level at the gate). A preliminary analysis of the test results is presented.

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JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-014

Characteristics of far-field propagation of recent trans-Pacific tsunamis

M. Heidarzadeh[1], K. Satake[2], S. Watada[2], A. Gusman[2]
[1]The University of Tokyo, Earthquake Research Institte, Tokyo, Japan
[2]The University of Tokyo, Earthquake Research Institute, Tokyo, Japan

We analyzed Deep-ocean Assessment and Reporting of Tsunamis (DART) and tide gauge records of recent trans-Pacific tsunamis to provide insights into their far-field propagation. The events analyzed were: 2011 Tohoku (Japan, Mw 9.0), 2010 Maule (Chile, Mw 8.8), 2014 Iquique (Chile, Mw 8.2) and 2007 Kuril (Russia, Mw 8.1) tsunamis. Results showed that the deep-water tsunami wave heights recorded on DARTs from all these events were in the range of 1-215 cm. The average values were ~28, ~7, ~2, and ~2 cm for the aforesaid tsunamis, respectively. Meaningful relations between maximum deep-water wave heights and directivity or distance from the source were not observed for the three events of Maule, Kuril and Iquique. However, weak relations were observed for the Tohoku tsunami which can be attributed to the extremely large size of the tsunami source and consequent large tsunami wavelengths which were far greater than the geographical aerial and submarine barriers within the Pacific Ocean. Spectral analysis showed that the tsunami spectra for DART records were much simpler than those recorded on coastal tide gauges indicating that the DART records are relatively free of non-tsunami signals. While the DART spectra for the Kuril and Iquique tsunamis contained mainly one or two peaks, those for the Tohoku and Maule showed more peaks. Analysis of reverse initial tsunami phases showed that their amplitudes were 1-3 cm on DARTs and arrive 30-60 min before the first normal tsunami phase. Analysis of tide gauge records showed that they also exist in the examined far-field tide gauge records; however, it was relatively harder to detect them due to their small amplitudes as well as high noise levels in tide gauge records.

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JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-015

Possibilities of measuring great tsunamis using GNSS-based ship height positioning

D. Inazu[1], *W. Takuji*[2], *T. Hibiya*[3]
[1]*University of Tokyo, UTokyo Ocean Alliance, Tokyo, Japan*
[2]*University of Tokyo, Graduate School of Frontier Sciences, Tokyo, Japan*
[3]*University of Tokyo, Graduate School of Science, Tokyo, Japan*

Offshore measurements of tsunamis are very useful for robust tsunami forecast and its source estimation. The measurements using ocean bottom pressure gauges and GPS buoys with good sensitivities have been established and installed in open oceans. Associated methods based on the on-line offshore data retrievals have been proposed and operated for real-time tsunami source estimation and forecast (e.g., Tang et al. 2012 JGRc; Tsushima et al. 2012 JGRb). In terms of extending the skills of the forecast and source estimation, it is useful to exploit further possibilities using other offshore measurements. In the present study we examined an offshore ship-borne GPS height record to evaluate noise level at frequency of the great tsunamis (10^-2-10^-1 cpm). The kinematic PPP (Precise Point Positioning) solution was expected to show possible detection of large amplitudes (> 10^-1 m) of offshore tsunami at the frequency. Such large-amplitude tsunamis seem to be hardly found in low-precision positioning solutions (DGPS (Differential GPS) and single point positioning) because of inherent background noise levels one order of magnitude larger than that in the PPP solution. The low-precision positioning GNSS equipments are, on the other hand, inexpensive and will be widely used as the AIS (Automatic Identification System) by a lot of ships including a larger number of small fishing vessels. The height information is not included in the current AIS data, but may be utilized in future. We are evaluating possibility of large tsunami detection by the low-precision GNSS height time-space series based on spatially-dense distribution from many ships.

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JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-016

Model accuracy of the transoceanic propagation of tsunami

Y. Shigihara[1]
[1]*National Defense Academy, Civil and Environmental Engineering, Yokosuka, Japan*

After recent mega-tsunami events in Indonesia (2004) and Japan (2011), a number of research on development of tsunami models for the transoceanic propagation have been reported. Nowadays tsunami simulations are able to be conducted easily, because we can obtain public data such asbathymetry, the parameter of the tsunami source model, and observation data of the post tsunami events. Although using detailed tsunami source models, finer bathymetry data, and higher-order equations for a tsunami simulation give us a more accurate solution, using rough data is sometimes sufficient to get preliminary results in practical use. This study aims to investigate the accuracy of tsunami simulation for the transoceanic propagation. Simulations of the 2011 Japan tsunami are performed with different numerical conditions and compared to the sea level data collected by DART buoys. Sensitivity analysis to spatial grid size and different tsunami source model shows that spatial grid size is a dominant factor for the accuracy of tsunami simulation without complexity of the tsunami source model at large distances from the source region. A tsunami simulation with less than 5 arc-min (9 km approximately) grid size is possible to satisfy the accuracy of maximum tsunami height in the range of 50 - 200 percentages and tsunami arrival time of the leading wave.

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JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-017

Assessment of the stability of the potentially tsunamigenic Monte-Nuovo landslide along the north-western flank of Mt. Epomeo (Ischia island, Italy)

M.A. Paparo[1], S.T. Tinti[1], F. Zaniboni[1], G. Pagnoni[1]
[1]Dipartimento di Fisica e Astronomia- Università di Bologna, DIFA, Bologna, Italy

The island of Ischia, located at the north-western end of the Gulf of Naples, is one of the emerged parts of the area belonging to the Phlegraean Volcanic District. Its main feature is the phenomenon known as block resurgence, which has uplifted the main relief (Mt. Epomeo) up 700 m a.s.l. in the last 33 ka (Orsini et al., 1991; Brown et al., 2008). This together with other factors has been recognised as the cause of slope instabilities that have affected repeatedly the flanks of the mountain with mass failures also reaching the sea with potential for tsunami generation, as confirmed by many studies (e.g. Chiocci et al., 2006; Della Seta et al., 2012).

Here we investigate the stability of the body known as the Monte Nuovo DSGSD that is found on the north-western flank of Mt.Epomeo and whose catastrophic tsunamigenic potential was studied by means of numerical codes (Zaniboni et al., 2013). Considering that this is a volcanic area also subject to seismic activity, we explore the relevance of the seismic load and of the pore gas pressure on the stability of the Monte Nuovo landslide by using the Minimum Lithostatic Deviation method (Tinti and Manucci, 2006, 2008; Paparo et al. 2013) and other techniques, and highlight that a critical combination of these factors can lead to the failure of the slope with catastrophic consequences.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-018

Towards a semi-automated method to estimate building damage caused by tsunami disasters using high-resolution SAR data

H. Gokon[1], *S. Koshimura*[2], *J. Post*[3], *E. Stein*[4], *M. Matsuoka*[5]
[1]*Tohoku University, Graduate School of Engineering, Sendai, Japan*
[2]*Tohoku University, International Research Institute of Disaster Science, Sendai, Japan*
[3]*United Nations Office for Outer Space Affairs, United Nations Platform for Space-based Information for Disaster Management and Emergency Response, Bonn, Germany*
[4]*German Aerospace Center, German Remote Sensing Data Center, Oberpfaffenhofen, Germany*
[5]*Tokyo Institute of Technology,*
Interdisciplinary Graduate School of Science and Technology, Yokohama, Japan

On March 11, 2011, a Mw. 9.0 earthquake and a subsequent tsunami attacked coastal areas of Tohoku region in Japan. To deploy relief activities efficiently, it is necessary to comprehend the affected areas and its impacts as soon as possible. The primary objective of this study is to develop a semi-automated method to estimate building damage caused by tsunami disasters using pre- and post-event high-resolution SAR (TerraSAR-X) data.

Study area encompassed the Sendai City in Miyagi prefecture in Japan. Pre- and post-event TerraSAR-X data acquired on 20 October 2010 (UTC) and 12 March 2011 (UTC) were utilized. The result was validated by the actual building damage data having attributes of surviving and washed-away buildings, that were created by the visual inspection of post-event aerial photos provided by GSI (the geospatial information authority of Japan).

First of all, a pre-processing was applied to TerraSAR-X data, which includes calibration, registration, and speckle noise reduction filtering. Next, change detection was conducted by calculating correlation coefficient image of pre- and post-event TerraSAR-X data. Built-up areas were extracted by a speckle divergence image that was calculated using pre-event intensity image of TerraSAR-X data. The correlation coefficient image within the built-up areas was divided into tiles with the size of 300 meters by 300 meters. Finally, the damage ratios of washed-away buildings were estimated by the statistical relationship between the correlation coefficient values and the damage ratios of washed away buildings. These approaches were semi-automated tool in the ArcGIS environment. It took 26 minutes to perform the building damage estimation in the study area with the size of 8.9 kilometers by 13.2 kilometers.

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JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-019

Is the 17th century great Hokkaido tsunami the 1611 Keicho tsunami in Japan?

K. Ioki[1], *Y. Tanioka*[1]
[1]*Institute of Seismology and Volcanology, Hokkaido University, Sapporo, Japan*

Historically, great underthrust earthquakes occurred off east Hokkaido, Japan because the Pacific plate subducts beneath the Okhotsk plate. Also, tsunami deposits by prehistoric tsunami have been found off east Hokkaido on the coast of Pacific Ocean. Previous study suggest that the 1611 Keicho tsunami earthquake is the 17th century great earthquake (Okamura and Namegaya, 2011). In this study, we examined effects of the 17th century great tsunami generated off east Hokkaido on the coast of Pacific Ocean in Tohoku region. We estimated fault model of the 17th century great earthquake by using locations and elevations where tsunami deposits were found (Ioki and Tanioka, 2013). The result shows that tsunami inundation spread far inland were explained by a large rupture area at deep part of the plate interface. Surveyed tsunami heights near the coast were explained by very large slip amount at shallow part of the plate interface near the trench. The total seismic moment of the 17th century great earthquake was calculated to be 1.7×10^{22} Nm (M_w 8.8). Tsunami heights and inundation were also calculated along the coast of Pacific Ocean in Tohoku region. Computed tsunami heights along the coast were almost less than 4 m and computed tsunami inundation area is very small at Yamada bay. Even if slip amount of estimated fault model is two or three times larger, computed tsunami inundation area in Tohoku region is small. Tsunami inundation area by the 1611 Keicho tsunami were not explained by our estimated fault model. By an effect of directivity, high tsunami was propagated toward east Hokkaido and low tsunami was propagated toward Tohoku.

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JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-020

Inversion of tsunami height using ionospheric observations. The case of the 2012 Haida Gwaii tsunami and earthquake

P. Lognonné[1]
[1]*Institut de physique du globe, Planétologie et sciences dpatiales, Paris, France*

Abstract

Large earthquakes (i.e MW≥6) and tsunamis associated are responsible for ionospheric perturbations. These perturbations can be observed in the total electron content (TEC) mea- sured from multi- frequency Global Navigation Satellite systems (GNSS) data (e.g GPS). In this poster we will study the Ha ̈ida Gwaii earthquake and tsunami case. It happened the 28 october 2012 along the Queen Charlotte fault of the Canada Western Coast. First, we compare data of perturbation of quasi vertical TEC to our model. We model the TEC perturbation in three steps. (1) We model the neutral atmosphere perturbation using a normal modes summation. (2) We couple the ionosphere with the neutral atmosphere. (3) We integrate the perturbed electron density along each satellite station line of sight. At last, we present first results about inversion of TEC data in order to know the water height of tsunamis.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-021

A method to ensure consistency between tsunami forecast chart-based warnings and instrumental Mercalli scale intensity-based evacuation

Y. Hayashi[1], *A. Katsumata*[1], *K. Miyaoka*[1], *H. Tsushima*[1], *P. Catalan*[2], *J. Baquedano*[2], *C. Zelaya*[3], *V. Orellana*[4], *T. Baba*[5]
[1]*Meteorological Research Institute, Seismology and Tsunami Research Department, Tsukuba, Japan*
[2]*Federico Santa María Technical University, Civil Engineering Department, Valparaíso, Chile*
[3]*Chilean Navy, Hydrological and Oceanographic Service, Valparaiso, Chile*
[4]*National Office of Emergency of the Interior Ministry, -, Santiago, Chile*
[5]*Tokushima University, Department of Civil and Environmental Engineering, Tokushima, Chile*

In Chile, ONEMI disseminates tsunami warnings and prompts residents to evacuate directly based on determination by SHOA and real-time seismic analysis by CSN. In addition, if large Mercalli Scale Intensities (MSIs) at coastal areas are reported, the precautionary evacuation may be operated in corresponding regions before disseminating tsunami warning. This paper focuses on the methodology for improving the Chilean tsunami warning before launching the operation of a tsunami database system.

One of tsunami forecast charts (TFCs) used in Japan during from 1987 to 1999 had three curves relating epicentral distance (D) and seismic magnitude (M). The curves were used as the boundaries between four tsunami warning categories, and were determined by referring past tsunami and seismic data for shallow near-field earthquakes. As the same manner, earthquake catalog by CSN, tsunami observation data by SHOA and some supplemental tsunami numerical calculations enable us to determine suitable thresholds for each tsunami forecast area in Chile.

An empirical equation among MSI, moment magnitude, and D can be derived from MSI data by ONEMI and an earthquake catalog by CSN. The criteria used for determination of the range of precautionary evacuation can be optimized, if the MSI-based evacuation have consistency to the TFC-based warnings. We also designed an instrument for real-time measurement of MSI.

This is promising approach to improve the reliability of early tsunami warnings in Chile. These methodologies could also be applicable to other countries.

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Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-022

Near-field tsunami inundation forecasting based on instant source inversion and high performance computing

Y. Oishi[1], *F. Imamura*[2], *D. Sugawara*[2], *T. Furumura*[3]
[1]*Fujitsu Laboratories LTD., Social Innovation Lab., Kawasaki, Japan*
[2]*Tohoku University, International Research Institute for Disaster Science, Sendai, Japan*
[3]*The University of Tokyo, Earthquake Research Institute, Tokyo, Japan*

Recently, real-time offshore tsunami observation systems are actively developed (e.g., Kanazawa, 2013). These widespread and dense observation networks will give useful data to instantly understand the entire pictures of tsunami sources. Making use of the evolving observation capabilities, we aim to develop a tsunami inundation forecasting system for near-field tsunamis and provide guidance for appropriate evacuation actions. Our inundation forecasting approach consists of the following two key technologies: a rapid inundation simulation model and an instant source inversion method.

The recent technology development of high performance computing enables sufficiently rapid inundation simulations. Therefore, we have developed a parallel tsunami inundation model and have tested its performance on a parallel computer. The model achieves more than 60 times faster-than-real-time speed (i.e., 2 hours can be simulated within 2 min) with a 5-m resolution at coastal area.

In terms of the instant tsunami source inversion, several schemes have been proposed thus far (e.g., Tsushima et al., 2014; Ohta et al., 2011). However, the existing methods are not necessarily designed to give accurate forecasts when combined with inundation simulations. Therefore, we develop a suitable source inversion method for accurate inundation predictions. To achieve good accuracy in inundation simulations, our method incorporates the ground subsidence at coastal areas using geodetic data analysis results and improves the accuracy of the incoming wave into the high-resolution inundation simulation area by applying appropriate weighting parameters in the inversion process.

In this presentation, our inundation forecasting approach and the application to the 2011 Tohoku-Oki earthquake will be introduced.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-023

"Odessa tsunami" of 27 June 2014: Observations and assessment of atmospheric processes

A. Rabinovich[1], *J. epic*[2], *V. Sytov*[3]
[1]*P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia*
[2]*Institute of Oceanography and Fisheries, CIESM, Split, Croatia*
[3]*Hydrometeorological Center for the Black and Azov Seas, Ukraine State Committee for Hydrometeorology, Odessa, Ukraine*

On 27 June 2014, during nice and calm summer day, a 2 m high tsunami-like wave struck the beaches of the third largest Ukrainian city Odessa and the neighbouring port town of Illichevsk in the northwestern Black Sea. Several people were injured and taken to the hospital. The wave sudden occurrence, height, destructiveness and run-up indicate that this was a tsunami, although the region was seismically quiet during the event, and Odessa is too far from the areas possible landslides. The event was a cause of great concern and mistery and a number of false explanations soon started circulating through the media, including an underwater explosion, ship (submarine) waves, whirlwind effect, extreme interacting currents, etc. Our investigation revealed that the Odessa event was not isolated, but the last in a chain of destructive events that took place during the period 23-27 June 2014 in the Mediterranean and the Black Sea regions. Analysis of sea level and air pressure time series from Odessa and other Black Sea stations showed the coincidence to air pressure oscillations, and was most likely a meteorological tsunami. Further examination of synoptic patterns and sounding data from the nearby Romanian stations revealed that favorable conditions for generation and trapping of atmospheric gravity waves existed over the Black Sea region at the time of the event. These waves are often associated to meteotsunamis. Numerical ocean model was utilized to estimate sea level response to the air pressure disturbances. A series of numerical experiments was performed to determine the propagation parameters (speed, direction, wavelength) of the disturbances generating maximum sea level oscillations in the northwestern Black Sea.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-024

A case study of a real-time tsunami simulation method using a vector supercomputer

S. KOSHIMURA[1], H. KOBAYASHI[2], R. HINO[1], Y. OHTA[3], A. MUSA[4], O. WATANABE[4], T. INOUE[5], Y. MURASHIMA[5], T. SUZUKI[5]
[1]Tohoku University, International Research Institute of Disaster Science, Sendai, Japan
[2]Tohoku University, Cyberscience Center, Sendai, Japan
[3]Tohoku University, Research Center for Prediction of Earthquakes and Volcanic Eruptions, Sendai, Japan
[4]NEC Corporation, cc, Tokyo, Japan
[5]KOKUSAI KOGYO CO.- LTD., Engineering Division I, tokyo, Japan

The Great East Japan Earthquake and Tsunami in 2011 revealed the importance of damage determination immediately after an event for efficient disaster response. Tsunami simulation models using the 2D non-linear long-wave theory are capable of estimating extent of tsunami inundation and consequent damage to population and buildings, but it generally takes several days to execute high-accuracy simulation for extensive areas by standard workstations.We therefore established a cutting-edge method using NEC SX-ACE, a vector supercomputer installed at Tohoku University, and completed tsunami propagation/inundation simulation within 10 minutes with 10-meter grid resolution for entire coastal city areas. Kochi city and Shizuoka city, which are said to involve a high degree of risk against Nankai trough earthquakes, were selected as study areas. In the case of Kochi city, the total number of meshes for calculation amounted to no less than 16 million.Firstly, a code of 2D non-linear tsunami simulation was optimized so that it delivers high performance on the vector supercomputer, resulting in the parallel performance of 99.76 %. Secondly, we built a simulation model including appropriate extent of calculation with high-accuracy elevation data. Finally, we developed a system where computation resources of the supercomputer that are necessary for this real-time tsunami simulation will be allocated to our study project in an actual tsunami event on a priority basis.It was demonstrated that this real-time simulation method is capable of implementing tsunami propagation and inundation estimation within 10 minutes, and this method is expected to contribute to higher resilience of coastal areas at risk.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-025

Hydraulic experiment on water surface fluctuation generated by underwater shaking table

T. FUJIHARA[1], *T. TAKAHASHI*[1]
[1]*Kansai University, Faculty of safety science, Osaka, Japan*

Barrick (1972) suggested the possibility to observe tsunamis directly by using the oceanographic radar and Hinata et al. (2011) succeeded to observed velocity distribution of the 2011 Tohoku Tsunami propagated in the Kii Channel. However, it has been not yet examined well that the oceanographic radar can detect tsunami sources or not. In this research, a hydraulic experiment was carried out to investigate the relation between tsunami sources and earthquakes. A hydraulic tank of 1.0 m long, 1.0 m width and 0.7 m height was made, and a shaking table was installed on the bottom of tank to simulate ground deformation due to earthquake. The shaking table was designed referring seismic waves of the 2011 Tohoku earthquake observed by the ocean bottom seismometer off Kamaishi. As experimental conditions, amplitude and frequency of shaking table, and water depth were changed. Water surface elevation and surface velocity were measured by using a capacitance-type wave gauge and an electromagnetic current meter. A spectrum analysis of case of 50 cm depth showed the dominant frequency around 2 Hz and the power spectrum was increased when bottom oscillations were 2, 4, and 6 Hz. And the natural frequency of this case was 2.21 Hz. The wide range spectrum was measured and the lower frequency spectrum is the larger power except the natural frequency. All other cases also gave almost same profile. The experimental result indicates that the water bottom oscillation generates various frequency waves on the surface. Therefore, tsunami sources include waves of various lengths and some waves might be corresponding with the electromagnetic waves used by the oceanographic radar. There is a possibility to detect tsunami source directly by checking backscattering of the oceanographic radar.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-026

Optimization performance of tsunami simulation algorithms

A. Romanenko[1], K. Lysakov[2], K. Oblaukhov[1], M. Lavrentiev[1]
[1]Novosibirsk State University, Information Technologies, Novosibirsk, Russia
[2]Institute of Automation and Electrometry SD RAS, Computer Graphics Software, Novosibirsk, Russia

Certainly, computation time is among the critical parameter in the most of tsunami warning systems as it takes only about 20 minutes for tsunami wave to approach the coast of Japan after earthquake at Japan trench, or at Sagami trench (as it was after the Great East Japan Earthquake on March 11, 2011). On the other hand, accurate wave height prediction requires fine meshes which leads to dramatic increase of the necessary CPU time for modeling.

The authors have put together several algorithms, optimized for some of the modern computer architectures, in order to achieve integrated performance from the seismic event to calculation of the wave parameters ay selected area (2000x2000 km, e.g.) compared to 12-15 minutes.

The Method Of Splitting Tsunami (MOST) software package, developed at PMEL NOAA USA (Pacific Marine Environmental Laboratory of the National Oceanic and Atmospheric Administration, USA), is discussed. After adaptation of MOST package to GPU, 40x performance gain for NVIDIA Tesla C2050 GPU vs. single core of Intel i7 processor was achieved. Results of numerical experiments were compared with other available simulation data. Calculation results, obtained at GPU, differ from the reference ones by parts of millimeters of the wave height simulating 24 hours wave propagation. Simulation is 3-4 times faster then the FPGA VC709 is used (double precision is supported). So, considering the computational domain 2000*2000 km (which well covers coast of Japan), simulation of tsunami wave propagation (time step 10 sec) should require only 1 min at FPGA with 0.5’ mesh.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-027

Comparison of fixed and movable bed conditions in tsunami modeling aimed at disaster mitigation measures

T. Takahashi[1], *Y. Morishita*[2]
[1]*Kansai University, Faculty of Safety Science, Osaka, Japan*
[2]*Pacific Consultans Co.-LTD., Land Conservation, Osaka, Japan*

Recently, the movable bed condition is adapted to some tsunami numerical modeling, because sediment transport due to tsunamis have caused various damages such as collapsing coastal structure, shoaling navigation channel in port, blocking water intake in power plant and damage from salt water. However, the conventional fixed bed condition is standard in tsunami numerical modeling, and many tsunami disaster assessment and tsunami hazard map have used the condition without considering topography change. In this study, the fixed and the movable bed conditions were adapted to a large-scale and a small-scale coastal regions to investigate the differences of water level and velocity by both conditions. In the large-scale coastal region, the both conditions gave almost same results. On the other hand, in the small-scale coastal region, the movable bed condition gave a little bit larger water level and velocity. The small-scale coastal region includes local topography variation such as a mouth of port. The movable bed condition erodes at the narrow region and expands the effective sectional area of the water flow. The movable bed condition could simulate more actual water level and velocity. However, the difference is not so large, and the conventional tsunami disaster assessment and hazard map might give a little bit overestimated results, so they can be used as disaster mitigation measures. Further, the movable bed condition requires large computational load and more complicated settings compared to the fixed bed condition. Therefore, the conventional fixed bed condition is suitable to check water level and velocity aimed at tsunami disaster mitigation.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-028

Earthquake related tsunami hazard between the Azores and Iberian Margin North East Atlantic

M.A. BAPTISTA[1,2], *L. MATIAS*[3], *J.M. MIRANDA*[1], *R. OMIRA*[1]
[1]*IPMA, METEOROLOGY AND GEOPHYSICS, LISBOA, Portugal*
[2]*INSTITUTO SUPERIOR DE ENGENHARIA DE LISBOA, CIVIL ENGINEERING, Lisboa, Portugal*
[3]*INSTITUTO DOM LUIZ, FACULDADE DE CIENCIAS, LISBOA, Portugal*

Regional tsunami sources can be potentially hazardous to Iberian and Morocco coastal communities, this is the case of the tsunamigenic earthquakes of the Gloria Fault in the Atlantic Ocean. The Gloria Fault constitutes the westernmost segment of the Azores–Gibraltar structure. Earthquakes in this transform fault can result in regional tsunamis for Iberia and Morocco coasts and in local tsunamis for the Azores Islands; other endangered areas are Madeira and Canary islands. The number of events included in the historical tsunami catalogue and recorded in the tide-gage network is quite small. Previous studies rely on scenario based approach for specific instrumental tsunamis recorded along the North East Atlantic basin namely the 25 November 1941. Other local events ruptured smaller segments of the Gloria fault with minor impact in the Azores islands e.g. the 8 May 1939 event. It is therefore, essential to develop robust methods for quantitatively estimating these type of hazards. Due to the lack of instrumental data in this area, we use the concept of the synthetic catalogue to generate a large number of possible seismic scenarios and the companion tsunami scenarios. The catalogue is generated for 10kyr and the use of Green summation method that allows for the computation of a large number of tsunami waveforms at pre-selected - points of interest. In the present study, the points of interest are the forecast points of the NEAMTWS in the North East Atlantic area. Results are presented in terms of offshore wave height and maximum water level distributions along the shore lines. This work was funded by projects ASTARTE – Assessment Strategy and Risk Reduction for Tsunamis in Europe Grant 603839 – FP7 and GEONUM FCT-ANR/MAT-NAN/0122/2012

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-029

Effectiveness of tsunami warning:A half-century of the Pacific tsunami warning system 1965-2015

L. Kong[1], K. Gledhill[2], C. McCreery[3], D. Coetzee[4], B. Aliaga[5], P. Dunbar[6]
[1]UNESCO/IOC-NOAA, International Tsunami Information Center, Honolulu- - Hawaii, USA
[2]GNS Science – Te Pu Ao, GeoNet Project, Lower Hutt, New Zealand
[3]NOAA, Pacific Tsunami Warning Center, Honolulu- Hawaii, USA
[4]New Zealand Ministry of Civil Defence & Emergency Management, Capability & Operations / National Controller, Wellington, New Zealand
[5]UNESCO/IOC, Tsunami Unit, Paris, France
[6]NOAA, National Geophysical Data Center, Boulder- CO, USA

Although damaging and deadly tsunamis have been occurring for centuries, it was not until after the April 1, 1946 Aleutian Islands tsunami that countries established dedicated tsunami warning centers to provide early alerts of potentially dangerous tsunamis. Through 1967, the US, Japan, Chile, France, and Russian Federation had spun up centers for monitoring earthquake and disseminating tsunami warnings for the Pacific. In the 50 years since the 1965 start of the International Tsunami Warning System for the Pacific (now named PTWS), there have been 46 deadly tsunamis around the world, with 76% occurring in the Pacific and its marginal seas. Eleven occurred along subduction zones facing the Pacific basin where tele-tsunamis could be generated and effective regional and distant international tsunami warning advice could be disseminated. The remaining occurred in the marginal seas and islands of Southeast Asia and the Southwest Pacific or the Northwest Pacific, or in enclosed bays and inlet that afford only 10s of minutes of lead time before the wave hits. In April 2015, Pacific countries will convene an International Symposium on “Making the Pacific Ready for the Next Tsunami” and meet for the 26th Session of the Intergovernmental Coordination Group for the PTWS to review the current state of the System, and identify practical next steps, partnerships, and commitments needed to sustain and evolve the PTWS for the future. This talk will summarize the outcomes of the meetings. We will also examine the effectiveness of tsunami warnings over the history of the PTWS, and the science and technology, disaster management, and preparedness tools that countries have deployed, with the goal of prioritizing the next generation countermeasures needed to save lives.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-030

Relationships between heights and damage of the 1854 Ansei Nankai tsunami inferred from historical records along Tokushima coast, Japan

Y. Namegaya[1], *K. Imai*[2]
[1]*National Institute of Advanced Industrial Science and Technology, Geological Survey of Japan, Tsukuba, Japan*
[2]*Tohoku University, International Research Institute of Disaster Science, Sendai, Japan*

The Pacific coast of western Japan was repeatedly inundated by large tsunamis which occurred along the Nankai trough. Estimation of the tsunami heights is basically based on historical documents which include marks of inundation height and inundation limit. Some documents recorded only damage, for example, numbers of damaged buildings. To estimate the tsunami heights from the damage, relationships between the tsunami heights and the damage are needed. The relationships are proposed as tsunami fragility (e.g. Koshimura et al., 2009, JDR), but it basically targets recent tsunamis. Therefore these relationships cannot be directly applied to the historical tsunamis, because resistance of buildings might be different between the present and the historical era.

From a historical record kept by Nakazai family documented in “Shinshu Nihon Jishin shiryo 5”, hamlets along the coast of Tokushima prefecture were damaged by the 1854 Ansei Nankai tsunami. The document recorded numbers of total buildings, buildings which were swept away, collapsed buildings, and damaged buildings. We calculated damage ratio as numbers of damaged buildings divided by those of total buildings for each hamlet. Moreover, the tsunami heights above sea level (T.P., Tokyo Peil) have already been reported by Murakami et al. (1996, J. JSNDS). Then, relationships between the damage ratio and the reported tsunami heights were constructed for 12 hamlets. The results show that the tsunami heights of more than 6 m correspond to damage ratio of more than 0.8. The tsunami height of 2 m - 3 m corresponds to damage ratio of 0.3. For the middle tsunami heights of 3 m – 6 m, the damage ratio basically distributed 0.2 to 0.4, but more than 0.6 for two hamlets.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-031

Spatio-temporal tsunami source of the 2011 Tohoku earthquake estimated from tsunami data including pop-up bottom pressure measurements inside the source

H. Tsushima[1], R. Hino[2], D. Inazu[3], Y. Ito[4], Y. Osada[5], T. Iinuma[2], S. Suzuki[5]
[1]Meteorological Res. Inst.- JMA, Seismology and Tsunami Research Department, Tsukuba, Japan
[2]Tohoku University, International Research Institute for Disaster Science, Sendai, Japan
[3]University of Tokyo, UTokyo Ocean Alliance, Tokyo, Japan
[4]Kyoto University, Disaster Prevention Research Institute, Uji, Japan
[5]Tohoku University, RCPEV- Graduate School of Science, Sendai, Japan

The tsunami source of the 2011 Tohoku earthquake has been investigated by many studies. The spatial distribution of coseismic slip with large scale is consistent with the seismic-inversion results, but the source time function is inconsistent although total moment is almost the same: according to tsunami inversion, the substantial moment release continues after 100 s, while seismic-inversion results show that large moment release finishes at the time. In this study, we investigate how well tsunami-generation process can be constrained by tsunami data in terms of time. Our tsunami inversion for spatio-temporal distribution of the seafloor deformation was performed by using the data of offshore tsunami-meters, including pop-up pressure gauges that had been deployed on the seafloor inside the source. Green’s functions were computed based on linear dispersive-wave equations. Two types of rupture model were assumed: (1) once the rupture-front passes a seafloor element, the element is allowed to displace repeatedly until the whole rupture process finishes; (2) each seafloor element can displace within a limited duration after the rupture-front passage. The comparison of the results shows that the temporal distribution of the seafloor deformation is very different in the both model although the total seafloor deformation and the resultant tsunami waveforms are very similar. In model 1, large elevation continues at the east of the epicenter until the end of the whole rupture, while in model 2 the elevation finishes in shorter time with larger amount. The results suggest that it is difficult to constrain the temporal distribution of tsunami-generation process only from the tsunami data, and using other observation data is necessary.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-032

Observations of extreme waves at south coast of Black sea

G. Ozyurt Tarakcioglu[1], C. Kirezci[2], G. Guler[1], C. Baykal[1], A.C. Yalciner[3], E. Pelinovsky[4], A. Zaytsev[5], A. Kurkin[6]
[1]METU, Department of Civil Engineering- Ocean Engineering Research Center, Ankara, Turkey
[2]METU, Department of Civil Engineering- Ocean Engineering Reserach Center, Ankara, Turkey
[3]METU, Department of CIvil Engienering- Ocean Engineering Research Center, Ankara, Turkey
[4]Institute of Applied Physics, Department of Nonlinear Geophysical Processes- Russian Academy of Sciences, Nizhny Novgorod, Russia
[5]Special Research Bureau for Automation of Marine Researches, Far Eastern Branch of Russian Academy of Sciences, Uzhno-Sakhalinsk, Russia
[6]Nizhny Novgorod State Technical University, Department of Applied Mathematics, Nizhny Novgorod, Russia

The utilization of the coastal areas of the Black Sea basin has increased in the recent years with the projects such as large commercial ports, international transportation hubs, gas and petrol pipelines, touristic and recreational infrastructures both along surrounding shoreline. Although Black Sea is a closed basin, extreme storms and storm surges have also been observed with an increasing frequency in the recent years. Among those events, the storm occurred on February 19-20, 1999 is one of the most destructive storms in the last decades. The 1999 event (1999 Southern Black sea storm) caused destruction at all harbors and coastal protection structures along the Black Sea coast of Turkey. The complete damage of the rubble mound breakwater of Giresun Harbor and damage on the harbor structures and cargo handling equipment was the major impacts of the 1999 Southern Black sea storm. The total economic loss is about 3.5 million dollars in the Giresun region as the port is one of the major ports in the Black Sea region of Turkey. The reasons behind such an amount of destruction have been an important argument within the coastal researchers from the 1999 storm till now. In this study the list of recent extreme marine events on the South coast of the Black sea, according to the available documents is evaluated. Extreme run-up of 1999 storm in Giresun city is investigated by using the time histories of the wind to hindcast the time history of the significant wave height and period. The comparison of the hindcasted and observed (images of the event) wave data is compared. The reasons

of the wave amplifications and the similarities of recent events at this certain location are presented and discussed.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-033

Study on dynamic system model of coastal tree damaged by tsunami

K. Harada[1]
[1]*Shizuoka University,*
Center for Integrated Research and Education of Natural Hazards, Shizuoka, Japan

By 2011 Tohoku tsunami attacks, coastal forests were damaged severely. And coastal forests were reduced tsunami flow and force at behind forest. In this study, the dynamic system of tree damage is modeled with some assumptions. The fluid force, the overturning moment and the bending moment is calculated some typical conditions of coastal tree damages by tsunami attack. The fluid force to tree is modeled as the drag force with tree stem and branches. Tree shape is modeled not only stem and branch but also root area volume under ground. And the tree damage patterns by tsunami are classified as inclination, root overturning, stem breaking and tree washed away. In the case of large root, the supporting moment of tree becomes large and the limitation of overturning with root becomes also large. For example in the case of root overturning, the overturning moment around the root becomes larger than the root supporting moment with ground. At the same time, the stem bending moment becomes smaller than the breaking limit of live tree. By using these dynamic systems of tree damage, the limitation of coastal forest can be evaluated quantitatively.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-034

The origin of predominant long-period tsunami in Tokyo Bay

K. Imai[1], Y. Tsuji[2], Y. Hayashi[3]
[1]Tohoku University, International Research Institute of Disaster Science, Sendai, Japan
[2]Fukada Geological Institute, -, Tokyo, Japan
[3]Meteorological Research Institute,
Seismology and Tsunami Research Department, Tsukuba, Japan

Tsunami characteristics of Tokyo Bay, east Japan were verified by tsunami observation data and numerical experiments. Tsunami waveform data of the 2010 Maule (Central Chile) earthquake tsunami observed in and around Tokyo Bay were analysed. Numerical experiment on tsunami propagation in and around Tokyo Bay were carried out by using single sine wave with various periods. Our conclusions include the following, and details of our work were published in the other paper by Imai et al. (2014).
(1) Tsunami waveforms obtained around Tokyo bay due to the 2010 Maule earthquake shows that large-scale water vibration (Seiche) has been excited in Sagami Bay, which is located west side of Tokyo bay.
(2) Through numerical experiments, we found that large-scale Seiche was excited in Sagami Bay if the tsunami period off Boso Peninsular was 30 minutes or longer. We also found that Tokyo Bay had a tsunami mechanism to maximize the second wave.
(3) We conclude that most of characteristics of tsunami propagation in Tokyo Bay originate in the Seiche of Sagami Bay.

Reference:
Imai, K., Y. Tsuji, and Y. Hayashi (2014): The excitation Source of Tsunami Characteristics on Tokyo Bay - Verification by observation and numerical experiment -. J. JSCE Ser.B2, **70**(2), I_211-I_215.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-035

"Marrobbio" (tsunami-like event) of 25 June 2014 at the southwestern coast of Sicily

S. Tinti[1], *J. epic*[2], *A.B. Rabinovich*[3], *I. Vilibic*[2], *A. Bonanno*[4]
[1]*Dipartimento di Fisica e Astronomia- Università di Bologna, DIFA, Bologna, Italy*
[2]*Institute of Oceanography and Fisheries, Institute of Oceanography and Fisheries, Split, Croatia*
[3]*P. P. Shirshov Institute of Oceanology- Russian Academy of Sciences, P. P. Shirshov Institute of Oceanology- Russian Academy of Sciences, Moscow, Russia*
[4]*Istituto per l'Ambiente Marino Costiero- CNR, IAMC- Sezione di Mazara del Vallo, Mazara del Vallo Trapani, Italy*

The tsunami-like waves of atmospheric origin affected the Mediterranean and Black Sea region on 23-27 June 2014. Probably the strongest waves were observed on the southwestern coast of Sicily. Intense atmospherically-induced waves regularly occur in this region; locally the phenomenon is know as “marrobbio” (“marrubbio”). These waves impacted the coast of Sicily between 18:00 and 20:00 UTC on June 25, 2014. Event was strongest in Mazara del Vallo, where destructive sea wave propagated into the Mazara River inlet as 1.5 m high hydraulic jump (bore), damaging a number of moored vessels. Moreover, a 30 m retreat of ocean, followed by wave activity which rolled out a large amount of sea grass Poseidonia Oceanica, was noticed at a nearby Tonnarella beach, and significant sea level oscillations of 1.5 m height were observed at Trapani. Tide gauge stations recorded sea level oscillations as well: maximum recorded wave heights ranged from 5 cm at Sciacca up to 35 cm at Lampedusa and Porto Empedocle. Pronounced high-frequency air-pressure oscillations propagated through the atmosphere just at the time of tsunami-like event. Atmospheric disturbances propagated northward from the African towards Sicilian coast with a speed of ~22 m/s. Coincidence of air pressure and sea level oscillations, as well as direction and speed of atmospheric disturbances indicate that this event was a meteorological tsunami. Tsunami-like waves were first generated and resonantly enhanced via Proudman resonance mechanism over the western part of shelf between Africa and Sicily and then additionally amplified at areas with large topographic amplification factor, such as Mazara del Vallo.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-036

Tsunami forecast modeling development for Turkish coastlines

N. Sharghivand[1], U. Kânoglu[1]
[1]Middle East Technical University, Department of Engineering Sciences, Ankara, Turkey

Aegean Sea and Eastern Mediterranean coastlines of Turkey are densely populated, and have substantial touristic activities and critical infrastructures. Yet, these coastlines have been exposed to tsunamis in the past. Therefore, capacity building in both long- and short-term tsunami forecasting and mitigation competences in the region is essential. One of the components of the tsunami forecasting system is a tsunami propagation database. The US NOAA Center for Tsunami Research (NCTR) models subduction zones and known faults with tsunami unit sources (100 km x 50 km fault planes having a slip value of 1 m). Linearity of tsunami propagation in deep sea allows scaling and/or combination of the pre-computed propagation results from unit sources to generate a desired seismic scenario.

Following the NCTR's approach, Hellenic Arc, other seismic faults and historical tsunami events were compiled from the tsunami catalogs and unit sources were placed (Hoto, MS Thesis 2015). Tsunami propagation from unit sources were calculated using validated and verified (Synolakis et al., Pure Appl Geophys 2008) MOST model (Titov and Synolakis, Geophys Res Lett 1997) to create a database.

Community Modeling Interface for Tsunamis (ComMIT) is then used for inundation modeling (Titov et al., Pure Appl Geophys 2011). ComMIT is a rich graphical interface to a pre-computed tsunami scenario database and to the MOST model. The compiled propagation database is used to model historical and potential events and the first version of the inundation map is prepared for the town of Fethiye, Mugla, Turkey.

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Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-037

Preliminary results of very fast computation of moment magnitude and focal mechanism in the context of tsunami warning

F. Schindelé[1], *J. Roch*[1], *L. Rivera*[2]
[1]*CEA, DAM- DIF, Arpajon, France*
[2]*Université de Strasbourg, EOST, Strasbourg, France*

Various methodologies were recently developed to compute the moment magnitude and the focal mechanism, thanks to the real time access to numerous broad-band seismic data. Several methods were implemented at the CENALT, in particular the W-Phase method developed by H. Kanamori and L. Rivera. For earthquakes of magnitudes in the range 6.5-9.0, this method provides accurate results in less than 40 minutes. The context of the tsunami warning in Mediterranean, a small basin impacted in less than one hour, and with small sources but some with high tsunami potential (Boumerdes 2003), a comprehensive tsunami warning system in that region should include very fast computation of the seismic parameters. The results of the values of Mw, the focal depth and the type of fault (reverse, normal, strike-slip) are the most relevant parameters expected for the tsunami warning. Preliminary results will be presented using data in the North-eastern and Mediterranean region for the recent period 2010-2014.

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Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-038

Probabilistic tsunami hazard assessment along middle America from local and regional seismic sources

N. Zamora[1], *A. Babeyko*[2]
[1]*GFZ, Potsdam, Germany*
[2]*GFZ, Geodynamic Modeling, Potsdam, Germany*

Central America represents a region of high seismicity as consequence of a complex tectonic setting where several plates interact. The Middle America mega-thrust developed from the subduction of the Cocos plate beneath the Caribbean plate. Historical data indicates that the Middle America subduction zone represents the primary tsunamigenic source that has affected coastal communities along Central America. In the last years, seismic tsunami potential in the region has been mainly assessed using the maximum credible earthquakes or historical events; however, such deterministic scenarios are not accompanied with their adequate probability of occurrence. In this study we modified the conceptual framework commonly used in seismic hazard analysis, adapting it to estimate to the probabilities of exceedance of tsunami amplitudes along the coast. We used the vast available geodetic and geophysical data to determine the seismic area sources where uniform seismicity patterns and geological changes were identified. With the aim of assessing the tsunami hazard posed only from local seismic sources, we derived earthquake statistical parameters for each source, and generated a series of synthetic earthquake catalogs using Monte Carlo method. Each of the synthetic earthquake catalogs were used as input data for tsunami modeling and aid to derive the probabilistic tsunami hazard assessment (PTHA) which final output is presented as hazard curves for selected sites. Thus, in order to ensure the robustness of the model, first, the Monte Carlo sampling accounts for the aleatoric uncertainties, and second, using a logic tree scheme, we account for the epistemic uncertainties. The approach followed in this study provides a relevant improvement of tsunami hazard analysis in this region.

Joint Inter-Association Symposium

JP05p - JP5 Tsunamis (IAPSO, IASPEI)

JP05p-039

Fault parameters estimated from seismic and tsunami data for magnitude~7 earthquakes occurred in the sea of Japan in 1900s

S. Murotani[1], *K. Satake*[1], *T. Harada*[1]
[1]*The university of Tokyo, Earthquake Research Institute, Tokyo, Japan*

We made teleseicmic waveform inversion and tsunami waveform analysis for the 1983 West off Aomori (M_{JMA} 7.1), 1971 West off Sakhalin (M_{JMA} 6.9), and 1964 off Oga Peninsula (M_{JMA} 6.9) earthquakes occurred in the Sea of Japan. Tsunami waveforms were calculated from the heterogeneous slip distributions obtained from the teleseismic waveform inversion on the eastward-dipping fault planes, as well as simpler rectangular faults with uniform slips, and were compared with the observed waveforms on tide gauges. Amplitudes and travel times of tsunami waveforms calculated from the teleseismic waveform inversion results did not reproduce the observed waveforms; to match with the observed tsunami amplitudes, larger seismic moment and average slips are required.

Eastern margin of the Sea of Japan has been considered as a nascent plate boundary between the Eurasian and North American plates but not a typical subduction zone, hence the maximum magnitude (M<8) of earthquakes is smaller than those in the Pacific Ocean. Nevertheless, several large earthquakes with M > 7.5 in the last century caused seismic and tsunami damages, such as the 1993 Southwest off Hokkaido (M_w 7.7), 1983 Japan Sea (M_w 7.7), 1964 Niigata (M_s 7.5), or 1940 Shakotan-oki (M_w 7.5) earthquakes. Detailed studies of source process were performed for these earthquakes.

There are many active faults along the eastern margin of the Sea of Japan. Smaller (M~7) earthquakes also cause seismic and tsunami damages if their hypocenters are near the land. However, there are few analyses for earthquakes around M7. Therefore, we study the characteristics of the M~7 earthquakes in the Sea of Japan using seismic waveform and tsunami waveform data.

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JS06a - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

IUGG-0311

Advances on analysis and signal processing of acoustic scattering responses by phythoplanktonic species.

M. Cinquini[1], P. Bos[1], I. Prario[1], S. Blanc[1]
[1]Argentinian Navy Research Office. UNIDEF National Council of Scientific and Tec, Underwater Sound Division., Vicente Lopez, Argentina

Acoustically monitoring phytoplankton scatterers living either within aqueous culture media or in seawater samples may be an interesting technique feasible to be applied in detection of harmful algae blooms or biological indicators of polluted sea areas. Very few measurements on acoustical responses of phytoplankton have been reported since the first ones were published in 1998. First results of biomass estimations using acoustical measurements on phytoplankton cultures have encouraged the improvement of the initially proposed methodology. Further improvements to assure repeatability during at-lab essays with several phytoplankton species at different ultrasonic frequencies are presented here. The complexity involved in measuring the scattering contribution due to phytoplankton presence leads to deal with the task of unmasking the acoustic response of those organisms from spurious scattering generated by bubbles and suspended particles. Signal processing techniques for attenuating the undesirable scattering contribution to the total backscattered power will be described in this presentation. At-lab measurements were performed by insonification of Skeletonema pseudocostatum, Chlamydomonas reinhardtii and Euglena gracilis cultures using 2.25, 3.5 and 5 MHz narrowband transducers. Additionally, Skeletonema pseudocostatum cultures were used to determine the Volume Backscattering Strength by two independent methods: experimental determination of the backscattered acoustic intensity to incident intensity ratio and application of theoretical scattering models combined with optical counting and culture media image analysis. The comparison of both methods provided encouraging results. Moreover, simulations for estimating algae cultures acoustic responses will be discussed.

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IUGG-0758

Ocean state estimation in the Philippine Sea combining acoustic and non-acoustic data

P. Worcester[1], *B. Cornuelle*[1], *G. Gopalakrishnan*[1], *M. Dzieciuch*[1]
[1]*University of California- San Diego, Scripps Institution of Oceanography, San Diego, USA*

An ocean acoustic tomography array approximately 660 km in diameter and consisting of six transceivers and a Distributed Vertical Line Array (DVLA) receiver was moored in the Philippine Sea from April 2010 to April 2011. The goal of the tomographic measurements was to determine whether acoustic methods, together with other measurements and ocean modeling, can yield estimates of the time-evolving ocean state useful for making improved acoustic predictions and for understanding the local ocean dynamics in this oceanographically complex and highly dynamic region. The DVLA recorded the transmissions from the six transceivers to study low-frequency, deep-water propagation and scattering. The time series of travel times from the tomographic array were analyzed to remove tidal signals and extract the low-frequency variability by performing a least square fit to a model consisting of long-period sinusoids and tidal harmonics. The resulting low-frequency travel-time series were compared with travel times computed from ocean state estimates made using a high-resolution regional implementation of the MITgcm that was constrained by satellite sea surface height and sea surface temperature observations and by Argo and expendable bathythermograph (XBT) profiles, but not by the acoustic data, providing a simple estimate of the novel information present in the travel times and a cross-validation of the state estimates. The ocean state estimates were then redone including the acoustic data. Comparisons of the state estimates with and without the travel-time data show the changes needed to fit the observations. The state estimates using the acoustic data compare favorably with independent observations.

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IUGG-1387

The 2011 Tohoku Tsunami detected by an array of ocean bottom electro-magnetometers

H. Utada[1], *L. Zhang*[2], *H. Shimizu*[1], *K. Baba*[1]
[1]*The University of Tokyo, Earthquake Research Institute, Tokyo, Japan*
[2]*Tongji University, State key Laboratory of Marine Geology, Shanghai, China Peoples Republic*

A tsunami induces secondary electromagnetic (EM) fields of significant intensity as a result of Faraday's law of electromagnetic induction. Resulting EM signals can be recorded by instruments on the seafloor. Such observations will provide parameters that are useful in understanding tsunami generation and propagation processes. In this study, we report the observation of EM signals induced by the 2011 Tohoku Tsunami, obtained by a small array of ocean bottom electro-magnetometers consisting of four stations in the Northwestern Pacific Ocean. The observation shows that the EM signals appeared when the tsunami passed the study area with mean depth of 5800 m and propagated with the phase velocity of an oceanic long wave. We estimated the motional impedance (ratio of transverse component of electric to radial component of magnetic signals) and the motional tipper (ratio of vertical component to radial component of magnetic signals) at each site and found that their amplitudes are approximately equal to the long wave phase velocity and their phases are approximately 90 degrees. This result proves that the observed EM signals are of motional induction origin. Then, several data analysis methods are used to estimate tsunami parameters. Referring to the theoretical relation, the wave height is estimated from the observed magnetic and electric fields. Also, the propagation direction of the 2011 Tohoku tsunami is estimated by applying analysis methods for an array and a single station. We conclude that EM sensors installed at seafloor can be used as a type of tsunami sensor.

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IUGG-4695

The electrical lithospheric structure of southern Australia derived from 3D inversions of the AusLAMP magnetotelluric data

S. Thiel[1,2], *G. Heinson*[2], *S. Hill*[1]
[1]*Geological Survey of South Australia, Department of State Development, Adelaide, Australia*
[2]*University of Adelaide, School of Physical Sciences, Adelaide, Australia*

The AusLAMP magnetotelluric program across Australia acquires long-period (5-20,000s) MT data every half-degree (roughly every 55 km) with the aim of providing an image of the electrical resistivity distribution of the lithosphere and constraining the geodynamic history of the continent. We present 3D inversion results of 120+ sites from the AusLAMP array and higher density profiles spread across southern Australia. The data cover the Archean/Proterozoic Gawler Craton and adjacent margins. The resistivity models provide an image of the electrical structure from the upper/mid crust to the lithosphere-asthenosphere boundary. A generally resistive upper crust is underlain by a resistive lower crust and upper mantle in the central part of the Gawler Craton. However, the eastern margin of the craton shows significantly lower resistivity in the lower crust and upper mantle coinciding with high mineralization potential of the Stuart Shelf at the surface. In the southern part of the array, the crustal conductivity is enhanced in the central Eyre Peninsula in a roughly N-S direction and reconfirms legacy induction arrow studies. The mantle lithosphere of the central Gawler Craton is resistive surrounded by lower resistivity margin underneath the Stuart Shelf and also beneath the western margin along the Karari Shear Zone. The lower resistivities along the margins spatially coincide with significant tectonism in those areas around 1.6 Ma ago and are likely imprints of elevated fluid release along the margins of the craton into the overlying crust.

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JS06a - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

IUGG-5417

Combining EarthScope long period magnetotelluric data with geomagnetic observatories: hypothetical events at continental scale

G. Egbert[1]
[1]*Oregon State University, CEOAS, Corvallis, USA*

The EarthScope USArray project has been collecting long period MT data on a quasi-uniform 70 km grid covering much of the continental US (2006-present). These data are being collected using a "rolling" array of approximately 20 five component (three magnetic, two electric) MT sensors, with roughly 70-100 sites occupied (for periods of 2-4 weeks) in each field season. Seven geomagnetic observatories have operated in the continental US over the same time period, providing essentially continuous observations of three components of the geomagnetic field. All instruments (Earthscope and observatories) have sampling rates of 1 hz. I will discuss application of multivariate array processing methods to these datasets. Our ultimate goal is to merge the large scale synoptic observatory array with the short partially overlapping EarthScope arrays, to create maps of electromagnetic (EM fields) that would be observed for highly idealized sources—both plane wave and gradient. These hypothetical events will provide a unique perspective on the internal induced fields within the Earth, and may suggest novel strategies for extracting reliable information about crust and mantle conductivity. The synthesis may also provide new insights into external source characteristics, and their interaction with the conducting Earth. Application of these results to development and validation of methods for modeling and predicting geomagnetically induced currents (GIC) will be discussed.

Joint Inter-Association Symposium

JS06b - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

IUGG-3233

GNSS buoy array in the ocean for a synthetic disaster mitigation

T. Kato[1], *Y. Terada*[2], *K. Tadokoro*[3], *Y. Shoji*[4], *H. Seko*[4], *M. Ishii*[5], *M. Nishioka*[5], *S.I. Yamamoto*[6], *M. Toyoshima*[7], *N. Iwakiri*[7], *N. Koshikawa*[8], *O. Motohashi*[8], *A. Wada*[9], *N. Imada*[9]
[1]*Earthquake Research Institute, The University of Tokyo, Tokyo, Japan*
[2]*National Institute of Technology, Kochi College, Kochi, Japan*
[3]*Graduate School of Environmental Studies, Nagoya University, Aichi, Japan*
[4]*Meteorological Research Institute, Japan Meteorological Agency, Ibaraki, Japan*
[5]*Applied Electromagnetic research Institute, National Institute of Information and Communications Technology, Tokyo, Japan*
[6]*Wireless Network Research Institute, National Institute of Information and Communications Technology, Ibaraki, Japan*
[7]*Wireless Network Research Institute, National Institute of Information and Communications Technology, Tokyo, Japan*
[8]*Satellite Applications and Promotion Center, Japan Aerospace Exploration Agency, Ibaraki, Japan*
[9]*Electronic Control Business Unit, Hitachi Zosen Corporation, Tokyo, Japan*

A system of GNSS buoy for detecting tsunami has been developed for more than 15 years in Japan. The buoys deployed around the Japanese coasts have successfully detected tsunamis of amplitude bigger than 10 centimeters including a large tsunami due to the 2011 Tohoku-Oki earthquake. The present study tries to extend the GNSS buoys for a wide variety of applications for monitoring disaster related signals in the ocean, such as ocean bottom crustal deformation, atmospheric water vapor detection for weather monitoring, and ionospheric disturbance detection for space weather monitoring as well as tsunamis.

Recent developments of real-time GNSS technology enabled us to estimate position of a moving platform like buoy in a few centimeter accuracy in real-time. Combination of precise positioning with acoustic ranging to the ocean bottom transponder stations enables positioning of the ocean bottom station. Moreover, GNSS data on the buoy provide us with accurate estimation of atmospheric water vapor and total electron content in the ionosphere. These geophysical data on the ocean surface, together with land based sensors, will serve us with unprecedented invaluable datasets for better understanding of ocean bottom crustal deformation, atmospheric and ionospheric disturbances as well as sea surface disturbances.

Combined this GNSS buoy technology with satellite data transmission is a key for materializing the capability of GNSS buoy. We propose to establish an array of GNSS buoy in the ocean for an international geodetic and geophysical infrastructure of earth science and disaster mitigation.

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IUGG-5474

The global tropical moored buoy array

M. McPhaden[1]
[1]*NOAA, PMEL, Seattle, USA*

This presentation describes the Global Tropical Moored Buoy Array, which is the result of multi-national effort to provide data in real time for climate research and forecasting. The array spans the Pacific, Atlantic and Indian Oceans and is the key tropical component of a global ocean observing system. Phenomena of primary interest span intraseasonal-to-decadal timescales, such as El Niño/Southern Oscillation, the monsoons, the 30-60 day period Madden-Julian Oscillation, decadal variations, and trends that may be related to global warming. Sustained, systematic and comprehensive observations are necessary to advance knowledge of critical processes that govern climate dynamics originating in the tropics. Observations are also needed to develop, initialize, and validate climate forecast models that can be used for advance warning of natural hazards and for many other societal benefits. A global tropical perspective is required not only because of the range and complexity of tropical phenomena that affect the climate system, but also because of basin-to-basin interactions that affect the evolution of climatic fluctuations. This paper highlights the development of the Global Tropical Moored Buoy Array and some of the major scientific advances it has enabled.

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IUGG-5717

Broadband acoustic propagation in shallow water waveguides with internal waves.

M. Badiey[1]
[1]*University of Delaware, College of Earth- Ocean- and Environment, Newark- DE 19716, USA*

For sound propagation on the continental shelf regions, the variability of water column can create anisotropic media where directionality between the source-receiver track and the front of variable sound speed becomes important. This problem can be modeled using the modal behavior of three-dimensional waveguides with variable spatial and temporal sound index of refraction. In this paper, we present a heuristic view of how broadband signals are affected by the shallow water sound speed variability caused by moving internal waves. Field observations on a horizontal and vertical receiver array are shown for coherent acoustic signals propagating in 20 km source-receiver distance in 100 m water depth. Observed field data is shown quantifying the phase variation of acoustic signals on the horizontal array. Modal behavior represents horizontal refraction that is modeled by the theory of horizontal rays and vertical modes.

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IUGG-5720

Acoustic monitoring of the global ocean

W. Munk[1]
[1]*Scripps Institution of Oceanography- UCSD, Oceanography IGPP, La Jolla, USA*

ACOUSTIC MONITORING OF THE GLOBAL OCEAN

Ocean acoustics had its beginning in 1944 with the discovery of the sound channel by Ewing and Worzell of Woods Hole, and two years later, independently, by Brekhovskikh in the Soviet Union. Because the sound channel is a central component of submarine detection, the results remained classified for many years. The global dimension of the sound channel was not appreciated until 1960 when, in an almost casual experiment, a few sticks of dynamite detonated off Perth, Australia, were recorded two hours later by Bermuda hydrophones. We now know, from the work of Dushaw, that the geodesic from Perth to Bermuda is partially blocked by Brazil and the Cape of Good Hope, and that a successful transmission requires some assistance by ocean scattering and refraction.

It came as a great shock in the 1960s when it was discovered that the oceans, like the atmosphere, have an active weather. Storms are called eddies, with typical dimensions of 100 km and 100 days. Traditional hydrocasts are designed to deal with geographic, seasonal and climatic variations; they are not competent to resolve mesoscale variability. Ocean Acoustic Tomography was designed to meet the new requirements.

Short range tomographic experiments were begun in 1978 in the North Atlantic and have been performed in many locations, at gradually increasing ranges, since then. In 1991, we transmitted from Heard Island in the central Indian Ocean to globally distributed receivers, some at antipodal ranges. I will discuss some of the difficulties we experienced and our attempts to overcome them. Oceanographers (like other marine mammals) will need to take advantage of the fact that the oceans are transparent to sound.

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JS06c - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

IUGG-0396

Towards global monitoring of the ocean environment

G. Nolet[1], *. Yann Hello*[2], *S. Bonnieux*[2], *A. Sukhovich*[3], *F. Simons*[4]
[1]*Geoazur, Sophia Antipolis, France*
[2]*Geoazur, Geoazur, Sophia Antipolis, France*
[3]*Geophysics, University of Brest, Brest, France*
[4]*Geosciences, Princeton, Princeton, USA*

The 'Mermaid', developed at Geoazur, is originally an underwater seismograph. It is currently being expanded to a multidisciplinary float with a very long lifetime. It will serve acoustic and other monitoring tasks while transmitting data in quasi real time. For seismology,P wave signals are automatically identified and transmitted using the detection algorithm from Sukhovich et al. (GRL, 2011). We have studied the performance of Mermaids for seismology under different noise conditions in the Mediterranean, Indian Ocean and most recently near the Galapagos islands and will show a selection of observations. In the Mediterranean, we regularly detect P waves at teleseismic distances of earthquakes with magnitude 6, occasionally below that. Local and regional earthquakes of much lower magnitude yield seismograms with a high signal to noise ratio.In the much noisier environment of the Indian Ocean the threshold for useful seismograms is close to magnitude 6.5. Yet we were also able to record 235 low magnitude events when a Mermaid was close to a swarm near the Indian Ocean triple junction with a lowest magnitude estimated to be 2.1.Initial data from the Galapagos indicate low noise conditions similar to those in the Mediterranean.Prototypes of the new, spherical, Mermaid ('Multimarmaid') are currently being tested. It allows for multidisciplinary observations (seismic and kHz acoustics, magnetic field, temperature) and will function 5-10 years with lithium-ion batteries, depending on the level of monitoring actovity, and possibly much longer with other power options currently under development. A global deployment of such instruments in a five-year program is affordable: project MariScope aims for at least 300 MultiMermaids in the world's oceans.

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IUGG-3181

Location of P-wave Microseism Sources Via Back-Projection of Large Aperture Seismic Array Data

K. Koper[1], *R. Burlacu*[1]
[1]*University of Utah, Geology and Geophysics, Salt Lake City, USA*

The Transportable Array (TA) component of the Earthscope USArray project consists of over 400 broadband, three-component seismometers that have been deployed across North America with average station spacing of approximately 70 km. The deployment began on the west coast of the United States in 2004 and gradually rolled eastward, reaching the east coast in 2012. Each TA site was occupied for 18-24 months, and the 40 Hz digital data are openly available to the scientific community (www.usarray.org/researchers/data). Here, we process continuous TA data to detect and locate sources of microseismic P waves, in the period band of 2-10 s, created by wind-driven ocean waves. At these periods, the large aperture of the TA precludes conventional plane wave (f-k) processing. Instead, we back-project the array data through a 1D reference Earth model (ak135) to grids of hypothetical source locations. The power, at each grid point and assumed origin time, is calculated from the amplitude of a windowed, filtered, and tapered time domain beam constructed with fourth-root stacking. As expected, microseism sources tend to cluster in the north Pacific and north Atlantic Oceans during northern hemisphere winters. The location accuracy of our method is evaluated using P waves from earthquakes with well-defined hypocenters. We also evaluate the ability of static travel time corrections calculated from a recent 3D tomographic model of the mantle to focus the array beams. The final P wave microseism locations are compared to predictions derived from wave-wave interactions in the WAVEWATCH III ocean model.

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IUGG-3943

Ambient seismic, hydroacoustic and flexural-gravity wave noise on atabular iceberg

E. Okal[1], *D. MacAyeal*[2], *Y. Wang*[3]
[1]*Northwestern University, Evanston, USA*
[2]*University of Chicago, Dept. of the Geophysical Sciences, Chicago, USA*
[3]*University of Chicago, Physical Sciences Division, Chicago, USA*

Cross-correlation of ambient seismic noise between four seismographs on tabular iceberg C16, Ross Sea, Antarctica, reveals both the source and the propagation characteristics of signals associated with icebergs. We find that noise-correlation functions computed from station data are asymmetric about zero-time lag, and this indicates that noise observed on the iceberg originates primarily from a compact, localized source associated with iceberg collisions between C16 and a neighboring iceberg, B15A. We additionally find two, and possibly more, distinct phases of noise propagation. We believe that flexural-gravity wave propagation dominates the low frequency noise (> 10 s period), and that hydroacoustic wave propagation in the water column between the ice and seabed appears to dominate high frequency noise (>10 Hz). While faster seismic propagation dominates the intermediate band (2 - 6 Hz),we do not have sufficient data to characterize the wave mechanisms more precisely, e.g., by identifying distinct longitudinal and shear body waves and/or surface waves. Secular changes in the amplitude and timing of ambient noise correlations, e.g., a diurnal cycle, and an apparent shift in the noise correlation of fast seismic modes between two periods of the deployment, allow us to speculate that ambient noise-correlation analysis may be helpful in understanding the sources and environmental controls on iceberg-generated ocean noise as well as geometric properties (such as water column thickness) of sub-glacial lakes.

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IUGG-4300

Seismicity and fault structure in the northeastern Atlantic oceanic lithosphere from array processing of the deep Sea DOCTAR array

F. Krüger[1], *T. Dahm*[2], *K. Hannemann*[1]
[1]*University of Potsdam, Earth and Environmental Science, Potsdam, Germany*
[2]*Deutsches GeoForschungsZentrum GFZ, Physics of Earthquakes and Volcanoes, Potsdam, Germany*

Within the DOCTAR project (Deep OCean Test ARray), we installed three medium aperture arrays: one in the deep ocean (4-6 km) 800 km west of the portuguese coast, a second one in western Portugal and the third one on Madeira Island. The deep Sea array was located 100 km north of the Gloria Fault which marks the plate boundary between the Eurasian and African plate in the Eastern Mid Atlantic. The arrays were equipped with broad band seismometers which recorded more than ten months of data.

Incoherent beam forming and migration techniques are used to locate seismic events in the region between the Azores Islands in the West, Portugal mainland in the East and the Canary Islands in the South. For seismic events in the oceanic lithosphere, we can demonstrate superior detection and location capabilities of the deep Sea array compared to the array installations on Madeira Island and western Portugal.

We find active seismic structures west of Madeira and indications for segmentation of the Gloria transform fault directly south of the deep Sea array.

Finally, we present indications for the presence of regionally varying attenuation for Po and So phases and So wave anisotropy.

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IUGG-5730

Arctic watch: acoustic in an Arctic ocean observing system

S. Sandven[1]*, H. Sagen*[1]*, P. Worcester*[2]*, P. Mikhalevsky*[3]*, M. Dzieciuch*[2]*, W. Munk*[2]
[1]*Nansen Environmental and Remote Sensing Center,*
Polar and Environmental Research Department, Bergen, Norway
[2]*University of California - San Diego, Scripps Institution of Oceanography,*
La Jolla, USA
[3]*LEIDOS Inc, LEIDOS Inc., Arlington, USA*

Synoptic in-situ year-round observational technologies are needed to monitor and forecast changes in the Arctic atmosphere-ice-ocean system at daily, seasonal, annual and decadal scales. This paper addresses the use of regional to basin wide multipurpose acoustic networks in the Arctic and sub-Arctic. These networks provide communication, underwater and under-ice navigation, passive monitoring of ambient sound (ice, seismic, biologic, and anthropogenic), and acoustic remote sensing (tomography and thermometry) supporting and complementing data collection from platforms such as floats, moorings and vehicles. This paper supports the development and implementation of regional to basin-wide acoustic networks as an integral component of a multi-disciplinary in-situ Arctic Ocean observatory. Steps towards a pan-Arctic observing system have been taken.

In 1994,a trans-Arctic acoustic propagation experiment provided the first evidence of basin-scale warming of the Atlantic Intermediate Water. In 1998–1999, a similar experiment showed continued basin-scale warming of the AIW. A prototype single-track ocean acoustic tomography system was deployed from 2008 to 2009 to measure the depth-averaged temperature in the eastern half of Fram Strait. Subsequently, three moored acoustic transceivers were deployed from 2010 to 2012 in a triangle with a moored receiver in the center. In 2014, the acoustic monitoring of the Fram Strait was continued. The acoustics system is augmented by oceanographic instrument, and will be recovered in 2016. In 2016, a tomographic experiment is planned in the Beaufort Sea.

Finally, we present the plan for implementation of an international Arctic Watch experiment with a source mooring at the North Pole and receiver mooring at the outskirts of the Arctic Ocean.

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JS06d - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

IUGG-1478

Simultaneous use of multiple seismic arrays

B. Kennett[1], *J. Stipcevic*[1], *H. Tkalcic*[1]
[1]*The Australian National University, Research School of Earth Sciences, Canberra, Australia*

Seismic arrays provide an important means of enhancing seismic signals and determining directional properties of the wavefield by beam-forming. When multiple arrays are to be used together the viewpoint needs to be modified from looking outwards from each array to focusing on a specific source area and so constraining the portions of the waveforms to be analysed. Beam-forming for each array is supplemented by the relative time constraints for propagation to each array to provide tight spatial control.
Simultaneous multiple array analysis provides a powerful tool for source characterisation, and for structural analysis of scatterers as virtual sources. The multiple array concept allows us to illuminate a specific point in the Earth from many different directions and thus map detailed patterns of heterogeneity in the Earth. Furthermore, illumination of the structure from multiple directions using data from the same event minimizes source effects to provide clearer images of heterogeneity.
The analysis is based on a similar concept to the back-projection technique, where a part of the seismic wavetrain is mapped to a specific point in space by ray-tracing. In contrast to the classic back-projection where the incoming energy is mapped onto a horizontal plane with limited vertical resolution, the multi-array method controls depth response by combining relative time constraints between the arrays and conventional beam-forming.
We illustrate this approach with synthetics for various source depths and for several recordings from real events. The results show significant improvement both in signal quality and resolution with the additional benefit of being able to accurately locate the source of the scattered energy and map large areas with only limited number of stations.

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JS06d - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

IUGG-1817

"Usage of joint beamforming and polarization analysis for array processing"

A. Fedorov[1], *V. Asming*[2]
[1]*Kola branch of Geophysical Survey of RAS, Apatity, Russia*
[2]*Geophysical Survey of RAS, Kola branch of Geophysical Survey of RAS, Apatity, Russia*

In European Arctic seismic stations are distributed rather sparsely. It is a common situation there when a weak earthquake is recorded by a single seismic station. In such conditions arrays are of great importance for seismic monitoring. So it is desirable to be able to detect and locate earthquakes by a single station or array.

We propose an automated routine which combines methods of array processing and three-component station processing for detection and location of seismic events. In this routine we have united beamforming and polarization analysis algorithms. In addition, some properties of signal envelopes are used to screen out false alarms of the detector. Detection and phase arrival time picking are based on statistical determination of ambient noise level and autoregressive technique.

We propose the idea to analyze couples of detected phases simultaneously and check a hypothesis that first phase is P-wave and second one is S-wave of the same event. For this we use two azimuth-depended functions: joint beamforming and joint polarization.

The idea of joint beamforming method is to make beamforming simultaneously for assumed P and S fragments and use related time delays calculated for P and S wave velocities.

The routine was used for processing data of three arrays placing in European Arctic: Spitsbergen archipelago (SPITS), north-east of Norway (ARCES) and Kola Peninsula (APA). The results show that using of proposed algorithms allows getting bulletins of events with a small number of false alarms and missing events.

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IUGG-2450

Array-based techniques for study of the deep mantle and core

G. Helffrich[1], *S. Kaneshima*[2]
[1]*ELSI, Tokyo Institute of Technology, Tokyo, Japan*
[2]*Earth and Planetary Sciences, University of Kyushu, Fukuoka, Japan*

Since the work of Mykkeltveit et al. (1983), the existence of a quantitative theory for optimizing seismic array geometry led to the design of small aperture arrays following experience gained from LASA and NORSAR and codified in the Manual of Seismological Observatory Practice (Schweitzer et al. 2002). There are still array innovations yet to be discovered as Christie & Kennett (2007) showed with spiral designs. We discuss more organically structured arrays as exemplified by HiNet (Japan), the UW network (Washington State, USA), and USArray. Here criteria other than optimal slowness resolution govern site choices, and due to their large scale (100s of km) they lack a common timebase notwithstanding local clocks based on GPS time. Thus only relative slowness and azimuth differences may be measured relative to a reference arrival. We show that despite these operational limitations, their large apertures lead to optical diffraction limit on the angular resolution on the order of milliradians, remarkable beam sensitivity. We also show that their application is quite diverse: from point scatterer detection in the deep mantle to detection of the inner core shear wave, PKJKP. From on experience gained in these studies, we've learned that the best signal detector is the signal semblance. We review the basic concepts and their use in representative studies.

Joint Inter-Association Symposium

JS06d - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

IUGG-2494

Matched Field Processing and Correlation Detection with Seismic Arrays

D. Harris[1]
[1]*Deschutes Signal Processing LLC, Maupin, USA*

Traditional beamforming and frequency-wavenumber analysis assume a plane-wave structure for wavefields incident upon an array. At high frequencies and in strongly heterogeneous media, scattering and multipath invalidate the plane-wave assumption, leading to poor array detection and estimation performance. Matched field processing and array correlation detectors are alternative coherent processing techniques that allow more general signal structure in the form of calibrated templates. Matched field processing is a narrowband method developed originally by the underwater sound community as a model-based technique, but has recently been adapted in empirical form to seismic applications. Array correlation detectors and their generalization, subspace detectors, are wideband techniques that find application as exquisitely sensitive detectors of repeating events. These techniques are successful in their empirical forms, which are relative methods requiring master events for calibration. This fact limits their applicability to repeating events in relatively small geographic regions. However, large-scale, autonomous calibration approaches under development use the entire recording history at an array to generate thousands of empirical templates covering broad geographic regions. And as 3D velocity models improve, there is a prospect that, at long periods, templates may be generated by synthetics, allowing extension of these techniques to detection and estimation in aseismic regions. This presentation briefly introduces and describes the methods and provides a number of examples at local and regional distances.

Joint Inter-Association Symposium

JS06d - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

IUGG-2540

Automatic location of local swarm earthquakes using simultaneous array and sparse network waveform stacking

N. Karamzadeh[1,2]*, S. Heimann*[1]*, F. Grigoli*[2]*, T. Dahm*[1,2]*, F. Krüger*[2]
[1]*Helmholtz Centre Potsdam- GFZ German Research Centre for Geosciences, Physics of Earthquakes and Volcanoes, Potsdam, Germany*
[2]*University of Potsdam, Institute of Earth and Environmental Sciences, Potsdam-Golm, Germany*

The aim of this study is to present an automatic earthquake location method which allows simultaneous use of array and sparse network waveform data. We have extended an existing method of automatic earthquake location based on waveform stacking which has been tested successfully in several local and regional networks as well as micoseismic monitoring applications (Cesca et all, 2014; Grigoli et all, 2013). In many seismic monitoring tasks, seismicity is recorded using both arrays and networks, while the data are processed mainly separately. Hence, adapting the waveform stacking method to process arrays and networks data simultaneously is of great advantages. The original location method is based on stacking STA/LTA traces along theoretical arrival time surfaces of P and S phases related to a trial hypocentral location. Iterating this procedure on a three-dimensional grid that includes the whole seismogenic volume, a multidimensional matrix is obtained which its absolute maximum corresponds to the coordinates of the seismic event. In this research, coherent arrival of phases with large amplitude, e.g. P and S phase, for an assumed source are investigated and coherency of corresponding beams are measured. The value of coherency is assumed as another value to judge about the final location, beside the stacked STA/LTA coherency factor. In addition the STA/LTA of array beam is used in the STA/LTA stacking procedure as a high quality/weight signal. Accordingly aside from network data, further information about the source location is considered in the location task which leads to reduction in location uncertainty.We present test cases using synthetic data as well as some examples of real data from the earthquake swarm region in NW Bohemia.

Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-538

Advances in subterranean electric instrumentation applying on a global scale

V. Bobrovskiy[1]
[1]*Distant School Cosmic-Meteo-Tectonics,*
Electric circuits and pulse electrical processes in the Galaxy-Helio-Planets System, Petropavlovsk-Kamchatskiy, Russia

Last few decades the geophysics, astrophysics and cosmophysics have run tight together. Theoretical, empirical and experimental researches were carried out to study nonstationary processes in subterranean, overground spheres, near Earth space and Solar system. The question is to determine a common nature of different phenomena, their relationship and variability. Electric circuits approach advances knowledge in the areas of the nonstationary phenomena and deals with new engineer-based instrumentation to investigate local manifestation of global electric phenomena. Since 1990 such new technique was applied to observe pulse subterranean electric parameters on the boundary of the tectonosphere-atmosphere on Kamchatka. Pulse manifestations of subterranean electric parameters are the essential part of electric processes in the electric circuits closed through the Earth’s core and solar corona (modified Solar Terrestrial Energy Program 1990/95 scheme) and in gigantic electric circuits of the Solar System and Galaxy. New technique to observe subterranean electric parameters involves the operational (from 30 days to “0”) prediction of tectonic sporadic phenomena. Since 2012 subterranean electric instrumentation network has covered northern hemisphere. The report sums recent activities in the field and propose the necessity to set subterranean electric instrumentation all over the globe.

Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-539

The NORSAR Long Period Detector: a tool for surface waves detection and parameter extraction

N.L. Celli[1], *J. Schweitzer*[2], *J. Fyen*[3]
[1]*Università degli studi di Trieste, Geoscience, Trieste, Italy*
[2]*NORSAR, Seismology, Kjeller, Norway*
[3]*NORSAR, National Data Center, Kjeller, Norway*

The deployment of new broadband instruments during 2012 at all sites of the large NOA array in central Norway allows detection and detailed analysis of long period surface waves over a large frequency range. We developed a real-time detection algorithm focused on teleseismic Rayleigh waves recorded with the 42 vertical components of the array. The detector has been tested for two years of data (2012-2014) and is now in regular operation at NORSAR. The detector is based on an STA/LTA algorithm and on the following signal parameter extraction broadband f-k analysis. The STA/LTA detector and the f-k analysis parameters have been adjusted and set frequency dependent, in order to correctly work over the interesting period range 10 – 50 s of the dispersive Rayleigh waves.
The North Atlantic is a permanent, partly very strong source of oceanic microseism observed at NOA. This microseismicity is regarded as noise but has Rayleigh-wave characteristics, with frequencies and propagation velocities as seismic surface waves. A clear separation between these two signals is not possible, but the application of wider bandpass-filter ranges reduces the amount of false detector triggers.
A post-processing event association shows that the new fine-tuned detection and analysis algorithm can provide up to 60% of true seismic detections, which is a significant improvement with respect to the processing algorithm implemented at the International Data Center of the Comprehensive Nuclear-Test-Ban Treaty Organization in Vienna, by detecting previously undetected surface waves signals.

Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-540

Regional seismic monitoring using 3-C array

I. Sanina[1], I. Kitov[1], S. Kishkina[2], S. Volosov[1], M. Nesterkina[1], N. Konstantinovskaya[1]
[1]Institute Of Geospheres Dynamics, Seismological Methods Of Lithospher Study, Moscow, Russia
[2]Institute Of Geospheres Dynamics, Near-surface geophysics, Moscow, Russia

A small aperture array consisting of seven 3-C sensors was tested for the purposes of regional seismotectonic monitoring. The aperture of several hundred meters is most suitable for detection and identification of the high-frequency regional P- and S-phases from sources within the Russian platform where this array was installed. The Russian platform is an aseismic area and almost all regional sources with magnitudes from 1.0 to 3.5 are associated with mining activity. These sources generate distinct P- and S-waves of compatible amplitude recorded by the array. However, the S-waves are most prominent at horizontal channels and are below the level of microseismic noise at vertical channels even after stacking of several channels. In this case, the 3-C array demonstrates a higher detection and phase identification capability than the vertical sub-array. We use seven quarries at distances from 50 km to 340 km with different back azimuths and compare the detection list (origin times, SNR, azimuth and slowness estimates) obtained by the sub-array consisting of only vertical (V-) channels with similar lists obtained by the sub-arrays of horizontal components (N-S, E-W, T, and R) as well as with the list obtained using all 21 channels. The V-component sub-array demonstrates a superior detection capability for the P-wave arrivals, but misses many S-waves. In a few cases, such S-waves were the only phases detected and the relevant events would be missed without the horizontal components. The 3-C array provides a significant improvement in detection of regional events.

Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-541

Improvement of the automated data processing system at KNDC

D. Gordienko[1], *J. Schweitzer*[2], *S. Gibbons*[2]
[1]*Institute of Geophysical Research, KNDC, Almaty, Kazakhstan*
[2]*NORSAR, NORSAR, Kjeller, Norway*

Since 2001, the Center for Acquisition and Processing of Special Seismic Information of RSE IGR (KNDC) in Kazakhstan applies the NORSAR array processing software together with own developed software tools. More than 10 years of on-line data processing by using this technology has shown its reliability and effectiveness for automated detecting and processing of seismic events from different regions in Kazakhstan and Central Asia.

However, a larger update of the processing system was needed because the used computers became outdated and the original software was not able to analyze data from the large-aperture Kurchatov-Cross seismic array. The key features of the updated processing system is that it runs on OS Linux instead of OS Solaris, and the additional possibility to use data from the large-aperture Kurchatov-Cross seismic array, originally designed to record teleseismic events. This array is an auxiliary station of the IMS system and has a non-standard configuration in comparison with other seismic arrays in Kazakhstan and the IMS. The algorithm for signal detection by this array is significantly different from the one used for seismic events recording by small-aperture arrays of standard configuration. The inclusion of this array in the daily regional monitoring task can enhance significantly the event location accuracy by automated processing software and improve the quality of the KNDC automated bulletin.

In November 2014, the new upgraded software was taken into test-mode operation, and first results of this new processing system will be presented herein.

Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-542

Localization of Infrasound Event Epicenters with use of the Data of Two Kazakhstan Infrasound Arrays

A. Smirnov[1]*, V. Dubrovin*[1]*, J. Vergoz*[2]
[1]*Institute of Geophysical Researches, Data Processing Group, Almaty, Kazakhstan*
[2]*CEA, LDG, Bruer-le-Chatel, France*

Kazakhstan National Data Center (NDC) has bulletins of infrasound detections constantly calculated with the use of the data of two infrasound arrays: IS31-Aktyubinsk – since 2001 and Kurchatov – since 2011. IS31- Aktyubinsk has been installed to the north-west of Kazakhstan, Kurchatov infrasound array – to the north-east of Kazakhstan. However, during more than two years the data of Kazakhstan infrasound arrays have been processed independently.
Infrasound arrays have an important difference from the seismic ones: according to data of a single seismic array one can localize a signal source, having determined azimuth to the source as per the difference of arrival times, recorded by various elements of the array and epicentral distance (for example, as per difference of arrival times of various phases). For the localization of epicenter of infrasound signals at least two arrays are required. In presence of two or more arrays the epicenter location is determined as per backazimuth cross-bearing. First experiments of application of the cross-bearing have shown that solving the task of localization of epicenters is complicated with a greater number of false resolutions. This result was reported at the Infrasound Technology Workshop 2012 in Korea. NDC of France has offered assistance in solving the tasks on localization.
The paper presents technology of data processing in the network of infrasound stations implemented in “Locinfra” software package designed at NDC of France. Even first results of localization of infrasound source epicenters by Kazakhstan arrays data show that Kazakhstani infrasound network has got very promising monitoring capability.

Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-543

The experience of seismic monitoring of Nuclear Power Plants territory with small seismic array

S. Kishkina[1], *I. Sanina*[1]
[1]*Institute of Geospheres Dynamic, Russian Academy of Science, Moscow, Russia*

The issue of safe construction and operation to nuclear power plant has become the focus of attention after the Fukushima nuclear disaster. The security of objects having potentially high level of damage is very important even when the probability of danger is low. As it is, for example, in the case of seismic safety for nuclear power plant which are located in a non-seismic areas. The probability of a significant earthquake in the nuclear power plant region is low, but the consequences of events could be catastrophic for the vast territory in case the earthquake happened.

We have conducted a series of seismological monitoring at the sites of several nuclear facilities. Our experience tells that the observing system should register the seismic signals having the magnitude from 3 up -1. We have detected weak seismic signals having magnitude of about and even less than 0, which were located in the fault zones and zones of “dynamic influence of faults” at all sites. The registration of weak events allows us to have more representative statistics and install currently activated structures. The estimation of parameters changes in time is important as well for a purpose of development the methods for prediction the catastrophic events.

For most parts of Russia the seismic monitoring is performed in the non-seismic areas having thick sedimentation masses under a significant anthropogenic bondage. We used a small-aperture seismic array that allows to get better detection and location of weak signals and to locate events associated to industrial blasting. The main difficulty is to find a non-antropogenic seismic signals as we have more then thousand signals per month and no more than 10 of them are nature.

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Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-544

On analytical computation of acoustic scattering by prolate and oblate spheroids and its applications to ocean acoustics

J.D. González[1], E. Lavia[1], S. Blanc[1], I. Prario[1]
[1]Argentinean Navy Research Office. UNIDEF National Council of Scientific and Technical Research, Underwater Sound, Vicente López, Argentina

The interior of the ocean is full of a great variety of objects whose shape can be approximated by a prolate spheroid (such as elongated fish, swimbladder fish, some phytoplankton, zooplankton and submergible vehicles) or by an oblate spheroid (such as other flattened type of fish, phytoplankton, zooplankton, submergible vehicles and also some fish shoals). Spheroidal wave functions have been used for over a century in dealing with scattering of sound by spheroids. These functions constitute analytical solutions of the wave equation when solving boundary value problems of acoustic scattering in prolate and oblate spheroidal coordinates. The advantage of considering analytical solutions of the wave equation lies upon the fact that they solve it exactly and consequently they don't need additional validation. However, their computation is a complex task and it requires numerical efficient methods. Only a few of the codes that have been developed and documented in the literature for certain particular scenarios (solutions valid for far-field conditions, limited scatterer size-wavelength ratios, ideal scatterers), are easily available. The purpose of this presentation is to provide the theoretical results obtained when modelling the acoustic scattering of soft, liquid and rigid prolate and oblate spheroids for an extended range of conditions of interest in ocean acoustics. Ad-hoc codes were implemented. Their predictions are compared with measurements for several marine organisms. Differences involved in computing prolate spheroidal wave functions and oblate ones are discussed in detail.

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JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-545

Depth estimation of Hindu Kush earthquakes using 3D backprojection of kurtosis processed regional P-waves

G. Euler[1], *H. Hartse*[1], *G. Randall*[1]
[1]*Los Alamos National Laboratory, Geophysical Modeling and Characterization, Los Alamos, USA*

We explore the use of 3D frequency-domain Capon backprojection of first arriving P-waves from earthquakes located in the Hindu Kush region to estimate source depth. In particular, we focus our efforts on discriminating between crustal and subcrustal earthquakes where depth phases (pP, sP) are difficult to identify. Subcrustal earthquakes sometimes display seismic amplitude characteristics that are similar to explosions, making identification of subcrustal earthquakes an important task in treaty monitoring. Our data consist of vertical component seismic recordings from a broad network of IMS arrays and individual stations at regional distances (<30deg). Such a dataset is highly incoherent and so co-processing the waveforms typically requires envelope processing that dramatically impairs source localization. Here we transform our P-wave dataset using sliding windows of kurtosis, a higher-order statistic, to derive impulsive and coherent characteristic functions that highlight P-wave onsets and provide high resolution source localization for backprojection. To assess confidence in our depth estimates, we analyze our dataset in light of network response functions and independent depth estimates for a subset of earthquakes.

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JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-546

Northern Finland seismological network: A tool to analyse long-period seismological signals

E. Kozlovskaya[1]*, H. Silvennoinen*[1]*, R. Hurskainen*[1]*, J. Narkilahti*[1]*, J. Nevalainen*[1]
[1]*University of Oulu, Sodankyla Geophysical Observatory/Oulu unit, Oulu, Finland*

Seismological observations at the University of Oulu and Sodankylä Geophysical Observatory started in1965 using short-period seismic instruments. During 2005-2008 and 2013-2014 the SGO enhanced the number of stations and equipped them with the VBB seismic sensors. In 2013-2014 The stations are located at latitudes from 65 deg N to 68 deg N. They form the Northern Finland Seismological Network (FN-Network). Since 2014 it is the part of Finnish EPOS research infrastructure (FIN-EPOS). At present, the data of the FN-network are routinely used for monitoring of seismic activity in Northern Europe and world-wide and information about seismic events is published in several on-line bulletins. Due to the recent mineral exploration and mining boom in northern Finland, a new task for the FN-network will be recording and analysis of mining-induced seismicity and estimating of seismic hazard associated with it.

During installation, particular measures were taken in order to improve instruments performance at long periods. In Arctic conditions the performance of broadband seismic instruments is affected by large ambient temperature variations and geomagnetic field disturbances (geomagnetic pulsations). Analysis of data recorded by the FN-network shows that the network is capable to detect signals in the period range of 30-140 s produced by slow glacial events from Greenland and events in the northern part of the Mid-Atlantic Ridge and Russian Arctic. This motivated further enhancement of the FN-network during the EPOS implementation phase. In 2015-2017 four new VBB seismic stations will be installed in the Finnish Lapland. Together with the existing stations, they will form a broadband seismic array aiming at detection and location of seismic events in long-period range.

Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-548

The upgraded ENIGMA magnetometer array

G. Balasis[1]*, I.A. Daglis*[2]*, N. Melis*[3]*, C. Papadimitriou*[1]*, H. Kontoes*[1]
[1]*National Observatory of Athens, IAASARS, Athens, Greece*
[2]*University of Athens, Department of Physics, Athens, Greece*
[3]*National Observatory of Athens, Institute of Geodynamics, Athens, Greece*

The **HellENIc GeoMagnetic Array (ENIGMA)** is a network of 3 ground-based magnetometer stations in the areas of Trikala, Attiki and Lakonia in Greece that provides measurements for the study of geomagnetic pulsations, resulting from the solar wind - magnetosphere coupling. ENIGMA magnetometer array enables effective remote sensing of geospace dynamics and the study of space weather effects on the ground (i.e., Geomagnetically Induced Currents - GIC). ENIGMA contributes data to SuperMAG (http://supermag.jhuapl.edu/), a worldwide collaboration of organizations and national agencies that currently operate more than 300 ground-based magnetometers. ENIGMA is currently extended and upgraded receiving financial support through the national funding KRIPIS project and European Commission's BEYOND project. In particular, the REGPOT project**BEYOND** is an FP7 project that aims to maintain and expand the existing state-of-the-art interdisciplinary research potential, by Building a Centre of Excellence for Earth Observation based monitoring of Natural Disasters in south-eastern Europe, with a prospect to increase its access range to the wider Mediterranean region through the integrated cooperation with twining organizations. The ENIGMA network is used within BEYOND in an attempt to address the issue of earthquake predictability by studying electromagnetic signals attributed to the coupled lithosphere-atmosphere-ionosphere system as one of the most promising potential pre-seismic transients.

Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-549

Deconvolution enhanced direction of arrival estimation applied to ocean induced microseisms

M. Gal[1]*, A. Reading*[1]*, S. Ellingsen*[1]*, S. Gibbons*[2]*, K. Koper*[3]
[1]*University of Tasmania, Physical Sciences, Hobart, Australia*
[2]*NORSAR, Geophysics, Kjeller, Norway*
[3]*University of Utah, Geology and Geophysics, Salt Lake City, USA*

Microseisms in the range 2-10 seconds are mainly generated in deep oceans as body waves and near coastal regions as surface waves. It is common to observe multiple arrivals with a variety of slowness vectors. It is therefore desirable to measure multiple arrivals accurately. Popular ways to estimate the direction of arrival of ocean induces microseisms are the conventional (fk) or adaptive beamformer (Capon). These techniques show robust estimates, but are limited in their resolution capabilities, hence do not detect all arrivals. One of the limiting factors in seismic arrays is the array response, which can strongly influence the direction of arrival estimation of weaker sources. In this work, we apply the CLEAN-SC algorithm widely used for the mapping of acoustic sources. The algorithm iteratively removes the strongest sources and their side lobe imprint and replaces them with a clean beam. We first apply CLEAN-SC to synthetic data to show its performance under known conditions and then evaluate real data from a range of arrays with apertures between 10 and 70 km including WRA and ASAR. We find that the CLEAN-SC can distinguish multiple weaker sources that were previously estimated as a single arrival for both synthetic and real data.

Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-550

Improving estimates of transfer functions for electromagnetic arrays using multivariate approach

M. Smirnov[1], *G. Egbert*[2]
[1]*University of Oulu, Oulu, Finland*
[2]*Oregon State University, CEOAS, Corvallis, USA*

With advances in electromagnetic (EM) geophysical instrumentation large synoptic digital EM array datasets are increasingly common. We developed and validated multivariate (MV) analysis scheme (MsDEMPCA, for Missing data EM Principal Components Analysis) which can fully exploit the simultaneous character of these data. Here we focus on applications of MsDEMPCA to several large magnetotelluric arrays: Magnetotellurics in Scandes (MASCA), IMAGE observatory data and various EarthScope MT arrays, with the goal of demonstrating how the MV approach can clarify signal and noise characteristics, improve estimates of TFs and quantify bias errors.

As discussed in Smirnov and Egbert (2012) one can apply MV statistical methods to EM array data having missing data to reduce bias, improve signal- to-noise ratios, and provide better control over source effects and coherent noise contamination in estimates of EM transfer functions (TFs). Within the framework of the MV analysis we explore several different approaches to estimate of these TFs. Most importantly we quantify bias errors due to source field effects as well as man made noise.

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JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-551

Improved detection and parameter estimation for regional S-phases using the fully 3-component ARCES array

S.J. Gibbons[1], *J. Schweitzer*[1], *M. Roth*[1], *T. Kværna*[1]
[1]*NORSAR, Seismology and Test-Ban-Treaty Monitoring, Kjeller, Norway*

In September 2014 all 25 sites of the ARCES seismic array in Norway were upgraded to 3-component stations, making it the first fully 3-C International Monitoring System (IMS) seismic array. S-phases are of paramount importance for detecting and locating seismic events at regional distances and it is important that these phases are both detected and attributed accurate slowness estimates. The estimated apparent velocity and backazimuth identify the phase and provide phase association algorithms with information necessary to form a high quality seismic event hypothesis. Previously, ARCES had 3-C stations at four sites only. While these 3-component seismometers were highly beneficial for detecting regional S-phases, it was often more reliable to perform f-k analysis on the 25 vertical sensors rather than on the rotated horizontal traces. We compare systematically the signal-to-noise ratio (SNR) on transverse and vertical beams for S-phases from regional events recorded since the upgrade. The horizontal traces provide both increased SNR and coherence, improving the stability of f-k analysis. The improved S-phase coherence on the transverse rotations provides the basis for superior S-phase detection capability using F-detectors and other coherence-based algorithms. The upgrade of other IMS seismic arrays to fully 3-C arrays would likely improve global event detection and location capability significantly.

Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-552

A new digital system of pinger control of deep-water oceanographic devices

T. Demidova[1], *A. Nosov*[2]
[1]*P.P.Shirshov Institute of Oceanology, Physics of the Ocean, Moscow, Russia*
[2]*P.P.Shirshov Institute of Oceanology, Acoustic Lab, Moscow, Russia*

A new complex of a real-time pinger control of the height of research devices off the bottom, developed in IORAN, was tested and used in several marine expeditions. The complex includes a new digital registration system and a pinger of a new generation. Modern electronic components and a design intended specifically for deep-water oceanography allowed to lessen the weight of the pinger, reduce size and simplify it. The pinger provides stabilized 12 kHz-pulses of 0,5, 1 ? 2 ms and safe performance for a long time at depths upto 6000 m. The registration system includes an electronic receiver unit with ADC and synchronization, software, and high-precision calibration hydrophone. The software is installed at any modern computer. Electronic units are designed using a controller of Mega-128 type. A low-level program for the controller allows digitization of signals at a desired time with the exact interval of digitizing of 2 s. Interface program provides visualization of the signals on the monitor in real time and record them in the computer's memory with the possibility of repeated screening. A wide range of amplification allows the operator to allocate very weak signals among noise and suppress 'false' reflections observing the main reflection from the bottom. For different pulse lengths, appropriate record scanning modes are provided. Log grid and a scale slider facilitates measurement of the height off the deep bottom with an accuracy better than 0,5-1 meters depending on the mode. Synchronization of the recorder and a pulsing time of a specific pinger is made on board by software using a hydrophone calibration. The results showed a high effectiveness of the new registration system with the new pinger evaluated by the signal/noise ratio in recorded signals.

Joint Inter-Association Symposium

JS06p - JS06/JP06 Array Techniques for Monitoring the State of the Earth (IASPEI, IAPSO, IAGA) / Acoustical Oceanography (IAPSO, IASPEI)

JS06p-553

High-resolution variations of teleseisms recorded by a highly-dense array on the San Jacinto fault zone

F. Wu[1], *Y. Ben-Zion*[2], *Z. Ross*[2]
[1]*SUNY Binghamton/USC, Geological Sciences, Binghamton, USA*
[2]*University of Southern California, Department of Earth Sciences, Los Angeles, USA*

A highly-dense Nodal array with 1108 vertical (10 Hz) sensors was deployed around the San Jacinto fault zone south of Anza, California, for ~4 weeks in 2014 in ~ 600 m x 600 m box configuration (nominal instrument spacing 10-30 m). In addition to recording local earthquakes, the ambient noise field and some small explosions, we have found that recorded teleseismic signals (~1 Hz) are coherent across the array. Eight M5.6-6.5 events in the SW Pacific and South America generated clear and coherent P waves. Although different wave groups appear at all stations, there are distinct and subtle variations in the later phases (within ~10 seconds of the first arrival). Because of the coherence of waveforms and high sampling rate (500 sps) precise relative arrival times at each station can be determined to within 0.002 sec or better. The maximum delay within the tight array is on the order of 0.3 seconds. While the overall delay times can probably be attributed mostly to near-surface variations, as the wave paths in deeper parts of the crust to the array stations are similar, the different phases can be correlated to differences in crustal structures near the San Jacinto fault zone.

Joint Inter-Association Symposium

JS02a - JS2/JS1/JA3 Physics and Chemistry of Earth and Planetary Interiors with Implications for their Structure, Process and Evolution (IASPEI, IAVCEI, IAGA, SEDI, IACS) / Planetary Physics (IASPEI, IACS) / Geophysical Constraints on Geodynamical Processes (IAGA, SEDI, IASPEI, IAVCEI)

IUGG-4353

Two spatiotemporal scales of mantle dynamics

A. Dziewonski[1], V. Lekic[2], B. Romanowicz[3]
[1]Harvard University, Earth and Planetary Sciences, Cambridge- MA, USA
[2]University of Maryland, Geology, College Park- MD, USA
[3]University of California- Berkeley, Earth and Planetary Sciences, Berkeley- CA, USA

Recent 3D global shear velocity mantle models derived from datasets able to resolve the structure from Moho to CMB show the presence of 3 shells with different characteristics: 1) From Moho to ~300 km depth (Zone 1), the structure is dominated by cooling of oceanic plates and by cratons, as reflected in the peak at degrees 4-6 in the spherical harmonic spectrum; 2) A transition region (Zone 2) from ~400-1000 km, where the spectrum is whiter except for a peak at degree 2 near the 660 km discontinuity; 3) Below 1000 km (Zone 3), the structure is weaker, with a white spectrum. Starting around 1800 km, degrees 2 and 3 increase and become dominant, reaching a maximum at the CMB. This long wavelength structure is vertically coherent but decorrelated from that in Zone 2. It corresponds to the 2 large low shear velocity provinces (LLSVPs) separated by a circum-Pacific ring of higher than average velocities (CPHSVR).

Comparing these results with the history of plate motions, and in particular, subduction during the last 200–500 Ma, we infer that circulation should be more vigorous in Zone I, with the characteristic time of major changes in plate motions (10 – 50 Ma). However, circulation in Zone 3 may be significantly more sluggish: the common perimeter of major subduction zones coincides with the CPHSVR of Zone 3 and has remained unchanged during the last 200 – 500 Ma. The LLSVP complement of the CPHSVR was named Mantle Anchor Structure (MAS) by Dziewonski et al. (2010) who speculated that it may be very long lived. Vertically coherent low velocity plume like features within the MAS as seen in a most recent mantle model further support the inference of a very high viscosity Zone 3.

What is needed is a numerical model of mantle flow consistent with these observations.

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IUGG-4855

Attenuation and Q-values in the crust and upper mantle beneath Uturuncu Volcano, Bolivia

S. McNutt[1], *A. Farrell*[1], *H. McFarlin*[1]
[1]*University of South Florida, School of Geosciences, Tampa, USA*

Uturuncu Volcano, in SW Bolivia, has been inflating at 1-2 cm/yr over an area ~ 70 km wide. The PLUTONS project deployed 28 broadband seismometers at Uturuncu from Apr 2009 to Oct 2012. We present results of two complementary studies of attenuation. For the shallow crust (upper 15 km) attenuation of seismic waves is measured by calculating Q-values, using the method of single station spectral ratios by Frankel (1982). Large scatter in Q for various distances and travel times appears to be a function of variations in source depth and azimuth. Preliminary Q-values calculated for azimuths in 30° bins range from about 100 to 1000, with many showing 2X lower Q in the direction of the summit from each station. We also analyzed P waves from teleseisms. These show the presence of a strong attenuating zone at depth SE of the summit. Analysis of 5 P-wave phases from 4 earthquakes from Japan (NW, ~155º) shows a consistent 'shadow zone' of decreased amplitudes in a 14 by 33 km area SE of the summit. Observations from 2 events in the South Sandwich Islands (SE, ~45º) show similar effects although the geometry differs. Similar trends hold for events to the NE and SW of the volcano, which indicate a zone of decreased amplitude in the same region SE of the summit. The observed Q in the shallow crust is not low enough to produce the strong amplitude variations observed in the teleseismic data. Rather, the attenuation of P-waves that would otherwise be of uniform amplitude could be the result of ray paths traveling through a mid-crustal, low-velocity and low Q zone, either magma/mush, highly fractured rock, or some other cause. This attenuating zone may be located near the center of the inflation zone, and physical processes associated with it may be related to the observed inflation.

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IUGG-5209

Testing the geocentric axial dipole hypothesis using regional paleomagnetic intensity records from 0-300~ka

L. Ziegler[1], *C. Constable*[2]
[1]*Oregon State University, College of Earth- Ocean- and Atmospheric Science, Corvallis, USA*
[2]*University of California- San Diego, Scripps Institution of Oceanography, La Jolla, USA*

Globally distributed absolute and relative geomagnetic paleointensity records are used to estimate variations in geocentric axial dipole (GAD) moment. Geographic variability in heat flow and/or composition at the core-mantle-boundary (inferred from large low shear velocity provinces (LLSVPs) centered under Africa and the Pacific) is widely suspected to influence paleofield structure and dynamics. Long term departures from GAD structure should be visible from differences in regional axial dipole moment (RADM) reconstructions. We investigate this using a penalized maximum likelihood modeling method, and a comprehensive absolute and relative paleointensity data set to construct separate time-varying models of RADMs spanning 0-300 ka. Our results show systematic regional differences. Average RADM is higher in the Pacific and in Equatorial regions than in the Atlantic and in mid-high latitude northern hemisphere regions. Higher average RADMs are associated with lower overall field variability and less pronounced excursional signatures. Notably, the lower variability in the Pacific sector (whether defined by longitude band or by LLSVP location), suggests that the low paleosecular variation seen in the modern field is a long-lived feature, extending to at least the hundred thousand year time-scale. RADMs based on regions identified with LLSVPs show systematic deviations from the non-LLSVP group of records, with distinct characteristics for the African and Pacific provinces. In particular the African LLSVP generates more pronounced RADM lows associated with excursions, and overall decreases in paleointensity associated with excursions occur first in the Atlantic longitude sector and over the African LLSVP. RADMs are also compared with overlapping 0-10 ka field models.

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IUGG-5413

Iron snow, crystal floats and inner core growth: Modes of core solidification and implications for dynamos in terrestrial bodies.

D. Breuer[1], *T. Rückriemen*[1], *T. Spohn*[1]
[1]*DLR- Institute of Planetary Research, Planetary Physics, Berlin, Germany*

Recent planetary space missions, new experimental data and advanced numerical techniques have helped to improve our understanding of the deep interiors of the terrestrial planets and moons. In particular, crystallizing processes in iron-rich cores that differ from the classical Earth case, i.e. Fe snow and FeS crystallization, have been identified and found to be important for the cores of terrestrial bodies. The Fe snow regime occurs for pressures lower than in the Earth's core on the iron-rich side of the eutectic for which iron freezes first close the core-mantle boundary rather than in the center. FeS crystallization instead occurs on the sulfur-rich side of the eutectic. Depending on the core temperature profile and the considered pressure range, FeS crystallizes either in the core center or close to the core-mantle boundary. The consequences of the various crystallizing mechanisms on the core dynamics and the magnetic field generation will be discussed.

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IUGG-5612

SS precursor imaging of mantle transition zones with curvelet filtering

C. Yu[1], D. Elizabeth[2], M. de Hoop[3], M. Campillo[4], R. van der Hilst[1]
[1]Massachusetts Institute of Technology,
Earth- Atmospheric- and Planetary Sciences, Cambridge, USA
[2]Imperial College London, Earth Science and Engineering, London, United Kingdom
[3]Purdue University, Center for Computational & Applied Mathematics, Indiana, USA
[4]Université Joseph Fourier, Institut des Sciences de la Terre, Grenoble, France

SS precursors are widely used to image the mantle transition zone. It provides crucial data coverage of areas far away from sources and receivers. One of several challenges is the interference of SS precursors by phases such as multiples of S phase or core-diffractions of S. This problem is usually minimized by simply removing data from epicentral distances where phase interference may occur. While straightforward in use, this data selection criterion significantly degrades the quantity of available dataset in certain areas, such as, Hawaii.

We improve mantle transition zone imaging with SS precursors by retaining data in critical distance ranges while suppressing contaminating phases. To achieve the latter, we apply curvelet transform to the stacked SS image. In the curvelet domain, SS precursors and interfering phases are well separated into different scales and different orientations. We mask curvelet coefficients corresponding to the contaminating phases and apply an inverse curvelet transform to obtain a filtered SS image. Tests with synthetic (reflectivity) seismograms verify the effectiveness of curvelet filtering. Application of this technique to the imaging of the mantle transition zone beneath the Central Pacific shows substantial improvement of resolution and SNR. We systematically detect signals associated with scattering near 410 and 660 km depth, and also near 200-, 300-, 520-, and 800 km depth. Generally, the transition zone beneath the Central Pacific is thinner than the global average. We also detect significant moveout of “660” at smaller epicentral distances, especially SE of Hawaii. This moveout suggests the presence of unaccounted wavespeed anomalies or that the “660” is locally more complicated

than inferred previously.

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IUGG-0286

Numerical modeling of viscous behavior of a rock sample from Alamkooh in Iran

S. Mollaei[1], S. Mehrabian[2], I. Hassani[1], A. Mollaei[1]
[1]university of tehran, Engineering, Tehran, Iran
[2]university of tehran, Earth Physics, Tehran, Iran

In the materials literature it has been common practice to describe the effect of strain and strain rate on the flow stress using the flow law. According to Rutter (1998) in experimental studies when strain dependent weakening occurs, it might be expected that a period of steady state creep will occur until a critical strain for the onset of recrystallization has accumulated. At this point a transition from the strain-independent flow law to the strain dependent formulation will occur.

Numerical modeling of rock deformation can be carried out using flow laws obtained in the experimental studies. In this approach we applied a finite element program which is written to solve equilibrium problems in experimental rock deformation for the viscous behavior of a cylindrical rock sample (from Alamkooh in Iran) with necking under high pressure and temperature conditions. This implementation has been carried out by using the physical properties of the sample. The various kinds of validation procedures in particular stages are achieved. For example one of validation processes, has been made by using the analytical calculations for a single element with uniform deformation conditions. Some calculated results in terms of displacement versus force, deformed shape with marks of initial shape, stress and strain invariants are shown in figures. By referring to the relevant figures, it can be concluded that the numerical results give reasonably satisfactory predictions. This numerical study also has shown the complexities involved in the simulation of deformation for higher bulk strains and strain gradients, where there are significant shear strains developed at the free surface for the boundary conditions specified here.

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IUGG-1472

Development of a rotational Drickamer apparatus (RDA) and its applications to the deep mantle processes

S.I. Karato[1]
[1]*Yale University, Geology & Geophysics, New Haven, USA*

During the last ~10-15 years, there has been a major progress in the experimental studies on plastic deformation to extend the maximum pressure of experiments from ~0.3 GPa (~10 km depth in Earth) to a higher level. This development is based on a combination of the development of in-situ stress/strain measurement and the development of new types of apparatus to conduct quantitative deformation experiments. The former was made largely by Don Weidner at Stony Brook, USA. In this talk, I will review the development of a new type of deformation apparatus, RDA (rotational Drickamer apparatus) by which we have extended the pressure range of quantitative deformation experiments at high temperatures to ~ 28 GPa (at ~2100 K).

After explaining some basic features of RDA, I will present several results based on the use of RDA including (i) the determination of the pressure effects on deformation of (dry) olivine, (ii) deformation of wadsleyite and ringwoodite, (iii) deformation a mixture of bridgmanite and ferropericlase and (iv) the formation of metallic Fe under the narrow depth range in the lower mantle conditions.

The latter two sets of studies under the lower mantle conditions have a few important implications including the possible shear localization and the limited depth range where partial melting might occur in the lower mantle.

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IUGG-4488

Slab stagnation and buckling in the mantle transition zone: Petrology, rheology, and the geodynamics of trench migration

C. Bina[1], *H. Číková*[2]
[1]*Northwestern University, Department of Earth and Planetary Sciences, Evanston, USA*
[2]*Charles University in Prague,*
Faculty of Mathematics and Physics- Department of Geophysics, Prague, Czech Republic

Recent work indicates that subducting slabs may exhibit buckling instabilities and consequent folding behavior in the mantle transition zone for various dynamical parameters, accompanied by temporal variations in dip angle, plate velocity, and trench retreat. Governing parameters include both viscous (rheological) and buoyancy (thermo-petrological) forces. 2D numerical experiments show that many parameter sets lead to slab deflection at the base of the transition zone, typically accompanied by quasi-periodic oscillations in largely anticorrelated plate and rollback velocities, resulting in undulating stagnant slabs as buckle folds accumulate subhorizontally atop the lower mantle. Slab petrology, of mantle phase transitions and hydrated crust, is a dominant factor in this process (Cí*ková and Bina, 2013).

For terrestrial parameter sets, trench retreat is found to be nearly ubiquitous and trench advance quite rare, largely due to rheological and ridge-push effects (Cí*ková and Bina, 2013). Recently updated analyses of global plate motions indicate that significant trench advance is also rare on Earth, being largely restricted to the Izu-Bonin arc (Matthews et al., 2013). Thus, we explore conditions necessary for terrestrial trench advance through dynamical models involving the unusual geometry of the Philippine Sea region. Our 2D modeling of such geometries, in which distal subduction of the overriding plate overprints an opposed slab-pull force on the usual ridge-push at the trench, yields persistent trench advance interrupted by episodes of back-arc extension, demonstrating that trench advance can occur for terrestrial rheologies in such special geometries.

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IUGG-4614

The lower mantle water reservoir

J. Chen[1,2], M. Pamato[3], T. Inoue[4], S. Kakizawa[4], B. Yang[1], C. Ma[1], Y. Lin[5], T. Katsura[3], T. Kawazoe[3], Z. Liu[6]
[1]Center for High Pressure Science and Technology Advanced Research, HPSTAR, Changchun, China Peoples Republic
[2]Florida International University, CeSMEC, Miami, USA
[3]Universitaet Bayreuth, Bayerisches Geoinstitut, Bayreuth, Germany
[4]Ehime University, Geodynamics Research Center, Matsuyama, Japan
[5]Institute of Geology and Geophysics, Institute of Geology and Geophysics, Beijing, China Peoples Republic
[6]Carnegie Inst Washington, Geophysical Lab, Washington DC, USA

We have conducted a sequence of high pressure experiments to study water solubility in aluminous magnesium silicate perovskite (bridgmanite) as a function of pressure at 1900^{o}C. The experimental high pressures were generated using multi-anvil presses at Bayerisches Geoinstitut (BGI) for pressures up to 28 GPa and at Geodynamics Research Center (GRC) for pressures above 30GPa. The starting material for these experiments was a mixture of oxides ($Mg(OH)_2$, Al_2O_3 and SiO_2) with equivalent of about 5 mol % of Al_2O_3 and 15 wt % of H_2O. The structure and composition of the bridgmanite phase after high P/T syntheses were examined using x-ray diffraction (XRD) and electron probe microanalysis (EPMA). Water concentration in the sample was measured using secondary ion mass spectroscopy (SIMS) and Fourier transform infrared spectroscopy (FTIR). The measurements yield that the aluminous magnesium silicate birdgmanite with about 2 wt% of Al_2O_3 may take as much as 0.13 wt % of H_2O at the P/T condition of the top of the Earth's lower mantle and this solubility increases significantly with pressure. At the bottom of Earth's lower mantle, this bridgmanite may take nearly a couple of weight percent of water according to simple extrapolation of the experiment result, indicating that the capacity of water reservoir of the lower mantle can be as large as a few to ten oceans of water.

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IUGG-5460

Proton conduction and hydrogen diffusion in olivine: Implications for the role of grain boundary diffusion in enhancing conductivity

A. Jones[1]
[1]*Dublin Institute for Advanced Studies, School of Cosmic Physics, Dublin, Ireland*

Proton conduction is directly related to the diffusion of hydrogen through the Nernst-Einstein equation, but prior attempts to use this relationship have always invoked additional terms to try to reconcile proton conduction and hydrogen diffusion data. However, experimental data on hydrogen diffusion through the mineral lattice only constrain the rate of proton migration coupled with defects (such as vacancies) or coupled to polarons (electron holes mostly associated to ferric iron) and not the diffusion of uncoupled free protons. New diffusion experiments on olivine demonstrate that lattice diffusion associated to vacancies is indeed highly dependent on the defect site where hydrogen is bonded, but in any case is not fast enough to explain the observed laboratory proton conduction experiments. Hydrogen diffusion associated to polarons (redox-exchange) is significantly faster but still cannot explain the low activation energy typical of electrical conductivity measurements. A process of bulk diffusion, which combines lattice diffusion (either associated to redox-exchange or vacancies) with the far faster grain boundary diffusion, explains both the laboratory results and also field observations, and infers an average grain size of 0.5-2 cm at 100 km below the Jagersfontein kimberlite field on the Kaapvaal craton, which is consistent with petrological observations on xenolith material. Beneath the Gibeon kimberlite field on the nearby Rehoboth terrane, the higher conductivity observed cannot solely be explained by elevated temperature; either there is more water in the lithosphere (approx. double), or the average grain size is smaller (approx. half), or a combination of the two.

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IUGG-5491

Pressure and temperature dependence of dislocation mobility in the [100](010) and [001](010) slip systems is comparable in olivine

L. Wang[1]*, S. Blaha*[1]*, Z. Pintér*[1]*, S. Chariton*[1]*, R. Farla*[1]*, T. Kawazoe*[1]*,*
N. Miyajima[1]*, T. Katsura*[1]
[1]*Bayerisches Geoinstitut, Bayerisches Geoinstitut, Bayreuth, Germany*

The deformation experiments found the olivine fabric transition from A-type to B-type with pressure, which explains the rapid decrease in seismic anisotropy below 200 km depth. Since the results of the deformation experiments might be misleading due to the orders of magnitude higher stress and strain-rate conditions in deformation experiments than in the upper mantle, the observed fabric transition has to be examined by an independent technique.

A- and B-type fabrics should be produced by the dominant slip systems of [100](010) and [001](010), respectively. We therefore have determined the mobility of [100](010) edge (a-dislocation) and [001](010) screw (c-dislocation) dislocations at pressures of 0 to 12 GPa and temperatures of 1470 to 1770 K by the dislocation recovery technique, in which the dislocation mobility is determined under quasi-hydrostatic conditions. Dominance of the a- and c-dislocations under [100](010) and [001](010) simple shear geometries were confirmed by TEM observations.

The experimental results show: (1) The mobility of a-dislocation is almost identical to or up to 0.5 orders of magnitude lower than that of c-dislocation at ambient pressure. (2) The activation energies of both dislocations are comparable, about 400 kJ/mol. (3) The activation volumes of both dislocations are also comparable, about 2.6 cm^3/mol.

The comparable activation energies and volumes suggest that the transition of A-type to B-type fabric by pressure and/or temperature is unlikely. The rapid decrease in seismic anisotropy below 200 km will be due to decrease in flow rate in this depth.

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IUGG-1271

Dawn arrives at ceres: initial results

C. Russell[1], C. Raymond[2], A. Nathues[3], P. Gutierrez-Marquez[3], M.C. DeSanctis[4], E. Ammannito[1], T. Prettyman[5], A. Konopliv[2], R. Park[2], H. McSween[6], R. Jaumann[7], S. Joy[1], C. Polanskey[2], M. Rayman[2], . Dawn Science Team[1]
[1]University of California- Los Angeles, Institute of Geophysics and Planetary Physics, Los Angeles, USA
[2]California Institute of Technology, Jet Propulsion Laboratory, Pasadena, USA
[3]Max Planck Institut, Max-Planck-Institut fur Sonnensystemforschung, Katlenburg-Lindau, Germany
[4]Istituto Nazionale de Astrofisica, Istituto di Astrofisica e Planetologia Spaziali, Rome, Italy
[5]Planetary Science Institute, Planetary Science Institute, Tucson, USA
[6]University of Tennesse, Planetary Geoscience Institute and Department of Earth and Planetary Sciences, Knoxville, USA
[7]Institute of Planetary Research, Germany Aerospace Center, Berlin, Germany

The Dawn spacecraft left Vesta orbit in September 2012 and set sail for Ceres, the second of its targets and the most massive body in the main asteroid belt. Unlike Vesta associated with both a prevalent class of meteorites the HEDs and an extensive family of asteroids, the vestoids, Ceres has neither associated meteorites or a family of asteroids. Thus while the prime objectives of the Vesta investigation were paradigm testings, the prime objectives of the Ceres investigation are pure discovery with few clues from remote sensing.

Dawn is equipped with a framing camera with one clear and seven color filters, a visible and infrared mapping spectrometer, VIR, a gamma ray and neutron detector, GRaND, and radiometric tracking for gravity determination. It obtained its first resolved image of Ceres on December 1, 2014. This 9-pixel across image has been used to improve the stray light from the framing camera. This improved correction benefits not only Ceres imagery but also all color images obtained at Vesta.

On approximately March 6, Dawn slips into orbit about Ceres. The initial orbit allows a search for any plumes emanating from the surface using a forward scattering geometry.

The Survey orbit at 4424 km altitude is reached in June. This orbit provides complete coverage for the VIR spectrometry. The next orbit is the High Altitude Mapping Orbit (HAMO) that provides stereo photogrammetry at an altitude of 1474 km. The final orbit is the Low Altitude Mapping Orbit (LAMO) at an altitude of 374 km. This orbit provides the GRaND elemental composition measurements and gravity data. Dawn's observations are scheduled to continue to June 2016.

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IUGG-1666

On the possible detection of a region with good electrical conductors at the bottom of the mantle

D. Jault[1], *N. Schaeffer*[2]
[1]*ISTerre, Grenoble Cedex 9, France*
[2]*ISTerre, CNRS, Grenoble Cedex 9, France*

Any information on the lowermost mantle conductivity obtained from the study of magnetic signals emanating from the core would help to constrain scenarios concerning the formation of the core and of the deep mantle or about ongoing chemical reactions at the core-mantle boundary (CMB). Today, the Swarm satellite mission gives us the opportunity to investigate how the rapid variations of the main magnetic field are affected by the electrically conducting mantle.
The usual approach consists in treating the conducting mantle as a linear time-invariant filter for the core magnetic field. The filter properties are almost independent on the presence of conducting rocks at the bottom of the mantle since the input magnetic field is considered to be prescribed at the CMB. This approach would be justified if the core could be treated as a solid and highly conducting body. Then, the electrical current sheet that arises at the top of the core cancels out any magnetic field induced outside (i.e. in the mantle). In reality, the magnetic perturbation in the fluid core is not confined to a boundary layer. We will illustrate this statement with combined studies of MHD in the core and conduction in the mantle. We plan to give two examples. First, we will simulate the geodynamo evolution in the presence of conductors in the mantle. Second, we will study the propagation of sub-decadal Alfvén waves, which can be subjected to both theoretical and numerical investigations.
Finally, there are, in all probability, strong lateral variations in the conductivity of the lower mantle. This implies that the radial magnetic field and the electrical potential are coupled through the electrical conduction in the mantle. We plan to discuss the significance of this effect from numerical simulations also.

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IUGG-1852

Spatial and temporal variation in Sr-Nd-Pb isotopic composition of Cenozoic alkaline basaltic rocks of the Bohemian Massif

V. Rapprich[1], *V. Erban*[1], *J. Mikova*[1], *T. Magna*[1], *Y. Kochergina*[1]
[1]*Czech Geological Survey, -, Praha, Czech Republic*

The Bohemian Massif (BM) was annealed during Variscan orogeny from several lithospheric domains; these can also be identified in the lithospheric mantle (Babuška – Plomerová 2013), but question emerges how the composition of pristine Cenozoic basalts (SiO_2<45 wt.% and MgO>7 wt.%) reflects individual domains of the mantle beneath the BM in space and time. Magmatism lasted since Eocene until Pleistocene and penetrated N part of the BM. 106 samples were characterized in terms of Sr-Nd-Pb isotopic compositions. The most enriched Nd isotopic fingerprint was identified in volcanic centers along the Eger Rift (ER), W of the Elbe zone (EZ, $\varepsilon Nd_i<3.5$). Slightly more depleted samples were traced with increasing distance from the major ER axis whereas the most depleted samples were documented in basalts more distant from the ER ($\varepsilon Nd_i>5$) with the highest values located in SW Poland ($\varepsilon Nd_i>7$). Sr isotopes give a similar picture. Regarding Pb, unradiogenic and highly radiogenic lavas were found in and around the Doupovské hory Mts. ($^{206}Pb/^{204}Pb$<19.4 and >20) whereas intermediate $^{206}Pb/^{204}Pb$ ratios were documented in the Teplá-Barrandian (TB) domain (19.9–20.3), the Ceské stredohorí Mts. and volcanoes E of the EZ (19.5–20.1). Collectively, the character of primitive basalts appears to be governed by the distance from the ER. Presence of enriched lithospheric mantle is suggested below the Saxothuringian (ST)/TB boundary west of EZ, that together with the parallel Lusatian Fault seem to be the most important tectonic features with dextral strike slip movement documented during the Late Paleozoic and Mesozoic (Ulicný et al. 2009). To the E of the EZ, suture between ST and TB/Moldanubian domains was shifted further S, with no volcanic rocks present. Supported by GACR project P210/12/1990.

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IUGG-5072

Last news from Planetary seismology : From the Moon and toward Mars

P. Lognonné[1]
[1]*Université Paris Diderot-*
Sorbonne Paris Cité- Institut de Physique du Globe de Paris,
Planétologie et Sciences Spatiales, Paris, France

46 years ago, in July 1969, Earth seismologists discovered the first data from a seismometer installed by the crew of Apollo 11 on the Moon. About 8 years later, in 1977, NASA decided to turned off the seismic network installed by the missions Apollo 12, 14, 15, 16 and 17 with about 12500 quakes on the detection score of the extremely sensitive Apollo Seismometers, including the Apollo 17 gravimeter. Surprisingly, discoveries from this unique set of data continue to be done by the science community and we first present the most recent results obtained in the re-processing of the Apollo data in the last years: re-estimation of the lunar crustal thickness, discovery of the Lunar core reflected seismic waves, characterization of the source dynamics of the deep moon quake and impacts, which are both exotic seismic sources not observed on Earth. These studies have strongly impacted the understanding of Lunar deep interior especially on which we will focus. We then discuss and present the few challenges remaining, not only in term of Apollo data processing, but also for future missions to the Moon.
We then move to Mars, where data will wait for the launch in March 2016 of the NASA InSight mission, which will carry to the Martian surface a 3 axis Very Broad Band and a 3 axis Short Period seismometer. Due to land on Mars in September 2016, it will restart the operation of a non-earth seismometer, 39 years (minus 2 days) after the end of the Lunar ALSEP seismometer's operations.
We present the mission's scientific perspectives, the technical challenges associated to the robotic installation of VBB instruments in an hostile and windy environment and the scientific strategy developed by the SEIS-InSight team to discover seismically Mars with a single seismic station.

Joint Inter-Association Symposium

JS02c - JS2/JS1/JA3 Physics and Chemistry of Earth and Planetary Interiors with Implications for their Structure, Process and Evolution (IASPEI, IAVCEI, IAGA, SEDI, IACS) / Planetary Physics (IASPEI, IACS) / Geophysical Constraints on Geodynamical Processes (IAGA, SEDI, IASPEI, IAVCEI)

IUGG-5311

HP-cubed, a Heat Flow Probe for Mars onboard the NASA InSight mission

T. Spohn[1], M. Grott[2], S. Smrekar[3], T. Hudson[3], N. Müller[2], D. Breuer[2], A.C. Plesa[2], C. Krause[4], O. Krömer[5], B. Banerdt[3]
[1]DLR Institut of Planetary Research, Berlin, Germany
[2]DLR Institut of Planetary Research, PLP, Berlin, Germany
[3]NASA, JPL, Pasadena, USA
[4]DLR, MUSC, Cologne, Germany
[5]DLR, RY, Bremen, Germany

The InSight Discovery-class mission to study the martian interior will deliver a geophysical package to the surface of Mars in 2016. The primary payload of the InSight lander consists of a seismometer and the HP-cubed heat flow probe. InSight will thus address fundamental questions of martian geophysics. The main mission goals are the determination of the size, physical state, and composition of the core and mantle, the thickness of the crust, and the thermal state of the martian interior. HP-cubed will measure the heat flow at the landing site in Elysium Planitia (139oE 1oN), and thereby provide an important baseline to constrain mantle potential temperatures and the bulk abundance of heat producing elements in the martian interior. HP-cubed will emplace a suite of sensors into the martian subsurface by means of a mechanical hammering mechanism tugging an instrumented tether. Sensors include temperature sensors and heaters to measure the thermal gradient and thermal conductivity of the regolith, tilt sensors to determine the position of the instrument in the ground, and a sensor to measure the deployed length of the tether. The instrument is planned to penetrate at least 3m – sufficiently deep to reduce errors from daily surface temperature forcings - and up to 5 m into the martian regolith and perform depth resolved measurements, from which the surface planetary heat flow can be directly determined. HP-cubed aims at determining the heat flow with an uncertainty better than 10%. In addition, HP-cubed has been augmented by a radiometer to determine the surface brightness temperature and aid in the data inversion.

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IUGG-5356

Seismic constraints on mixing and melting in Earth's mantle

S. Rost[1]*, H.L.M. Bentham*[1]*, D.A. Frost*[2]
[1]*University of Leeds, School of Earth and Environment, Leeds, United Kingdom*
[2]*Arizona State University, School of Earth and Space Exploration, Tempe, USA*

The large scale velocity structure of the Earth’s mantle has been imaged using tomographic methods since the early 1980s. These tomographic studies were essential for our current understanding of the dynamics, structure and composition of our planet. In modern seismological studies there is strong evidence for thermo-chemical or thermal heterogeneities in the form of features such as subducted slabs and the Large Low Shear Velocity Provinces, demonstrating the dynamic interior of our planet. On the other hand, structures on shorter scale-lengths have been resolved using high-frequency seismic methods predominantly on regional scales. These high-resolution methods help us to differentiate the compositional and thermal contributions to the velocity variations resolved in seismic tomography. Here we show results at the edge of the teleseismic resolution using scattered seismic energy in the high-frequency seismic wavefield to resolve small-scale structure with scale-lengths on the order of 10 km throughout the mantle. We use different seismic scattering probes to resolve the fine scale structure from crust to core. Our results point to strong lateral and radial variations in the strength and distribution of the fine scale heterogeneities throughout the mantle. We likely image mixing of crustal material into the ambient mantle in subduction zones as well as mixing and melting along the core-mantle boundary and perhaps the entrainment of recycled crustal material in mantle plumes. Our studies allow us to image mantle flow and small-scale processes that are essential for our understanding of the Earth’s composition and evolution.

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JS02p-395

Application of experimental rheology to natural deformation

S. Mollaei[1], *S. Mehrabian*[2], *I. Hassani*[1], *A. Mollaei*[1]
[1]*university of tehran, Engineering, Tehran, Iran*
[2]*university of tehran, Institute of Geophysics, Tehran, Iran*

The continental lithosphere has been modeled as a simple, thickness-averaged plate, with Newtonian or power law stress dependencies. By considering these models one can obtain extremely valuable insights into the large scale structures and dynamics of continental deformations. The high-temperature creep behavior of many crystalline solids is usually interpreted in terms of a constitutive flow law which shows that the stress is related to the strain rate and not to the finite strain and this has important implications for interpreting structures of ductile deformation which are observed in rocks. In general, in the midst of the complexities of detail arising from experimental rock deformation observations, a few simple principles have been applied in lithospheric deformation studies. At present, analytical and numerical simulation of the development of extensional, transcurrent, compressional and flexural deformation is becoming more representative of real geometries.

In this study we illustrate the concept of rheological stratification of the lithosphere, by assuming mechanical properties dominated by particular minerals in certain depth intervals of the lithosphere, quartz dominated upper crust, feldspathic lower crust and olivine upper mantel. It seems likely that the flow behavior of the microstructurally modified rocks in shear zones will effectively control the mechanical behavior of the lithosphere at all levels. It may be concluded that from experiments (at least for small strains up to nearly 20% shortening), a crude rheological stratification is expected to accompany the lithological stratification, where the lithosphere is expected to show bands of high strength at the top of each lithological 'stratum'.

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JS02p-396

The frequency-dependent seismic properties of cracked and fluid-saturated synthetic glass media

I. Jackson[1], Y. Li[1], E. David[1], S. Nakagawa[2], D. Schmitt[3]
[1]Australian National University, Research School of Earth Sciences, Canberra, Australia
[2]Lawrence Berkeley National Laboratory, Earth Sciences Division, Berkeley, USA
[3]University of Alberta, Department of Physics, Edmonton, Canada

In order to properly assess the potentially frequency dependent wave speeds of cracked and fluid-saturated rocks, access to a broad range of frequencies is required. To this end, conventional measurements of P- and S-wave speeds with ultrasonic (MHz) methods are being complemented by kHz-frequency resonant bar measurements in both extensional and torsional modes, along with sub-resonant forced-oscillation tests in both torsion and flexure that provide access to mHz-Hz frequencies. Such measurements have been conducted on a series of soda-lime-silica glass samples with porosities varying from 0 to 6%. Samples were prepared either from dense glass rod or by sintering glass beads under controlled conditions, and subjected to subsequent thermal cracking. Samples are successively measured uncracked and cracked, and dry and fluid-saturated with gas or water. The results show systematic increases in wave velocities or elastic moduli with increasing differential pressure (confining pressure minus pore pressure) – interpreted in terms of crack closure. Fluid saturation, especially with water, results in a substantial increase in the moduli measured at MHz frequencies - evidence that the ultrasonic technique is sampling the saturated isobaric regime – a finding to be clarified by resonant bar measurements in progress. A micromechanical model, based on Eshelby's results and using the differential effective medium scheme, yields crack density as a function of pressure and hence and crack aspect ratios, and for this inferred microstructure, theoretical estimates of the effect of saturation and frequency on elastic moduli. Such dispersion between Hz and MHz frequencies needs to be taken into account in seismological applications of laboratory wave-speed measurements.

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JS02p-397

Experimental investigation on the low-temperature plasticity of garnet

S. Mei[1], *G. Zhang*[1]
[1]*University of Minnesota, Earth Sciences, Minneapolis, USA*

The low-temperature plasticity of polycrystalline garnet has been experimentally investigated at high pressures (~4 – 9 GPa) and relatively low temperatures ($773 \leq T \leq 1273$ K) under anhydrous conditions. Experiments were carried out using a deformation-DIA apparatus on beamline at Brookhaven National Laboratory. In a run, differential stress and sample displacement were monitored in-situ using synchrotron x-ray diffraction and radiography, respectively. The low-temperature plasticity of garnet is constrained by our data with a value for the Peierls stress of 9.8 ± 0.3 GPa. This value is higher than that for olivine (~ 6 GPa); obtained in our previous study using similar techniques [Mei et al., 2010]. The low-temperature, high-stress flow behavior for garnet quantified in this study provides a necessary constraint on the rheological property of subducted lithosphere.

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JS02p-398

Studying the activity of slip systems of lower mantle minerals

S. Speziale[1], H. Marquardt[2], L. Miyagi[3], H.P. Liermann[4]
[1]GFZ German Research Centre for Geosciences,
3.3 Chemistry and Physics of the Earth, Potsdam, Germany
[2]BGI- University of Bayreuth- Bayreuth- Germany, BGI, Bayreuth, Germany
[3]University of Utah, Department of Geology and Geophysics, Salt Lake City, USA
[4]Photon Science- DESY, PETRA III, Hamburg, Germany

The main mechanism of energy transport in the Earth is convection. Mantle convection takes place by plastic flow of silicate and oxide minerals which make up this very thick layer of the Earth inner structure (80% of Earth volume).

Determining the deformation behavior of the minerals of the mantle at relevant conditions of pressure and temperature is necessary to perform realistic models of mantle flow. Continuous technical development of deformation devices allows us to access new ranges of pressures and temperatures which nowadays cover part of the lower mantle. However controlled deformation studies of minerals at conditions of the deep lower mantle are still not possible.

X-ray diffraction in radial geometry of solids compressed in the diamond anvil cell is currently the only technique which can investigate the effects of plastic deformation of minerals at pressures comparable to the deepest part of the Earth mantle. Quantitative analysis of texture combined with self consistent modeling of visco-plastic and elasto-plastic material behavior allow us to make inferences on the relative activity of different slip systems in dislocation glide regimes. This precious information helps us to make predictions of elastic anisotropy of rocks at depth. In the last several years our group has developed an experimental setup which allows one to perform measurements of texture development at simultaneous high pressures and temperatures. We will present new results on ferropericlase, bridgmanite and mixtures of the two phases to pressures in excess of 50 GPa at temperatures as high as 1200 K.

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JS02p-399

The location of slabs, plumes and LLSVPs

E. Tan[1]
[1]*Academia Sinica, Institute of Earth Sciences, Taipei, Taiwan Republic of China*

The two Large Low Shear Velocity Provinces (LLSVPs) at the base of lower mantle are prominent features in all shear wave tomography models. Various lines of evidence suggest that the LLSVPs are thermo-chemical and are stable on the order of hundreds of million years. Hotspots and Large Igneous Province (LIP) eruption sites tend to cluster around the edges of LLSVPs. With 3-D global spherical dynamic models, we investigate the location of slabs, plumes and basal chemical structures, which are composed of dense, high bulk modulus material. With reasonable values of bulk modulus and density anomalies, we find that the anomalous material forms dome-like structures with steep edges, which can survive for billions of years before being entrained. We find that more plumes occur near the edges, rather than on top, of the chemical domes. Moreover, plumes near the edges of domes have higher temperature than those atop the domes. We find that the location of downwelling region (subduction) controls the direction and speed of the lateral movement of domes. Domes tend to move away from subduction zones.

Joint Inter-Association Symposium

JS03p - JS3 Geophysical Imaging of Natural Resources (IASPEI, IAG, IAGA, SEG)

JS03p-400

Transforming matrices in the space domain for concurrent upward continuation and differentiation of potential fields: an application to multiscale methods

J. Baniamerian[1], *M. Fedi*[2], *B. Oskooi*[1]
[1]*University of Tehran, Institute of Geophysics, Tehran, Iran*
[2]*University of Federico II Napoli,*
Department of earth- environment and resources sciences, Naples, Italy

Multiscale methods study potential fields at different levels to image the unknown source-density distribution. Their related algorithms, e.g. that in Depth from Extreme Points and migration methods, are mainly based on upward continuation or on a simultaneous application of upward continuation and differentiation to potential fields. Therefore, when using these interpretative methods, it is very important to perform the whole procedure as more accurate and insensitive to noise as possible. To this purpose, a new approach is proposed in the space domain for performing upward continuation and vertical differentiation more efficiently than those in the frequency domain. So, the integral equations for upward continuation and Hilbert transform are discretized and written as linear matrix relations by which the measured and transformed fields are related one each other through transforming matrices. Upward continued field obtained by this procedure has less border errors than that of computed by the conventional Fast Fourier Transform algorithm and this feature is really important to retrieve accurately the field at large altitudes. Other features are that of allowing level-to-drape upward continuation and that differentiation is more stable at high frequencies, so that field derivatives can be efficiently computed without preliminary data extrapolation. The most important aspect is that upward continuation and differentiation kernels may be merged into a general kernel is created which yields the upward continuation of any field derivative, more accurate than that obtained in the frequency domain. We illustrate this combined kernel as applied in multiscale and imaging methods.

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JS03p - JS3 Geophysical Imaging of Natural Resources (IASPEI, IAG, IAGA, SEG)

JS03p-401

Figueira branca intrusive suite (Brazil): A geophysical perspective of a layered mafic intrusion in the SW Amazon Craton

V. Louro[1], *M. Mantovani*[1], *V. Ribeiro*[1]
[1]*Universidade de São Paulo - IAG/USP, Geophysics, São Paulo, Brazil*

The Jauru Terrain is a Paleoproterozoic structure in the SW of the Amazon Craton that hosts the Figueira Branca Intrusive Suite (FBS) in west Brazil. The FBS is a 1420 Ma layered mafic intrusion understood as an anorogenic suite, however its Nd-Sr affinity and similar age with the adjacent Santa Helena Orogeny granitic rocks, along a complex tectonic evolution, implies in the necessity of complementary studies to uncover the origin and evolution of this suite. The FBS presents occurrences of Cu, Cr, Co and Ni in concentrations typically associated with basic-ultrabasic rocks.

Gamma-ray spectrometry, magnetism and gravity were used in this study to characterize the FBS geophysically. The magnetic and gravity methods present three anomalies where the FBS is geologically recognized. A fourth anomaly is located to the north without geological recognition in the literature. All FBS magnetic anomalies are marked by reverse polarization evidencing the presence of remanence. The Curie Depth was estimated indirectly by the magnetic data at about 10.1 km. The gravity data showed positive anomalies as expected for mafic rocks hosted by metasediments.

Gamma-ray emissions indicated a strong correlation between the mapped geological bounds and the FBS geophysical anomalies. The pattern of low counts, typical of mafic rocks, is seen in all anomalies and the predominantly high Th/K ratio reinforces this evidence.

Magnetization, susceptibility and density data were gathered from samples and used as constraints in the composition of a geophysical model of the FBS. This model represent the subsurface distribution of the FBS bodies as sills, being a reference model for future exploration of Cu, Cr, Co and Ni, and a valuable asset in the deciphering of the evolution of the Amazon Craton.

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JS03p - JS3 Geophysical Imaging of Natural Resources (IASPEI, IAG, IAGA, SEG)

JS03p-402

Geophysical characteristics of Brunswick No. 12 VMS deposit in Bathurst Mining Camp, Canada

V. Ribeiro[1], *M. Mantovani*[1], *V. Louro*[1]
[1]*Universidade de São Paulo - IAG/USP, Geophysics, São Paulo, Brazil*

The Bathurst Mining Camp (BMC), Canada, is well known for its volcanogenic-sedimentary hosted massive sulphide deposits (VHMS), including the world-class Brunswick No. 12 deposit. BMC formed in a sediment-covered back-arc continental rift (Tetagouche-Exploits backarc basin), in periods when the basin was stratified and presented a lower anoxic water-column. The basin was subsequently intensely deformed by multiple collisional events related to the east-dipping subduction of the basin. Contrasts in magnetic, electromagnetic, and gravitational properties in sulphides deposits provide direct exploration vectors. These methods were used for a local geophysical characterization of the Brunswick No. 12 and in the composition of a regional geologic-geophysical interpretation model. The constrained 3D forward magnetic modeling of the Brunswick No. 12 area was used to generate susceptibility isosurfaces that enclosed regions within the anomalous contrast, and to compare this areas with pseudo-sections of apparent conductivity obtained though the EM data. Gamma-ray spectroscopy provides an indirect technique based on chemical contrasts associated with near-surface alteration. Gamma-ray analysis in VHMS focus especially in the potassium enrichment or depletion within and surrounding the deposit as a product of the typical hydrothermal alteration. Four hydrothermal events spanning 12 to 14 million years have been recognized in BMC. The Th/K ratio was applied to identify alterations zones related with the deposits. The interpretation model generated by the integration of the known geology and geophysical methods supports many previous interpretations of the region but also provides new important features for future targeting of sulphides deposits in the area.

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JS03p-403

Deconvolution as an instrument to enhance amplitude-frequency domain and resolution on 2D/3D seismic on Romania offshore and onshore fields

A. Akhverdiev[1]
[1]*OMV - Petrom SA Romania, PE-X Exploration, Bucharest, Romania*

The spectrum of the seismic data contains a complete set of received frequencies; however, dominant frequency is a result of superposition of all present frequency spectrum at a certain instant, where every spectrum depends on the energy of the wave. The separation of the high-frequency, from the full spectrum, to obtain an increase in seismic resolution, can enable better fault and geological features detailing.

The recorded seismic signal can be considered as a convolution of the source signal with instruments, geophones and Earth’s response. The Earth’s response includes some undesirable effects (such as reverberation, attenuation, ghosting, etc.) and also certain signatures from studied formations relating to their properties and geometry.

Deconvolution enhances the resolution and increases the amplitude of the wavelet by concentrating more energy in the peak. Within the full frequency spectrum of recorded signal, different frequency bandwidths can be isolated which can be shown to relate to different formation thicknesses. These will depend on seismic resolution, data quality and geological compliance at each targeted interval. A discrete frequency signature for each different formation is the main assumption for the approach used in this work.

Analysis of sparse spikes’ amplitude-frequency spectrum indicates the presence of useful reflections on a much wider frequencies range than usually presented on full-spectrum seismograms. A workflow designed using deconvolution and filtering procedures, applied to stacked data, assisted the separation of high-frequency components on different types of offshore and onshore 2D/3D seismic data. By applying this technique the frequency content and resolution at the targeted intervals has been improved by an average of 35%.

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JS03p-404

Electric and magnetic signatures associated with cylces of loading and unloading of a deep cavity

J. Zlotnicki[1], *J.L. Le Mouël*[2], *P. Morat*[3]
[1]*CNRS, Observatoire de Physique du Globe, Aubières cedex, France*
[2]*Institute of Physics of the Globe, Geomagnetic and Paleomagnetic laboratory, Paris, France*
[3]*Institute of Physique du Globe, Geomagnetic Laboratory, Paris, France*

Electric and magnetic fields are very sensitive to the electrical resistivity and ground water flows in the sub-surface. In natural hazards as on volcanoes and geothermal fields, and active faults, changes in the regional or local stress field generate signals up to several tens of mV/km and some nanoTeslas (nT) at the ground surface, when the lithology is inhomogeneous. Therefore, the monitoring of these fields contribute to estimate transient duration disturbances of a steady-state system, and the leakage of ground fluids through porous media and fractures. Therefore, the monitoring of these fields for environmental hazards would be also more carefully studied. We present observations of the electric and magnetic fields made during successive loading and unloading of a reservoir of about 200,000 m^3 in volume and buried at 1430 m, near Etrez (France). Such reservoirs are used by Gaz de France for temporary gas storage. Seven total field magnetometers and three telluric stations were installed around the reservoir till distances of several kilometers from the reservoir. The reservoir was loaded with salted brine to 97 bars and then unloaded by simply opening a pipe valve at the ground surface into a pool. Clear magnetic signals were observed in correlation with the loading and unloading of the cavity. The amplitude is a few nT. We assume that these signals are due to electrokinetic effect at the expense of a piezomagnetic mechanism which requires the presence of magnetized rocks. Although affected by local anthropogenic noise, telluric field shows signals of several mV/km related to experiment. This experiment shows the numerous potential applications in environmental projects as in natural hazards ones.

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JS03p-405

Borehole-to-surface controlled-source electromagnetic experiment using deep vertical and horizontal sources

E. Vilamajo[1], B. Rondeleux[2], P. Queralt[1], A. Marcuello[1], J. Ledo[1]
[1]University of Barcelona, Institut Geomodels. Dept. Geodinàmica i Geofísica, Barcelona, Spain
[2]CGG, Massy, France

A borehole-to-surface CSEM experiment was carried out in April 2014 at the Hontomín Storage Site (Spain). Vertical and horizontal source dipoles were used taking advantage of the electrodes installed in the injection and monitoring boreholes. Receiver stations deployed at the surface used a permanent array of surface electrodes surrounding the site facilities. The experiment was the baseline of an ongoing monitoring experiment with the goal of detecting and characterizing the CO2 migration inside the reservoir. Future repetitions of the experiment are planned to be carried out after the CO2 storage will begin. The surface electric field was simultaneously measured at 70 dipoles. The processing of the data acquired in the baseline experiment consisted of the calculation of the earth response: the transfer function between the emitted signal and the signal measured at the surface after signal propagation through the subsoil. The data measured during the vertical EM emission and during the horizontal EM emission were satisfactorily processed and are presented in this contribution. Strong influence of the metallic casings over the acquired data has been observed. The processing results are presented in terms of amplitude and phase of the transfer function. The processing of the complete data set shows an attenuation of the surface electric field when increasing the receiver-borehole offset. The processing methodology permitted to obtain experimental errors below 1%. Local effects caused by topography, high contact resistance or the presence of surface conductors/resistors, among other possible causes, can be observed.

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JS03p-406

Micro-scale flow simulations in coal matrix and cleats

J. Busse[1], *A. Scheurmann*[1], *S. Galindo Torres*[1], *D. Bringemeier*[2]
[1]*University of Queensland,*
Geotechnical Engineering Centre- School of Civil Engineering, St. Lucia, Australia
[2]*Golder Associates Pty Ltd, Hydrogeology, Milton, Australia*

Coal mining raises a number of environmental challenges, including the impact of changing groundwater levels and flow patterns on adjacent aquifer and surface water systems.

Flow in coal seams takes place on a wide range of scales from large faults and fractures to a micro-structure of a porous matrix intersected by a characteristic cleat network. On the micro-scale these cleats provide the principal source of permeability for fluid flow. Description of the behaviour of the flow within the network is challenging due to the variations in number, sizing, orientation, aperture and connectivity at a given site.

A profound characterisation of the geometry of the cleat network in micrometre resolution is based on CT-scans of core samples taken at a coal mine in central Queensland, Australia. The structural information are fed into a Lattice Boltzmann Method based model that allows to quantify microscopic features, e.g. tortuosity, with sufficient accuracy. The imposition of boundary conditions permits the calculation of the full permeability tensor in 3D to describe and quantify the groundwater flow in the coal.

Joint Inter-Association Symposium

JS04a - JS4 Deformation of the Lithosphere: Integrating Seismology and Geodesy through Modelling (IASPEI, IAG)

IUGG-1328

Coseismic subsidence and postseismic uplift along the Pacific coast of Tohoku and Kanto dstricts associated with the 2011 Tohoku-oki Earthquake

T. Iinuma[1], S. Miura[2], Y. Ohta[2], T. Kato[3], T. Sun[4], K. Wan[5], R. Hino[1]
[1]Tohoku University, International Research Institute of Disaster Science, Sendai, Japan
[2]Tohoku University, Graduate School of Science, Sendai, Japan
[3]The University of Tokyo, Earthquake Research Institute, Tokyo, Japan
[4]University of Victoria, School of Earth and Ocean Sciences, Victoria, Canada
[5]Natural Resources Canada,
Geological Survey of Canada- Pacific Geoscience Centre, Sidney, Canada

The 2011 Tohoku-oki Earthquake (M9.0) produced up to 1.2 m subsidence along the Pacific coast NE Japan. GPS monitoring has detected continuing postseismic coastal uplift over the past 4 years since this earthquake. We demonstrate that this uplift is caused mainly by the postseismic viscoelastic relaxation of the asthenosphere. We constructed a 3D spherical-Earth viscoelastic finite element model using postseismic seafloor as well as terrestrial GPS observations as constraints. Although the model was constrained only by the horizontal components of GPS observations, its predicted vertical displacements by the end of 2014 agree reasonably well with the observed uplift time series. Thus, we can use this model to estimate the time when the cumulative postseismic uplift fully compensates the coseismic subsidence. The results show that in the area of largest coseismic coastal subsidence, directly landward of the area of peak coseismic fault slip (>50 m), postseismic uplift will fully offset coseismic subsidence in several decades. To the immediate north, the model underpredicts postseismic uplift, possibly indicating unaccounted postseismic fault creep offshore. Farther south, postseismic uplift of the coast of Boso Peninsula is observed to have already exceeded the small amount of coseismic subsidence over the past 4 years, as is predicted by the model. In the past, long-term uplift of the Boso Peninsula was fully attributed to the effect of past Kanto earthquakes along the Sagami Trough subduction zone where Philippine Sea plate is subducting. Our observation and model results suggest that the effect of Japan Trench earthquakes should also be taken into account, such that net uplift due to the Kanto earthquakes is not as large as previously thought.

Joint Inter-Association Symposium

JS04a - JS4 Deformation of the Lithosphere: Integrating Seismology and Geodesy through Modelling (IASPEI, IAG)

IUGG-1376

Postseismic deformation of the 2008 Wenchuan earthquake and its effects on the motions of the blocks around eastern Tibetan Plateau

C. XU[1,2], *Q. Fan*[1]
[1]*Wuhan University, School of Geodesy and Geomatics, Wuhan, China Peoples Republic*
[2]*Collaborative Innovation Center of Geospatial Technology, Wuhan, China Peoples Republic*

The 2008 Wenchuan earthquake which is one of the largest inland earthquakes occurred on the Longmen Shan fault which locates at the eastern margin of the Tibetan Plateau. Large dip-slip occurred on the southwest of the fault, while the dextral slip gradually increased from the southwest to the northeast. The coseismic stress change caused by the Wenchuan earthquake greatly affected the movements of the eastern Tibetan Plateau.

Near- and far-field GPS observations from right after the earthquake to January 2015 were collected. Compared to the movements before the earthquake, apparent postseismic deformation was recorded not only around the Longmen Shan fault but also in a wide range of Sichuan-Yunnan area. In the near-field, the displacements perpendicular to the fault decreased to zeros after 2013, while along the fault are still significant.

We try to use the afterslip and the viscoelastic relaxation models to explain the deformations and invert the lower limits of the viscoelastic coefficients of the low velocity zone and the lower crust of the Bayan Har block with the far-field observations. The motions of the blocks around the Longmen Shan fault and the locking state of the other faults in the eastern Tibetan Plateau are also checked and compared to the state before the earthquake. We also investigate the effects of the other faults across which may have discontinuous stress change during Wenchuan earthquake on the postseismic deformation.

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JS04a - JS4 Deformation of the Lithosphere: Integrating Seismology and Geodesy through Modelling (IASPEI, IAG)

IUGG-2055

Coseismic deformation of the 2014 northern Nagano earthquake detected by ALOS-2/PALSAR-2

M. Hashimoto[1]
[1]*Kyoto University, Disaster Prevention Research Institute, Uji, Japan*

On November 22, 2014, an earthquake of Mw 6.3 hit the northern part of the Nagano Prefecture, central Japan. We analyzed ALOS-2/PALSAR-2 (Japanese new L-band synthetic aperture radar) images before and after this event to detect coseismic surface deformation. Two pairs of images are available that covers the source region. One pair of images is from descending orbit and left looking, the other is from ascending orbit and right looking. We used the RINC developed by Dr. Ozawa and the Gamma software. Digital Ellipsoidal Height Model based on the GSI's 10 m digital elevation model was used to reduce the topography phase.

Obtained interferograms have rather high coherence even in this mountainous region. We observed LOS decrease of ~ 80 cm on the eastern side of the NEN-SWS trending Kamishiro fault. On its western side, LOS increases of > 20 cm are found. These observations are consistent with thrust faulting on an eastward dipping plane. The area of large deformation is limited in a ~ 5 km long part of the fault south of the epicenter. LOS change rapidly decreases north of epicenter, but still discontinuity of LOS change is found in the area where fault traces are not previously mapped.

A preliminary inversion of LOS displacement implies that up to 130 cm slip occurred on a plane dipping eastward with 55 degree. Although the peak of slip is located at a depth of < 4 km beneath the area of large LOS displacement, slip may be extended about 8 km northward and deeper than 10 km. Total geodetic moment is estimated 3.9 x 10^18 Nm (Mw6.3).

PALSAR-2 images were provided by JAXA through GSI as a project of the Earthquake SAR Analysis Working group. Copyright and ownership of PALSAR-2 images belong to JAXA.

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IUGG-2797

Time-varying upper-plate deformation during the megathrust subduction earthquake cycle

K. Furlong[1], *R. Govers*[2], *M. Herman*[3]
[1]*Penn State University, Geosciences, University Park, USA*
[2]*Utrecht University, Earth Sciences, Utrecht, Netherlands*
[3]*Penn State University, Geosciences, University Park PA, USA*

Over the past several decades, our abilities to observe and image the deformational behavior of the upper plate in megathrust subduction zones has dramatically improved. Inferences that can be made from these observations include apparent lateral variations in locking along subduction zones, which differs from interseismic to coseismic periods; the significant magnitude of post-earthquake deformation; and incompatibilities between rates of slip deficit accumulation and resulting earthquake co-seismic slip.

Modeling capabilities have grown from fitting simple elastic accumulation/rebound curves to sparse data to having spatially dense continuous time series that allow us to infer details of plate boundary coupling, rheology-driven transient deformation, and partitioning among inter-earthquake and co-seismic displacements. Our preliminary model results lead to the following:

1. Co-seismic stress transfer from the unloading elastic layer (shallow) into an elastically loading visco-elastic layer (deeper) - extends ~ 100 km inboard of locked zone- affecting both coseismic and post-seismic surface displacements.
2. Post-seismic response of upper plate involves seaward motion for initial 10-20 years (~ 2 Maxwell times) after EQ. This occurs in spite of there being no slip on locked plate boundary - i.e. this is not plate boundary after-slip but rather is a consequence of stress relaxation in co-seismically loaded visco-elastic layer.
3. By approximately 80 years (8 Maxwell times) system has returned to simple linear displacement pattern - the expected behavior for a shortening elastic beam..

These preliminary results indicate that care is needed in interpreting observed surface displacement fields from GPS, InSAR, etc. during the interseismic period.

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IUGG-2980

Observing Multiscale temporal behavior on a mega-thrust: Nicoya Earthquake cycle and 2012 megathrust event.

R. Malservisi[1]*, S. Schwartz*[2]*, N. Voss*[1]*, M. Protti*[3]*, V. Gonzalez*[3]*, T. Dixon*[1]*,*
Y. Jiang[4]*, A. Newman*[5]*, J. Richardson*[1]*, J. Walter*[5]*, D. Voytenko*[1]
[1]*University of South Florida, School of Geosciences, Tampa, USA*
[2]*University of California Santa Cruz, Seismology Laboratory, Santa Cruz, USA*
[3]*Universidad Nacional, Observatorio Vulcanologico y Sismologico de Costa Rica, Heredia, Costa Rica*
[4]*Geological Survey of Canada, Pacific Geosciences Center, Victoria, Canada*
[5]*Georgia Institute of Technology, School of Earth and Atmospheric Sciences, Atlanta, USA*

Subduction interfaces are the loci of some of the largest and most destructive earthquakes. Understanding the strain pattern and slip deficit of large megathrust seismic events is one of the keys to better characterizing their earthquake cycle.

The Nicoya peninsula, Costa Rica has the advantage to be located just above the seismogenic. During the interseismic period, we observed the pattern of fault locking, plate coupling, and surface displacement associated with different Slow Slip Events located at different depths (including events updip of the main locked patch).

On September 5, 2012, after years of slow-slip event observations, a MW 7.6 megathrust earthquake occurred just underneath a dense continuous GPS (CGPS) network on the Nicoya Peninsula of northern Costa Rica. The network recorded at high rate and has sensitivity to measure deformation from aseismic slip on the plate interface both updip and downdip of the locked subduction interface.

In this study, we analyze the temporal and spatial evolution of the surface deformation at different temporal scales (from hours to years after the earthquake) to infer the aseismic slip on the fault interface. Our results show that the main rupture was followed by significant early afterslip for the first 3 hours after the main event. The behavior of the fault can then be represented by relaxation processes with three characteristic times. We suggest that the three relaxation times correspond to poroelastic, afterslip and viscous processes. With this assumption,

during the first few months, the afterslip has most likely filled different gaps left by the coseismic rupture (in particular updip). We also show that the afteslip seems to be bounded by region affected by SSE.

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IUGG-5310

Cross-scale thermo-mechanic model of seismic cycle of great megathrust earthquakes

S. Sobolev[1], *I. Muldashev*[1]
[1]*GFZ German Research Centre for Geosciences, Geodynamic Modeling, Potsdam, Germany*

Time-scale of subduction process is spanning from geological (>10^6yr) to earthquake scale (about 10^{-5}yr) with the seismic cycle in between. Here we present a cross-scale modelling approach capable to model entire subduction process from rupture to geological time. Our technique is based on the finite element code SLIM3D (Popov and Sobolev, PEPI 2008) employing elasto-visco-plastic rheology with strongly non-linear temperature and stress-dependent viscosity and free surface.

First we generate a 2D thermo-mechanical model of subduction zone including a narrow subduction channel with “wet-quartz” visco-elasto-plastic rheology and static friction. We next introduce in the same model classic non-steady state rate-and state friction law in subduction channel, leading to stick-slip instability. For simplicity we assume all rate and state parameters (a,b,Lcr) constant and instability range depth-unlimited. The adaptive time-step algorithm recognizes moment of instability and drops the integration time step to its minimum value of 10^{-5}yr during the earthquake. The time step is then gradually increased to its maximal value of 5 yr, following decreasing displacement rates during the postseismic relaxation, until next instability. The model is tested by comparison with observations and theoretical expectations (see accompanied abstract by Muldashev and Sobolev).

We apply our model for seismic cycles of earthquakes with M>9 and show that the entire postseismic slip process can be explained by visco-elastic relaxation with viscosity that strongly varies in time and space in internally consistent way. We emphasize that in this model an average slip velocity at the fault in the time range from days to few years closely follows hyperbolic decay law usually interpreted as an afterslip.

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IUGG-1208

Earth's surface deformation of Baikal rift zone from the data of 2011-2014 GNSS companies

A.V. Basmanov[1], V.I. Kaftan[2], R.A. Sermyagin[1], I.A. Oshchepckov[1], L.I. Serebryakova[1], A.A. Spesivcev[1]
[1]Federal Scientific and Technical Center of Geodesy- Cartography and Spatial Dat a, Department of gravimetry and geodynamics, Moscow, Russia
[2]Geophysical center of Russian academy of sciences, Laboratory of geodynamics, Moscow, Russia

Baikal rift zone is a giant tectonic structure producing catastrophic earthquakes. Lake Baikal is the biggest reservoir of fresh water all over the world. Geodynamical monitoring of the region is a high important activity of scientific and stakeholder community. Historical seismic records showed that the main deformation of the region is an extension across the axis line of the Baikal rift. Different repeated geodetic measurements were done in the region. Several GNSS field companies are executed in the area from 1994 to 2014. Observation data were processed and deformation characteristics are received. First epochs of absolute gravity measurements are executed. Received displacement vectors demonstrate the existence of movements of the order of 3 mm/yr in general. Deformations of territory have the mean level of 10-6. The study shows that the south and the north parts of the Lake Baikal are in a state of different deformation tendencies in different time intervals. The line of zero-deformation is close to the continuation of the Obruchev fault zone divided the Lake Baikal for north and south parts. Future plans of geodynamic study are discussed.

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IUGG-3006

Elastic and inelastic deformation process in the Mid-Niigata Area, Central Japan

A. Meneses Gutierrez[1], *T. Sagiya*[2]
[1]*Nagoya University, Nagoya, Japan*
[2]*Nagoya University, Graduate School of Environmental Studies, Nagoya, Japan*

The Mid-Niigata area, central Japan, has been previously characterized as an inland large contraction (1.65 X 10^{-7} /year) zone along the Japan Sea coast. However, mechanical nature of the contraction, whether it is elastic or inelastic, remained uncertain. Large historical earthquakes have occurred in this area, including, two shallow events, known as the Chuetsu Earthquake (M 6.8) on October 23th, 2004 and the Chuetsu-Oki Earthquake (M 6.6) on July 16th, 2007, within 40 km that considerately affected the crustal deformation pattern. Additionally, there has been no large historical earthquake in the area between the source regions of 2004 and 2007, which strongly suggests that the ongoing deformation is largely inelastic and accommodated by aseismic slips. To study this possibility, we review temporal variation of crustal deformation pattern in the Mid-Niigata region based on daily coordinates of 100 GPS sites, including 48 campaign sites deployed across the area of interest from 2008, as well as hypocenter information from the Japan Meteorological Agency. We recognize a migration of the deformation pattern in the East-West direction after the occurrence of each event and a heterogeneous distribution of the seismicity, with concentrated activity on faults to the southwest of the coseismic source for 2004 event, which decreases in time. These time-dependent behaviors suggest strong interaction between seismic and aseismic fault segments.

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IUGG-3436

Crustal deformation around the northern Itoigawa-Shizuoka Tectonic Line and its implications for the 2014 Northern Nagano earthquake (Mw6.3)

T. Sagiya[1], N. Teratani[2], T. Nishimura[3], H. Yarai[4], H. Suito[4]
[1]Nagoya University, Disaster Mitigation Research Center, Nagoya, Japan
[2]Nagoya University, Graduate School of Environmental Studies, Nagoya, Japan
[3]Kyoto University, Disaster Prevention Research Institute, Uji, Japan
[4]Geospatial Information Authority of Japan,
Geography and Crustal Dynamics Research Center, Tsukuba, Japan

The Itoigawa-Shizuoka Tectonic Line (ISTL) is a major geologic boundary intersecting the Japanese mainland into the northeastern and the southwestern parts. It is also an active fault system that is supposed to have a high seismic potential. We have conducted dense GPS observation and identified a highly localized E-W contraction around the Kamishiro fault at the northern ISTL. Kinematic modeling of this deformation pattern suggests that the fault is dipping to the east and accommodating the E-W contraction by aseismic faulting below the depth of 2-4 km.

On November 22, 2014, a Mw 6.3 earthquake occurred at the Kamishiro fault. The hypocenter is located at a depth of 5 km and surface rupture appeared for about 9 km along the fault trace. Considering the pre-seismic deformation pattern and aseismic fault slip at depth, this earthquake is considered to rupture the remaining shallow locked part. Thus no further large earthquake is not anticipated in this area in the near future although much larger event is expected to occur along the whole ISTL.

This earthquake caused a heavy damage on a small neighborhood called Horinouchi. It should be noted that the same neighborhood had experienced a severe damage by another earthquake in 1714. Considering that the locked portion is limited to the shallowest 5 km and strain rate around this area is very large, it is possible that the same fault segment was reactivated in 300 years, which is an unusually short recurrence interval as a intra-plate active fault. This example demonstrates an importance of dense as well as precise geodetic observation for seismic hazard evaluation and understanding the crustal seismogenesis.

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IUGG-4302

Subduction, collision and the long-term tectonic deformation of the Aleutian arc and southwest Alaska

J. Freymueller[1]*, K. DeGrandpre*[1]*, S. Li*[1]
[1]*University of Alaska Fairbanks, Geophysical Institute, Fairbanks, USA*

The Aleutian arc features an extreme variation in the obliquity of plate convergence, and the western part of the arc has long been recognized as an example of slip partitioning of highly oblique subduction. The direction of Pacific-North America relative motion is essentially trench-normal along the Alaska Peninsula in the eastern part of the arc, and reaches almost trench-parallel at the western end of the arc. The combination of oblique subduction and the collision of the Yakutat terrane at the eastern end of the arc results in pervasive deformation of the overriding plate. Along much of the arc, a tectonic sliver of the overriding plate moves in a mostly trench-parallel direction with the rate of motion increasing to the west, and additional blocks or microplates (southern Alaska, Bering plate) accommodate eastward extrusion of material away from the Yakutat block collision. Here we examine the long-term velocities of sites in southern Alaska, the Aleutian arc and the Bering Sea region after removing the effects of recent earthquakes and postseismic deformation. We will re-examine the extent of the proposed Bering plate and evidence for block motions along the Aleutian arc in the light of an expanded and more precise data set, and recent seismicity and earthquake focal mechanisms. Our block models suggest a more complex pattern of deformation than previously proposed.

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IUGG-5241

Crustal deformation in the Taupo Volcanic Zone

S. Hreinsdottir[1]*, I. Hamling*[1]*, N. Fournier*[2]*, N. Palmer*[1]*, E. D'Anastasio*[3]*,*
W. Wittmann[4]
[1]*GNS Science, Tectonophysics, Lower Hutt, New Zealand*
[2]*GNS Science, Volcanology, Lower Hutt, New Zealand*
[3]*GNS Science, GEONET, Lower Hutt, New Zealand*
[4]*University of Iceland, Institute of Earth Sciences, Reykjavík, Iceland*

The oblique convergence of the Australian and Pacific plates at the rate of 40 to 50 mm/yr in the North Island of New Zealand is partitioned into a trench parallel translation, accommodated by large strike slip faults in the upper crust, and subduction of the Pacific plate along the Hikurangi margin. Geodetic and geophysical studies suggest that the subducting slab interface is creeping steadily under the northern part of the North Island while it remains largely locked and accumulating stress along its southern segment. The subduction and rotation of the fore arc result in back arc rifting, with extension and volcanism in the Taupo Volcanic Zone. The Taupo Volcanic Zone has been active for 2 Myr and is one of the worlds most productive rhyolitic systems. It has numerous high temperature geothermal fields and a very high heat flow. GPS studies suggest increasing rate of extension from south to north along the Taupo Volcanic Zone with over 15 mm/yr extension at the Bay of Plenty. Fault slip data have suggested that the current active extension is taken up over 20 km wide zone, however GPS measurements suggest that the deformation zone is wider. In 2005 over 100 GPS sites were measured in the Taupo Volcanic Zone. The network was re measured and further densified in 2007, 2011 and 2015. In addition GEONET has installed a number of continuous GPS stations since 2002 with focus on the volcanic centers. Crustal deformation within the Taupo Volcanic Zone is complex and varies both in space and time. InSAR and GPS measurements show widespread subsidence with of rates up to 20 mm/yr, possibly related to the cooling and contraction of magma. We present an updated velocity field for the Taupo Volcanic Zone and reevaluate rate of spreading in the region.

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IUGG-5455

The global earthquake activity rate model

D. Jackson[1], *P. Bird*[2], *Y.Y. Kagan*[3], *C. Kreemer*[4], *R. Stein*[5]
[1]*UCLA, Earth- Planetary- and Space Science, Los Angeles, USA*
[2]*UCLA, Earth- Planetary- and Space Science, Los Angeles- CA, USA*
[3]*UCLA, Earth- Planetary- and Space Science, Los Angeles- CA, USA*
[4]*Univ. Nevada Reno, Nevada Geodetic Lab, Reno- NV, USA*
[5]*US Geological Survey, Earthquake Hazards Program, Menlo Park- CA, USA*

Scientists from academia, government, the private sector and the Collaboratory for Study of Earthquake Predictability (CSEP) are constructing and testing a global earthquake rate model as a function of magnitude at 0.1 by 0.1 degree resolution. Nicknamed "GEAR", the model relies on a global strain rate model (GSRM) and instrumental earthquake catalogs. After testing, the model may be used by GEM and others in seismic hazard estimation. GEAR covers magnitudes 5.8 and larger and times from years to decades with no explicit time-dependence. The normalized magnitude distribution at each location is a combination of tapered Gutenberg-Richter distributions with b-values and corner magnitudes determined by just a few global parameters that depend on tectonic style and focal mechanism proportion. The seismic and strain-rate components of the model are specified separately and then combined optimally to fit earthquake occurrence over the last several years. GEAR performs well in quasi-prospective tests using the GCMT catalog after 2005 and the GEM catalog from 1918 to 1976; GEAR will be tested prospectively against future earthquakes. Because of its simplicity, GEAR can serve as a well-vetted reference model and as a null-hypothesis against which more complex models can be tested. With its high spatial resolution, GEAR can be compared with detailed regional models too. Comparing GEAR with alternate models, we can address enduring scientific questions: Do large and small earthquakes come from different population? Do large earthquakes cluster, or do they consume enough strain energy to prevent future ones? Are the factors that control earthquake statistics relatively uniform, or highly variable from region to region?

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JS04p-494

Block modeling of crustal deformation in Tierra del Fuego from GNSS velocities

L. Mendoza[1], *A. Richter*[2], *M. Fritsche*[2], *J.L. Hormaechea*[3], *M. Horwath*[2], *R. Perdomo*[4], *R. Dietrich*[2]
[1]*Universidad Nacional de La Plata, Facultad de Ciencias Astronomicas y Geofisicas, La Plata, Argentina*
[2]*Technische Universität Dresden, Institut für Planetare Geodäsie, Dresden, Germany*
[3]*Universidad Nacional de La Plata, Estación Astronómica Río Grande, Río Grande, Argentina*
[4]*Universidad Nacional de La Plata, Facultad de Ciencias Astronómicas y Geofísicas, La Plata, Argentina*

The Tierra del Fuego (TDF) main island is divided by a major transform boundary between the South America and Scotia tectonic plates. Using a block model, we infer slip rates, locking depths and inclinations of active faults in TDF from inversion of site velocities derived from Global Navigation Satellite System (GNSS) observations. We use interseismic velocities from 48 sites, obtained from field measurements spanning 20 years. Euler vectors consistent with a simple seismic cycle are estimated for each block. In addition, we introduce far-field information into the modeling by applying constraints on Euler vectors of major tectonic plates. An average strike-slip rate of 5.8 +/- 0.2 mm/yr was determined in agreement with published geodetic and geophysical estimates for this tectonic boundary. Our results indicate dislocations dipping 66 +/- 6 degrees southward, locked to a depth of 10 km, which are consistent with geological models for the MFS. Normal slip also dominates the secondary sense of motion throughout the eastern MFS, with a maximum rate along the Fagnano Lake.

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JS04p-496

Kinematics and Seismotectonics of the Montello Thrust Fault (Southeastern Alps Italy) revealed by local GPS and Seismic networks

S. Danesi[1], *S. Pondrelli*[1], *S. Salimbeni*[1], *A. Cavaliere*[1], *L. Anderlini*[1], *E. Serpelloni*[2], *P. Danecek*[2], *M. Massa*[3], *S. Lovati*[3]
[1]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, CNT, Roma, Italy*
[3]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Milano, Milano, Italy*

The southern Alps fold-and-thrust belt (FTB) in northern Italy is a tectonically active area accommodating large part of the ~N-S Adria-Eurasia plate convergence, that in the southeastern Alps ranges from 1.5 to 2.5 mm/yr, as constrained by a geodetically defined rotation pole. Because of the high seismic hazard of northeastern Italy, the area is well monitored at a regional scale by seismic and GPS networks. However, more localized seismotectonic and kinematic features, at the scale of the fault segments, are not yet resolved, limiting our knowledge about the seismic potential of the different fault segments belonging to the southeastern Alps FTB. Here we present the results obtained from the analysis of data collected during local seismic and geodetic experiments conducted installing denser geophysical multi-parametric networks across the Montello-Bassano-Belluno system, a segment of the FTB that is presently characterised by a lower seismicity rate with respect to the surrounding domains. The Montello anticline, which is the southernmost tectonic features of the southeastern Alps FTB (located ~15 km south of the mountain front), is a nice example of growing anticline associated with a blind thrust fault. The new, denser, GPS data show that this area is undergoing among the highest geodetic deformation rates of the entire south Alpine chain, with a steep velocity gradient across the Montello anticline. The earthquakes recorded during the experiment, precisely relocated with double difference methods, and the new earthquake focal mechanisms well correlate with available information about sub-surface geological structures and highlight the seismotectonic activity of the Montello thrust fault.

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JS04p-497

Crustal deformation and interplate coupling associated with the 2011 Tohoku-oki earthquake based on a viscoelastic earthquake cycle model

T. Sagiya[1]

[1]*Nagoya University, Disaster Mitigation Research Center, Nagoya, Japan*

The 2011 Tohoku-oki earthquake caused a large subsidence along the Pacific coast of northeast Japan, where long-term uplift is estimated from marine terraces and geodetic data showed rapid (5mm/yr) subsidence in the 20th century. So how to balance long-term and short-term coastal vertical motion remains unsolved. On the other hand, there are different views about deeper limit of the interplate locked zone. These questions are important when we consider future seismic hazard.

In order to tackle these problems, we construct a simple kinematic model of earthquake deformation cycle considering viscoelastic responses to periodic recurrence of slip deficit and its coseismic releases. Earthquake sources are modeled as two rectangular faults in an elastic lithosphere overlying a viscoelastic asthenosphere. These two faults represent sources of large (M~9) earthquakes with a long (500 yrs) interval and moderate (M~7.5) earthquakes with a shorter (50 yrs) interval, respectively. Model calculation demonstrates that we can reconcile above-mentioned contradicting observations. Postseismic uplift can recover both interseismic and coseismic subsidence. Such a situation appears only if the shallow fault has a much longer recurrence interval than the viscoelastic relaxation time. The same model also reproduces rapid postseismic landward motion above the shallow fault as evidenced by the GPS/acoustic measurements. Since the interseismic coastal subsidence is interpreted as a result of viscoelastic effects, we do not need interplate locking below 50 km depth, which is consistent with coseismic slip distribution, and aftershocks of the 2011 earthquake. Thus effects of viscoelastic relaxation and earthquake cycle are essential in interpreting the observed crustal deformation.

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JS04p-498

Origin of Chiayi blind backthrust beneath the foreland basin in southcentral Taiwan: Insight from seismic tomography and geodynamic modeling

W.H. Wang[1], *S. Wen*[2], *Y.L. Yeh*[1], *Y.C. Chiu*[1]
[1]*National Chung Cheng University, Earth and Environmental Sciences, Chiayi, Taiwan Republic of China*
[2]*National Center for Research on Earthquake Engineering, Southern Taiwan Center, Chiayi, Taiwan Republic of China*

Backthrusts are much less found in a fold-and-thrust belt because the basal decollement is often hinterland-dipping with small but not trivial friction. Both characters favor formation of foreland-vergent thrusts. However, in southwestern Taiwan, a major blind backthrust, associated with a M_L=6.4 event in 1999, has been found beneath Chiayi City, which is just several kilometers in front of the toe of the mountain range. The origin of this backthrust remains unclear. We have conducted high-resolution seismic tomography and found that a foreland-dipping decollement characterized by a distinct Vp/Vs contrast with inclined seismicity is present beneath the foreland basin. This new finding suggests that illite-muscovite transition of pelitic metamorphic rocks, instead of brittle-ductile transition of felsic rocks, may occur along this decollement. We explore the likely geological structure evolution in this area with this newly found structure by conducting both numerical and physical modeling. Our simulation results suggest a triangle zone will appear in the deformation front when a weak, foreland-dipping decollement is present in middle crust over another even more weaker decollement embedded in lower crust.

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JS04p-499

A new recipe to compute internal deformation fields in a spherical earth excited by earthquakes

S. Okubo[1], *Y. Takagi*[1]
[1]*The University of Tokyo, Earthquake Research Institute, Tokyo, Japan*

Co-seismic deformations 'within' the earth have been mostly modeled by using the compact formulation of Okada (1992), which is based on the dislocation theory in a homogeneous half-space. Its application can be found in estimating temporal change of Coulomb failure functions after the 2011 Tohoku-oki M9.0 earthquake (Toda et al., 2011; Yoshida et al., 2012). According to the result of Toda et al. (2011), the Delta CFF takes significant values (>0.1 bar) at points over 400 km from the epicenter. This raises, however, a serious concern whether internal stresses are adequately estimated using the simple flat earth model that ignores the earth's sphericity and radial stratification.
In this paper, we propose a new recipe to compute the internal displacement, stress/strain, and gravity potential change due to an earthquake using a more realistic SNREI (Spherically symmetric, Non-Rotating, perfectly Elastic and Isotropic) earth model, such as PREM. We will show that our recipe has an advantage over normal mode sum approach that it is immune from the awkward oscillatory inconvergence near the source, known as the Gibbs phenomenon of the Fourier expansion. We will also show co-seismic volumetric strains excited by the 2011 Tohoku earthquake and discuss its relevance to the surface gravity change observed by satellite gravity and by terrestrial gravimetry.

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JS04p-500

3D Surface Displacement Rates in the Upper Rhine Graben area, Southwest Germany, derived from leveling, GPS, and InSAR

T. Fuhrmann[1]*, M. Westerhaus*[1]*, B. Heck*[1]
[1]*Karlsruhe Institute of Technology, Geodetic Institute, Karlsruhe, Germany*

The Upper Rhine Graben (URG) is the most prominent part of the Cenozoic rift system crossing Central Europe. In recent years, the URG is characterized by moderate tectonic and seismic activity with a significant probability for large earthquakes (Mw > 6). The long-term surface displacements induced by tectonic processes are expected to be small (less than 1 mm/a). As the complex fault system of the URG is capable of both, extensional and strike slip faulting, vertical as well as horizontal displacements are possible. Magnitude and direction of the recent 3D displacement field of the graben system are not well constrained from previous geodetic studies, mostly because of the poor spatial or temporal coverage of the available data.

We study the lithosperic deformation of the URG area using all currently available geodetic data sets in a multi-technique combination approach. Focusing on long-term, linear displacement rates, we analyze a transnational network of leveling data, GPS data observed at approx. 80 cGPS sites located in Germany, France and Switzerland, and SAR data acquired by ERS-1/2 and Envisat on one descending and two ascending tracks. First, we estimate linear displacement rates in vertical, horizontal and line-of-sight directions from single-technique analyses. Second, we mathematically combine the displacement rates resulting in a dense grid of 3D velocity vectors.

The combined map of the current 3D displacement field resolves the ongoing deformation of the URG with unprecedented detail and accuracy. Within the presentation, our method for the combination of displacement estimates from leveling, GPS and InSAR will be explained. The resulting 3D velocities will be presented w.r.t. the tectonic setting as well as anthropogenic activities affecting the result.

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JS04p-501

Stress analysis of plate motions

M. Kollár[1], *Z. Minarechová*[1]
[1]*Faculty of Civil Engineering- Slovak University of Technology in Bratislava, Department of mathematics and descriptive geometry, Bratislava, Slovak Republic*

The work deals with a study of the stress and strain fields resulted from the plate motions. The theoretical part is devoted to causes and types of plate motions and deformations, then it presents the basics of elasticity theory with the derivation of Lame`s equations of 3D elasticity and their solution by the finite element method. The practical part discusses the numerical experiments, where the 3D computational domain is bounded by the real Earth's surface from above and by the Moho surface from bellow. The input boundary conditions applied on the upper boundary are in the form of displacement vectors obtained by HS3-NUVEL1A, while on the lower one we suppose the symmetry boundary conditions, i.e. displacement vector component perpendicular to this boundary is zero. For numerical implementation, the 3D linear elements in FEM software ANSYS are used and several local refinements in chosen fault regions are presented as well. Results are represented in the form of components of stress tensor.

Joint Inter-Association Symposium

JS04p - JS4 Deformation of the Lithosphere: Integrating Seismology and Geodesy through Modelling (IASPEI, IAG)

JS04p-502

Model of the horizontal deformation of the earth's crust surface of the Sudeten (SW Poland) based on GPS data

B. Kontny[1], P. Grzempowski[2], P. Aleksandrowski[3], J. Kaplon[1], V. Schenk[4], Z. Schenkova[4]
[1]Wroclaw University of Environmental and Life Sciences, Institute of Geodesy and Geoinformatics, Wroclaw, Poland
[2]Wroclaw University of Technology, Institute of Mining- Faculty of Geoengineering- Mining and Geology, Wroclaw, Poland
[3]Polish Geological Institute - National Research Institute, Lower Silesia Branch in Wroclaw, Wroclaw, Poland
[4]Academy of Sciences of the Czech Republic, Institute of Rock Structure and Mechanics, Prague, Czech Republic

Monitoring data from permanent GNSS stations located in the study area and archival periodical GPS measurements made in period 1997 - 2012, were employed in the project. All the monitoring data were reprocessed with the latest version of the Bern software in a standardized frame of reference, applying new, absolute models of antenna phase centers and latest models of parameters of the rotary motion of the Earth, as well as models of the atmosphere. An new approach to the estimation of displacement velocities of the sites of the research networks was introduced, consisting in an integration of measurements from permanent GNSS stations with those from periodic measurement sites. Standardized and corrected results of the aggregated and integrated GPS network processing were used for a preliminary geodynamic interpretation. This concerned primarily the stage of identification of the model of surface deformations in the study area based on calculated velocity vectors. Certain modifications of well-known methods of creating surface models (GRID-based interpolation) of intraplate velocities vector fields referring to motions of the outermost layer of the Earth's crust and of horizontal deformation models of the Earth’s surface (linear deformations), were applied. Thus generated models were subjected to geodetic (geometrical) and structural geological interpretation. The latter interpretation was performed together with geologists, geophysicists and seismologists. The outcomes of this interpretation can be considered as the basis for a due recognition of the actual nature of a tectonic behavior of the area of the Sudeten mountains and the Fore

Sudetic block at their northern margin, as well as for verification of results of the hitherto made geodetic and geological studies.

Joint Inter-Association Symposium

JS04p - JS4 Deformation of the Lithosphere: Integrating Seismology and Geodesy through Modelling (IASPEI, IAG)

JS04p-503

Testing a cross-scale model of seismic cycle

I. Muldashev[1], *S. Sobolev*[1]
[1]*GFZ German Research Centre for Geosciences,*
Section 2.5 Geodynamic Modeling, Potsdam, Germany

We model seismic cycle of great megathrust earthquakes using finite element numerical technique that employs elasto-visco-plastic rheology consistent with laboratory data of crustal and mantle rocks and is capable to describe both geological and seismic-cycle time-scale deformation of lithosphere (see accompanied abstract by Sobolev and Muldashev). Here we present details of model design and testing.

We prepare model setup by modeling subduction process for several Mln yr, with the different assumptions for initial lithospheric structure and temperature of the overriding and subducting plates and kinematic boundary conditions. As a result we get the subduction model with appropriate geometry and stress distribution. We then substitute static friction by rate and state friction law and employ adaptive time-step integration procedure that changes time step from 10^{-5} yr at instability (earthquake) and gradually increase it to 5 yr during postseismic relaxation.

We study sensitivity of model in 2D to the magnitude of static friction, rate and state parameters (a, b and Lcr) and viscosity in subduction channel and demonstrate agreement with theoretical expectations and observations. In particular we obtain almost linear relation between the earthquake period and stress drop from one hand and the rate and state parameter (b-a) from another, and realistic values of stress drop of few MPa for the typical great earthquakes. The model also shows classic instable behavior at low Lcr and conditionally stable behavior at high Lcr.

Next we investigate dependency of seismic moment (and average slip) of model earthquake on rupture area in 3D. We obtain relations close to the theoretical expectation for the average stress drop of earthquake weakly dependent from its magnitude.

Joint Inter-Association Symposium

JS05a - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

IUGG-0301

Characteristic cryoseismic waves associated with surface environmental variations in the Lützow-Holm Bay, East Antarctica

M. Kanao[1]
[1]*National Institute of Polar Research, Polar Data Center, Tokyo, Japan*

Among the IPY projects, the 'Polar Earth Observing Network (POLENET)' was the largest contributions in establishing seismic network in Antarctica. Several kinds of environmental signals associated with atmosphere - ocean – cryosphere - solid earth systems were detected in continental margins and surrounding oceans. Ice-related seismic motions for small magnitude events are generally named ice-quakes (ice-shocks) and can be generated by glacially related dynamics. Such kinds of cryoseismic sources are classified into the movements of ice sheets, sea-ice, oceanic tide-cracks, oceanic gravity waves, icebergs and the calving fronts of ice caps (Kanao et al., 2012). Cryoseismic and oceanic waves (microseismis) are likely to be influenced by the variations in environmental conditions, and the continuous study of their time-space variability provides indirect evidence of climate change. In this presentation, characteristic features of cryoseismic waves observed around the Lützow-Holm Bay (LHB), East Antarctica are introduced, involving surface environmental changes in vicinity of the area from continental coast to Southern Ocean. Hypocenters of local events are identified to be located along the coast and the edges of fast-ice area; harmonic tremor waveforms were observed involving large sea-ice discharge from LHB in 1997 winter; oceanic tide relating ice-shock signals represent strong correlation with sea-ice revel changes; these all evidence have characteristic frequency contents and time variability. As glacial earthquakes are the most prominent phenomena found recently in polar regions (Nettles and Ekstrom, 2010), these new innovative studies from seismology are expected by long-term monitoring under extreme conditions in polar environment.

Joint Inter-Association Symposium

JS05a - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

IUGG-1141

Icequakes in the Cryosphere: a review

E.A. Podolskiy[1], *F. Walter*[2]
[1]*Hokkaido University, Institute of Low Temperature Science, Sapporo, Japan*
[2]*Swiss Federal Research Institute WSL,*
Mountain Hydrology and Mass Movements, Birmensdorf, Switzerland

The last decade witnessed an explosion in a number of publications on glacier seismology. The seismic signals from a wide range of processes fill a broad band of frequencies (from 10^{-3} to 10^{2} Hz) and seismic magnitudes (from M-3 to M7) and give a fresh and unprecedented view on multiple phenomena in the Cryosphere. New insights into stick-slip motion, calving, glacier-, iceberg- and sea ice dynamics and precursory seismicity of hanging glaciers collapses and disintegrating ice-shelves are being discovered. These observations promise to provide invaluable foundations for understanding ongoing environmental changes and for future exploration of extra-terrestrial ice bodies. In this overview we discuss characteristics of previously reported seismic sources in the Cryosphere and indicate interesting research challenges in the near future. With an overwhelming number of recent papers and rapidly growing seismic data volumes provided by modern seismic networks and arrays in polar and mountain regions (e.g., POLENET, GLISN, USArray), we hope that this introduction to glacier seismicity will be a timely and useful reference for glaciologists and seismologists.

Joint Inter-Association Symposium

JS05a - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

IUGG-2283

Tidally modulated cryoseismicity at a shear margin of the Fimbul Ice Shelf, Antarctica

M. Pirli[1], *J. Schweitzer*[2], *K. Matsuoka*[3]
[1]*-, Skjetten, Norway*
[2]*NORSAR, -, Kjeller, Norway*
[3]*Norwegian Polar Institute, -, Tromsø, Norway*

Seismic activity of cryogenic origin was recorded at the Fimbul Ice Shelf, Dronning Maud Land, Antarctica, between March 2012 and August 2014. The location of the activity has been determined within the shear zone between the outlet of the fast-flowing Jutulstraumen glacier and the "Kupol Moskovskij" ice rise, about 180 km downstream the glacier's grounding line, and at distances of about 220 km from the seismic stations SNAA and TROLL. A waveform cross-correlation detector identified more than 3000 events associated with the same source region. High waveform similarity levels and the use of cross-correlation time-differences helped establish a very narrow spatial extent, in the order of about one kilometer. The phenomenon commenced on low levels in March 2012 and continued with similar intensity until August 2013, when an impressive outburst of seismic activity took place. High activity continued until the end of the calendar year, but with gradually decreasing intensity. From March to July 2014, activity levels returned to those observed in early 2013. Such a manifestation of cryoseismicity in the particular source region is unprecedented since the start of SNAA records in 1997. The most striking characteristic of the observed seismicity is a clear modulation by the ocean tide, following both the neap-spring and the semi-diurnal tidal cycle. We will focus on the presentation of different aspects of this modulation, and a discussion of its implications for ice-sheet dynamics.

Joint Inter-Association Symposium

JS05a - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

IUGG-3634

Seismic monitoring of a moulin and its influence on the stick-slip flow of the Greenland ice sheet

C. Roeoesli[1], *J.P. Ampuero*[2], *F. Walter*[3], *A. Helmstetter*[4], *E. Kissling*[1]
[1]*Inst. of Geophysics, ETH Zurich, Zurich, Switzerland*
[2]*Seismology Laboratory, California Institute of Technology, Pasadena, USA*
[3]*Mountain Hydrology and Mass Movements,*
Swiss Federal Research Institute WSL, Birmensdorf, Switzerland
[4]*Institut des Sciences de la Terre, Université Joseph Fourier, Grenoble, France*

Assessment of recent changes in flow dynamic of the Greenland Ice Sheet (GrIS) and understanding of its response to climate change are still incomplete. To further improve ice sheet flow models and subsequently sea level rise predictions, understanding of subglacial drainage system and conditions at the ice-bed interface are of key importance.

With our temporary seismic network installed in the ablation zone of the GrIS, we were able to monitor seismic signals related to basal stick-slip motion of a slowly flowing part of the GrIS. These basal icequakes are a main characteristic of ice flow with more than 10’000 observed basal icequakes distributed over the area of investigation (~6 km^2) and time span of measurements of 45 days. The basal icequakes can be grouped into clusters of same location repeatedly emitting seismic energy.

Our continuous seismic records furthermore shed light on melt water drainage within and under the ice sheet. As a main feature of the drainage system, a moulin within our network constantly evacuates large amounts of surface melt water to the glacier bed changing the subglacial hydraulic conditions at short time scales. We are able to monitor the drainage activity of this moulin as during most days it emits long term seismic tremors lasting several hours per day. This allows us to constrain geometry and water flow inside the moulin and thus image the moulin by remote sensing. Moreover, some basal icequake clusters show a strong correlation in their activity to the moulin water flow, whereas other clusters exhibit no correlation to melt water input. The interplay between moulin drainage and stick-slip motion reveals new insights into the influence of melt water on subglacial processes and and thus the dynamic flow behaviour of the GrIS.

Joint Inter-Association Symposium

JS05a - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

IUGG-4662

Periodic, episodic, and complex behavior of glacial earthquakes

P. Winberry[1], H. Conway[2], A.D. Huerta[3], S. Anandakrishnan[4], R.C. Aster[5], M. Koutnik[2], A. Nyblade[4], D.A. Wiens[6]
[1]Central Washington University, Ellensburg, USA
[2]University of Washington, Earth and Space Sciences, Seattle, USA
[3]Central Washington University, Geological Sciecnes, Ellensburg, USA
[4]Penn State University, Geosciences, University Park, USA
[5]Colorado State, Geosciences, Fort Collins, USA
[6]Washington University in Saint Louis, Earth and Planetary Sciences, Saint Louis, USA

Stick-slip sliding is a ubiquitous mode of glacier motion, occurring over a range of spatial scales, with potentially significant implications for the understanding of both glacier motion and glacier erosion. The most prominent manifestation of the glacial stick-slip phenomena is generation of seismic waves associated with "glacial earthquakes" that can be observed at great distances (> 100 km). We report on a new family of repeating glacial-earthquakes originating from a small glacier in the Transantarctic Mountains. Similar to previous studies in the region, the family is composed of events that are approximately magnitude 2 in size. Additionally, all events are characterized by similar waveforms. The stability in the waveform indicates a stationary source during the entire observational period and allows us to develop a six-year catalog of over 250,000 events. In contrast to previous studies, the inter-event separation exhibits a range of behavior that includes periodic, oscillating and periods of dormancy. These new observations once again highlight the complexity of glacial sliding and potential similarities of stick-slip induced glacial earthquakes with traditional earthquakes.

Joint Inter-Association Symposium

JS05b - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

IUGG-1700

Continuously imaging sub-ice shelf geomorphology with the vibroseismic method

O. Eisen[1], *A. Lambrecht*[2], *C. Mayer*[2], *C. Hofstede*[3]
[1]*Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany*
[2]*Bayrische Akademie der Wissenschaften, Komission für Erdmessung und Glaziologie, Munich, Germany*
[3]*Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Glaciology, Bremerhaven, Germany*

Bathymetry, seabed geomorphology and water column thickness are three important quantities to investigate the current and past interaction of ice shelves with the ocean and underlying geologic strata. Whereas ice thickness of meteoric ice can best be derived with radar, the thickness of accreted (marine) ice, the water column and the stratigraphy of the seabed require seismic techniques. Without an ice shelf, geomorphology can best be obtained with swath sounding methods. With a floating ice shelf, things become more difficult. Although AUVs provided sub-shelf data, their deployment is restricted to regions where the AUV can safely return. In other regions, sub-shelf bathymetry was so far only estimated by sparse seismic point measurements or deduced in coarse resolution from gravimetric surveys. Here we present results from a vibroseismic traverse on the Ekströmisen, Antarctica, which recorded 80 km of high resolution seismic data in 2014 on the ice shelf. Seabed geomorphology shows considerable variations, from undisturbed regions to troughs several tens of meters deep. Some features show a height of 300 m and could be interpreted as past grounding lines of the active ice stream. Our results demonstrate that imaging sub-ice shelf regions with vibroseismic techniques could provide 3D images of the seabed, not as highly resolved as with swath bathymetry in open water, but considerably better than presently available data sets, and should be routinely obtained to improve our understanding of past ice activity and current processes.

Joint Inter-Association Symposium

JS05b - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

IUGG-1824

"Local glacial seismicity study using automatic processing of single three component station data"

A. Fedorov[1], *V. Asming*[2]
[1]*Kola branch of Geophysical Survey of RAS, Apatity, Russia*
[2]*Kola branch of Geophysical Survey of RAS,*
Kola branch of Geophysical Survey of RAS, Apatity, Russia

Seismic events generated by glaciers (icequakes) often are very weak and generally are recorded by a small number of stations or even by only one station. Therefore it is important to have an opportunity to detect and locate icequakes by single station data for automatic monitoring of glaciers.

We propose automatic detector and locator of seismic events by a single thee component station. In this routine we have implemented automatic procedures of accurate phase arrival time picking based on statistical determination of ambient noise level and autoregressive technique. Phase type determination (P or S) and back azimuth calculation are based on polarization and correlation analyses. Some properties of signal envelopes are used to screen out false alarms of the detector.

We use average frequency criterion to select glacier related events from all detected events. It was shown that such events have low frequency content with spectral maximum in the range 2 – 5 Hz.

We have processed data sets of seismic stations placed in Spitsbergen and Franz Josef Land archipelagos. The results show that single-station detector allows getting bulletins of glacier-related events with a small number of false alarms. And automatic location is good enough for most part of events but artifacts can occur sometimes because of complexity of wave forms.

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Joint Inter-Association Symposium

JS05b - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

IUGG-1921

Seismological contribution to the study of snow avalanches

E. Surinach[1]
[1]*University of Barcelona, Geodynamics and Geophysiscs, BARCELONA, Spain*

Like other mass movements, snow avalanches are multiple and moving sources of seismo-acoustic energy. This energy recorded with appropriate equipment can provide information about these sources. Once reproducibility and repetitivity of avalanche seismic signals are demonstrated, their analyses are helpful in the detection and/or study of avalanche dynamics.

Since 1995 the snow Avalanche Group of the Universitat de Barcelona (UB) has been studying the characteristics of snow avalanches using seismological methods. Natural and artificially triggered avalanches of different types (flow and size) have been recorded at diverse distances (0 - 3 km) with different azimuths with respect to the flow at four experimental sites.

Pressure and radar measurements, video images and field observations including cartography, type of flow and deposits complemented and corroborated the seismic and infrasound data. This gives value to the information supplied by the analysis of the seismic and infrasound data obtained by non invasive sensors.

The seismo-acoustic signals generated by snow avalanches were analysed with different methodologies in the time and frequency domains. The physical processes (source generation and wave propagation characteristics) were borne in mind. The results obtained concern the avalanche description: type and size, speed, energy dissipation and characteristics of the flow (signatures of powder and wet avalanches).

Joint Inter-Association Symposium

JS05b - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

IUGG-2029

Inferring avalanche run-out and flow regimes from seismic measurements

C. Pérez- Guillén[1], *B. Sovilla*[2], *E. Suriñach*[3], *M. Tapia*[4], *A. Köhler*[2]
[1]*University of Barcelona,*
RISKNAT Group- GEOMODELS- Dpt Geodinàmica i Geofísica- Faculty of Geology, Barcelona, Spain
[2]*WSL Institute for Snow and Avalanche Research SLF, Avalanches and prevention, Davos, Switzerland*
[3]*University of Barcelona,*
RISKNAT Group- GEOMODELS- Dpt. Geodinàmica i Geofísica- Faculty of Geology, Barcelona, Spain
[4]*Institut d'Estudis Catalans LEGEF-IEC,*
Laboratori d'Estudis Geofísics Eduard Fontserè, Barcelona, Spain

The ground motion generated by snow avalanches is a complex natural phenomenon produced by the interaction of the avalanche with the snow cover/terrain. Nowadays avalanches are recorded using arrays of seismic sensors providing data that may be potentially used to get inherent information about the characteristics of the source (type of flow regime), the basic dynamical processes (erosion and deposition) and the approximate size of the avalanche.

In order to better understand the connection between seismic signals and the avalanche dynamics, we analyze data of about thirty avalanches acquired at Vallée de la Sionne test site in Switzerland. Seismic sensors are installed along the path and the avalanches flow over them. Duration, Peak Ground Velocity (PGV), Intensity (I) and the frequency content of each seismic signal have been compared with the avalanche flow regimes and snow cover depths obtained from FMCW radar measurements and with the avalanche run-out obtained from pictures.

We show that the frequency content of the seismic signal can be used to infer the avalanche flow regime allowing the distinction between dense and energetic, turbulent flows. Furthermore, signal duration can be correlated to avalanche run-out for both dense and energetic flows. When the snow cover at the seismic station location is smaller than approximately 2m, and the energy absorption does not significantly weaken the intensity of the signal, the avalanche run-out can be deduced also from PGV and I.

These results suggest that seismic data can be used to infer flow type characteristics and the run-out of avalanches providing an interesting tool for practical applications for avalanche monitoring and management purposes.

Joint Inter-Association Symposium

JS05b - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

IUGG-3863

Towards the automatic detection of avalanches in seismic data using Hidden Markov Models

M. Heck[1], *A. van Herwijnen*[1], *C. Hammer*[2], *J. Schweizer*[3], *D. Fäh*[2]
[1]*WSL Institute for Snow and Avalanche Research SLF, Avalanche Formation, Davos Dorf, Switzerland*
[2]*Swiss Seismological Service, Engineering Seismology, Zürich, Switzerland*
[3]*WSL Institute for Snow and Avalanche Research SLF, Snow Avalanches and Prevention, Davos Dorf, Switzerland*

Seismic monitoring systems are very well suited for the remote detection of gravitational mass movements, such as landslides or debris flows. Since the 1970s it has been known that snow avalanches can also be detected through seismic monitoring.

The goal of this work is to develop a system capable of automatically detecting avalanches in continuous seismic data, to get accurate information about the number and release time of avalanches. We used a Hidden Markov Model (HMM), a statistical pattern recognition tool widely used for speech recognition, to generate a probabilistic model to determine the likelihood that a signal belongs to a certain class. We further used a new technique which exploits the abundance of data containing mainly ‘background signals’, to learn a model representation of the overall observable feature space. This background model then serves as seed for deriving HMM parameters for avalanche waveforms using as little as one single training sample.

While the HMM method is tailored to detect rare and highly variable events, due to the variability of signals generated by avalanches, a substantial training set was required to obtain acceptable detection rates. Since local heterogeneities in the ground strongly affect seismic wave fields, separate models were required for each site. Finally, due to the continuously evolving snow cover above the seismic sensors, the background model had to be recalculated on a regular basis, resulting in improved classification rates.In the long term, this approach will be of great use for avalanche forecasting, since accurate information on the number and release time of avalanches will provide an important contribution for avalanche warning services.

Joint Inter-Association Symposium

JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-212

Seismic monitoring of glaciers on Alexandra Land Island in Franz Josef Land Archipelago

A. Danilov[1], *G. Antonovskaya*[1]
[1]*Institute of Environmental Problem of the North,*
Ural Branch of Russian Academy of Science, Arkhangelsk, Russia

A network of seismic stations was installed on Alexandra Land Island in Franz-Joseph Land Archipelago. It provides a basis for seismic monitoring of glaciers on arctic islands in Russia.

Data acquired by this new network reveals different mechanisms behind the icequakes along with the link between these events and ambient temperature variations. Icequakes can be split into two groups. The first group consists of events with the majority of power residing in 1 to 10 Hz frequency range. The processes behind these are related to caving of massive ice chunks – iceberg creation. The second group is characterized by the majority of power residing in 10 to 22 Hz frequency range. Such events are attributed to the formation of fractures in glaciers.

Long-period oscillations (480 s) were detected near one glacier. They are accompanied by a background of high-frequency micropulses in 25-35 Hz range. The temporal evolution of one of such events was followed by I category icequake. The possible conclusion is that similar events act as trigger for I category icequakes.

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Joint Inter-Association Symposium

JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-213

Multi-seasonal seismic monitoring of the fracture drainage system at the base of Rhonegletscher, Switzerland

P. Dalban Canassy[1], C. Röösli[2], F. Walter[3]
[1]*Swiss Federal Institute of Technology ETH,*
Laboratory of Hydraulics- Hydrology and Glaciology, Zurich, Switzerland
[2]*Swiss Federal Institute of Technology ETH,*
Swiss Seismological Service / Institute of Geophysics, Zurich, Switzerland
[3]*Swiss Federal Institute for Forest- Snow and Landscape Research WSL,*
Mountain Hydrology and Mass Movements, Birmensdorf, Switzerland

Subglacial processes play a key role in glacier dynamics, ice sheet stability and sea level rise. Nevertheless, due to inaccessibility of glacier beds, many important theoretical advances on glacier sliding and basal drainage are unfortunately starved of data. To fill these data gaps, scientists have resorted to passive seismic monitoring on or near glaciers. This has provided unprecedented observations of sliding motion and hydraulic processes near the glacier base. For example, seismic monitoring has revealed tensile faulting near the bed of temperate glaciers. Such faults may lead to basal and englacial fracture networks, which have been observed on borehole videos or radar reflections. However, the role of these fracture networks in subglacial drainage remains poorly understood, in particular the relationship to efficient low-pressure channels.

Here we present results from yearlong seismic monitoring on Rhonegletscher, Switzerland, with the goal to constrain the seasonal evolution of subglacial fracture networks. We combine long-term on-ice seismometer installations with a temporary high-density seismometer array. This provides a base for high-precision location of faulting within the ice ('icequakes') and automated cross-correlation searches to study subglacial regions of elevated seismic activity. Our results suggest an evolving subglacial fracture network, even in the absence of surface melt. Furthermore, the life cycles of individual fractures likely exceed one year, even if fracture activity intermittently ceases. In the future we propose to supplement these results with advanced icequake waveform analysis to further constrain the extent and temporal changes of subglacial fracture drainage.

Joint Inter-Association Symposium

JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-214

Wavelet analysis of high-frequency seismic events triggered by the interaction of ice sheet flow with the Sør Rondane Mountains, East-Antarctica

F. Collin[1], *. Lombardi*[1], *. Camelbeeck*[1], *. Martin*[1], *. Rapagnani*[1]
[1]*Royal Observatory of Belgium, seismology, Uccle, Belgium*

To study the interactions of the Antarctic ice sheet with the Sør Rondane Mountains of eastern Queen Maud Land (East Antarctica), we installed in early 2014 five new broadband seismic stations, in addition to an existing permanent station setting up a 90 x 30 km wide seismic network.

Over several months of collected data, we proceed 1 month with the perspective of defining methods to use for measuring and analysing the complete dataset.

We observed numerous local seismic events, from which 155 were localized. Part of these seismic events show a relatively chaotic pattern associated to high frequency content between 15 and the Nyquist frequency limit of 50 Hz. For this kind of events, the classical picking methods are not efficient and their onset is not clearly identifiable. To overcome this difficulty, we pick the P-wave first arrival time on the wavelet transform of the signal, permitting an accurate time precision for high frequencies using the modulo of the wavelet analysis. Using Morlet wavelet as 'mother wavelet' and studying the phases of the wavelet analysis our aim is to improve the absolute arrival-time of the signals and thus the sources localizations.

The analysed dataset indicate 2 major source regions: at the border between the ice sheet and outcropping mountains and within the fastest moving ice flow suggesting that the detected seismicity is correlated with the ice flow dynamics.

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JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-215

Seismic and infrasound data analysis to assess the possibility of an avalanche triggered by a local earthquake

C. Pérez- Guillén[1], *M. Tapia*[2], *E. Suriñach*[1], *G. Furdada*[1], *J.N. McElwaine*[3], *W. Steinkogler*[4], *M. Hiller*[4]
[1]*University of Barcelona,*
RISKNAT Group- GEOMODELS- Dpt Geodinàmica i Geofísica- Faculty of Geology, Barcelona, Spain
[2]*Institut d'Estudis Catalans LEGEF-IEC,*
Laboratori d'Estudis Geofísics Eduard Fontserè, Barcelona, Spain
[3]*Durham University, Department of Earth Sciences, Durham, United Kingdom*
[4]*WSL Institute for Snow and Avalanche Research SLF, Avalanches and prevention, Davos, Switzerland*

Seismically induced snow avalanches can represent an important collateral hazard associated with earthquakes in mountainous regions. The vibrations caused by earthquakes could lead to a destabilization of the snowpack and hence the release of an avalanche.

An earthquake of magnitude M_L3.1 with the hypocenter in France at approximately 43 km from the Vallée de la Sionne (VDLS, Switzerland) avalanche test site occurred on 6 December 2010. The site is monitored with different instruments along a main avalanche path. The earthquake triggered the seismic alarm system of the test site. An array of seismic and infrasound sensors installed in VDLS recorded data continuously in the area. Initially, this event was not considered as an avalanche because no data were recorded by the monitoring instruments situated in the main avalanche path.

A further seismic analysis demonstrated that shortly after the arrival of the earthquake an overlapping signal generated by an avalanche was recorded. The movement of the avalanche generated seismic and infrasound waves owing to the interaction of the avalanche with its environment.

The time-frequency joint analysis of the data provided information on the avalanche and earthquake characteristics. Seismic data were used to quantify energy parameters and changes in the elastic stress field within the snowpack due to the earthquake. The event was compared with two stronger earthquakes that did not trigger any avalanches. The study was complemented with nivo-metereological

data and snowpack stability evaluations of the days of the earthquakes. The results show that the coseismic displacement produced by such a small earthquake was in the order of magnitude of the displacements measured in a snow layer before the occurrence of a fracture.

Joint Inter-Association Symposium

JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-216

DETECTING AVALANCHE ACTIVITY USING DISTRIBUTED ACOUSTIC FIBER OPTIC SENSING

A. Prokop[1]
[1]*BOKU - University of Natural Resources and Applied Life Sciences, Department of Structural Engineering and Natural Hazards, Vienna, Austria*

A new tool for avalanche monitoring, called „The Avalanche Detector“, a distributed fiber optic system, was for the first time installed and adapted for the purpose of monitoring snow avalanche activity. The method is based on an optical time domain reflectometer system, which dates back to the 1970‘s and detects seismic vibrations and acoustic signals on a fiber optic cable that can have a length of up to 30 km. In winter 2013/14 the system was run in an operational mode as a warning tool and for the verification of avalanche events due to blasting actions in the ski resort of Lech am Arlberg, Austria. Both natural and by blasting triggered avalanches were recorded. In this work a description of the theoretical background, the system implementation, the field installation, realization of tests and an investigation of the recorded data is presented as well as the warning software that was programmed. So far we measured 60 avalanches with runout distances ranging from a few meters to approximately 250 meters, as well as the 90 not successful attempts of artificial triggering. Moreover we measured properly if critical infrastructure (a ski run) was reached by the avalanches or not. In conclusion we summarize that distributed acoustic fiber optic sensing is a very expensive but precise method to monitor avalanche activity and runout distances.

Joint Inter-Association Symposium

JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-217

Cm-scale variations of crystal orientation fabric in cold Alpine ice core from Colle Gnifetti as source for englacial seismic reflections

J. Kerch[1], *O. Eisen*[2,3], *I. Weikusat*[2,4], *T. Erhardt*[5]
[1]*Heidelberg University, Institute of Environmental Physics, Heidelberg, Germany*
[2]*Alfred-Wegener-Institute Helmholtz-Zentrum for Polar and Marine Research, Glaciology, Bremerhaven, Germany*
[3]*University of Bremen, Department of Geosciences, Bremen, Germany*
[4]*University of Tübingen, Department of Geosciences, Tübingen, Germany*
[5]*University of Bern,*
Oeschger Center for Climate Change Research and Institute for Climate and Envir onmental Physics, Bern, Switzerland

Analysis of the microstructural parameters of ice has been an important part of ice core analyses so far mainly in polar cores in order to obtain information about physical processes (e.g. deformation, recrystallisation) on the micro- and macro-scale within an ice body.

More recently the influence of impurities and climatic conditions during snow accumulation on these processes has come into focus. A deeper understanding of how palaeoclimate proxies interact with physical properties of the ice matrix bears relevance for palaeoclimatic interpretations, improved geophysical measurement techniques and the furthering of ice dynamical modeling.

Variations in microstructural parameters e.g. crystal orientation fabric or grain size can be observed on a scale of hundreds and tens of metres but also on a centimetre scale. The underlying processes are not necessarily the same on all scales. Especially for the short-scale variations many questions remain unanswered.

The observed changes in anisotropy resulting from these distinct short-scale variations are deemed strong enough to be the cause of englacial seismic reflections that were recorded during measurements on Colle Gnifetti, Switzerland/Italy, in 2010.

Fabric Analyser measurements were conducted on ice samples from different depth ranges of a cold Alpine ice core (72 m length) drilled in 2013 at Colle Gnifetti and located on the earlier seismic profile line.

Results were obtained by automatic image processing, providing estimates for grain size distributions and crystal orientation fabric.

A first estimate of the causal relationship between the short-scale anisotropy structure and the englacial seismic reflections is presented. The relevance of these results for palaeoclimate reconstruction are discussed.

Joint Inter-Association Symposium

JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-218

Distributed seismic network ("geoPebbles") on ice sheets and glaciers: Results from West Antarctica

S. Anandakrishnan[1], *S. Bilen*[2], *J. Urbina*[2]
[1]*Pennsylvania State Univesity, Geosciences, UNIVERSITY PARK, USA*
[2]*Pennsylvania State Univesity, Electrical Engineering, UNIVERSITY PARK, USA*

Development of the network of seismic and GPS sensors (the so-called 'geoPebbles') is reviewed. Results from the first deployment at the West Antarctic Ice Sheet Divide (WAIS Divide) ice coring location is presented. The sensors combine a three-component seismometer along with a GPS receiver for timing and position. They form a distributed, wireless network allowing for easier three-dimensional imaging of ice sheets. The development process was driven by cryospheric needs and requirements, along with pedagogical goals of training and education of the next generation of engineers and scientists. In addition, a goal of open-source development underlies the engineering philosophy.

The network was deployed in parallel with a multi-channel seismic system (used previously) and with geodetic-grade GPS receivers. Seismic sources were chemical explosives detonated in 20m deep shotholes. Ice at the WAIS Divide location is approximately 3000m thick. We present results from both the active-source and a short passive deployment.

Joint Inter-Association Symposium

JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-219

Automatically detecting snow avalanches using a machine learning tool – a case study in the Swiss Alps

C. Hammer[1]*, D. Fäh*[1]*, M. Ohrnberger*[2]
[1]*ETH Zürich, Swiss Seismological Service SED, Zürich, Switzerland*
[2]*University of Potsdam, Institute of Earth and Environmental Sciences, Potsdam, Germany*

Information on avalanche activity, i.e. the number and size of snow avalanches within a specific time and area, is one of the key input parameters for avalanche forecasting. Currently information on avalanche activity is mainly obtained through visual observations. However, this involves large uncertainties in the number and exact timing of avalanches influencing the subsequent avalanche forecast. Therefore, alternative methods for the remote detection of mass movements in particular in non-observed areas are highly desirable. Producing a specific seismic signature we identify avalanches based on the exited ground vibration. We take advantage of an automatic classification procedure for continuous seismic signals to automatically detect snow avalanches. A probabilistic description of the signals, called hidden Markov models, allows the robust identification of corresponding signals in the continuous data stream. The procedure is based upon learning a general background model from continuous seismic data. Then a single reference waveform is used to update an event specific classifier. Thus, a minimum amount of training data is required by constructing such a classifier on the fly whilst enabling the recognition of highly variable time series. In this study we processed five days of continuous data recorded during the extreme winter in 1999. The data were recorded at a broadband station operated by the Swiss Seismological Service. Supported by very promising classification results of 90 % detected events and only 4 false alarms during the complete observation period, we conclude that the suggested approach provides a valuable tool for the avalanche related hazard assessment.

Joint Inter-Association Symposium

JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-220

Glacier seismicity in the vicinity of SPITS monitoring array

M. Ohrnberger[1], *C. Hammer*[2], *M. Spieler*[1], *J. Schweitzer*[3]
[1]*University of Potsdam, Institute of Earth and Environmental Sciences, Potsdam, Germany*
[2]*ETH Zürich, Schweizer Erdbebendienst SED, Zürich, Switzerland*
[3]*NORSAR, Seismology, Kjeller, Norway*

Aiming to add to the improvement of rapid seismic event screening at the SPITS monitoring array on Svalbard, we have analyzed several years (2009-2013) of the continuously recorded wave field within three frequency bands from 1.5 to 18 Hz. From a total of more than one billion short time window f-k analysis results, we have summarized statistical properties of the high frequency wave propagation characteristics in terms of slowness, direction, power, and coherency. One particular observation when looking at the temporal dynamics of the wave field is the existence of yearly patterns of slowness dependent directional changes of the wave field. The changes are remarkable sudden in their appearance and correlate closely with air temperature records from the nearby Longyearbyen airport. We associate these patterns with the sudden onset of glacier movement in the vicinity of the array. In order to verify this hypothesis derived from wave field statistics we returned to a detailed analysis of small-scale short lived transient events (2-10s duration). Picking first onsets and the maximum of the Rg wave train we use the arrival time differences and travel time curves derived from local velocity models to estimate roughly the epicentral distance of those transient signals to SPITS array. In combination with the directional information obtained from the f-k analysis we are able to pinpoint the origin of this micro-seismic events to local glaciers located in south-western directions of SPITS. This result confirms an earlier result about a notable source of seismicity recorded at SPITS and adds the temporal context of the occurrence of those events. This may allow in future getting further insight into the source process of those cryogenic events.

Joint Inter-Association Symposium

JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-221

On using highly resolved avalanche activity data obtained through seismic monitoring to improve avalanche forecasting

A. van Herwijnen[1], *M. Heck*[1], *J. Schweizer*[2]
[1]*WSL Institute for Snow and Avalanche Research SLF, Avalanche formation, Davos, Switzerland*
[2]*WSL Institute for Snow and Avalanche Research SLF, Snow avalanches and prevention, Davos, Switzerland*

Accurate avalanche occurrence data are of crucial importance for avalanche forecasting, since recent avalanching provides direct evidence on snowpack instability. We therefore explore how accurate avalanche activity data obtained through seismic monitoring can be used for avalanche forecasting. By visually inspecting data from a seismic sensor deployed in an avalanche start zone, we obtained avalanche activity data for two entire winters and one period of 10 days with intense wet-snow avalanche activity in the spring of 2013. Observed local avalanche activity derived from the seismic data compared reasonably well with conventional visual avalanche observations for the surrounding region, and mean local daily avalanche activity generally increased with increasing forecasted avalanche danger level. Furthermore, before periods of high avalanche activity the waiting time between avalanches decreased towards peak avalanche activity, suggesting that an early warning based on accurate avalanche activity is possible. Finally, by performing a detrended cross-correlation analysis to investigated typical time scales involved in avalanche formation processes, we could show that there are inherently different time scales involved in dry and wet-snow avalanching. While it is clear that for large-scale operational avalanche forecasting automatic avalanche detection still has to be developed, overall our results show that accurate avalanche activity data obtained through seismic monitoring would yield very valuable and novel data for avalanche forecasting, provided a large enough area can be monitored.

Joint Inter-Association Symposium

JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-222

Pattern of hybrid seismic event occurrence in Antarctica

C. Hammer[1], M. Ohrnberger[2], V. Schlindwein[3]
[1]ETH Zürich, Swiss Seismological Service SED, Zürich, Switzerland
[2]University of Potsdam, Institute of Earth and Environmental Sciences, Potsdam, Germany
[3]Alfred Wegener Institute, Geophysics, Bremerhaven, Germany

Mobility of glaciers such as rapid retreat or disintegration of large ice volumes produces a large variety of different seismic signals. Thus, evaluating cryogenic seismic events (e.g. changes of their occurrence in space and time) allows to monitor glacier dynamics. In this study we analyse a one year data span recorded at the Neumayer seismic network in Antarctica. Events are automatically recognized. The classification system is based on a generative (probabilistic) model description of seismic signal classes, known as hidden Markov models (HMM). We use an approach that requires a minimum amount of training data, i.e. a single reference waveform. In that way we do not rely on a large number of manually classified training events, which are currently not available for the Neumayer seismic network. We focus on a specific event type occurring close to the grounding line of the Ekström ice shelf. The observed waveform characteristics are consistent with an initial fracturing followed by the resonance of a water filled cavity. This type of event is also known as so-called hybrid event. The number of events detected strongly correlates with dominant tide periods. Based on this, we assume the cracking to be driven by existing glacier stresses trough bending. Voids are then filled by sea water, exciting the observed resonance. Consistent with this model, events mostly occur during rising tides and are located at the bottom of the glacier. Moreover, event occurrence shows variations beyond tide induced sea level changes (i.e. days without any detection, a seasonal variation), which cannot be fully explained by the proposed model and will be subject to future research.

Joint Inter-Association Symposium

JS05p - JS5 Glacier, Ice Sheet and Snow Seismology (IASPEI, IACS)

JS05p-223

Running realtime, year-round seismic stations across the Greenland ice sheet and beyond

M. Reusch[1]
[1]*IRIS PASSCAL, Socorro, USA*

Advances in the design of very low-power, cold-tolerant seismic instruments have led to a larger presence in the polar regions. Presented here is an update of the technology that allows the year-round-operation of PASSCAL-monitored stations in the GLISN (Greenland Ice Sheet Monitoring Network) project. Station designs pioneered at PASSCAL have improved the durability and endurance of polar seismic stations. Enclosed systems were developed to allow for batteries and key electronics to stay inside a vacuum-panel-insulated station enclosure with bulkhead connectors to external cabling, reducing the installation complexity and isolating the internal instrumentation from the harsh external environment. To address the low-end operating temp limitations (~-40C) and the limited and costly deep-field transportation resources, the station overall design requires a careful balance of: low power usage, battery array size, insulation, and power-production capability. In the past, most seismic telemetry from cold/remote sites has only sent limited state of health (SOH) and allowed limited remote command/control. Data were recovered by infrequent on-site visits. A new type of Iridium telemetry using existing Xeos modems (RUDICS) was introduced in 2012. This allowed for the 3X/day-automated collection of all continuous SOH and 1Hz waveforms. In 2013-14, after extensive in-house and field-prototype testing, 6 GLISN stations were upgraded to pull both 20 and 1Hz data streams in real-time using full-time RUDICS. Station-side problems are now deciphered with greater clarity and confidence and sometimes solved remotely and, if this is not possible, allow for a better-prepared field visit. Full-time RUDICS has also been used to deliver data from test stations in Antarctica.

Joint Inter-Association Symposium

JV03a - JV3 Geophysical Imaging and Monitoring of Volcanoes (IAVCEI, IASPEI, IAGA)

IUGG-2140

Magnetic Fingerprint of Hydrothermal System at Vulcano Island (Italy)

R. Napoli[1], *G. Currenti*[1], *C. Del Negro*[1]
[1]*Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo-Sezione di Catania, Catania, Italy*

To image the hydrothermal system of Vulcano Island and to correlate it with local faults and other structural lineaments, more than 18,000 magnetic data were retrieved from three high resolution ground magnetic surveys carried out at the volcanic island in 1989, 1994 and 2001. Shipborne data were also gathered offshore, along the coast line to constrain the magnetic field extent. Overall an area of about 42 km^2 was surveyed by an ELSEC 770 and a Geometrics G-856 magnetometers with 1 and 0.1 nT resolution, respectively. The total-intensity anomaly field, obtained after data reduction process, reveals intense maxima located in the South-East flank of La Fossa Cone and in the South–West area of the island. Magnetic lows are observed between La Fossa Cone and Vulcanello. A Quadratic Programming algorithm was applied to invert the magnetic anomalies and obtain a 3-D subsurface magnetization model. It reveals the presence of large reduced magnetized volumes located in the North and Central part of the island, between Vulcanello and La Fossa Cone, along the rims and in the western part of Fossa Caldera. These low magnetic volumes are larger than the current hydrothermal system, which is limited to the Fossa Caldera area. Anyway, it is likely to suppose that lack of magnetic properties in these large areas is the evidence for hydrothermal alteration processes and/or thermal demagnetization effect occurred when hydrothermal circulations were not restricted to the central part of the volcano edifice but involved also peripheral areas.

Joint Inter-Association Symposium

JV03a - JV3 Geophysical Imaging and Monitoring of Volcanoes (IAVCEI, IASPEI, IAGA)

IUGG-2955

DInSAR deformation analysis of flank collapsing volcanoes: examples from Etna, Piton de La Fournaise and Fogo

G. Solaro[1], *F. Casu*[1], *C. De Luca*[1], *A. Pepe*[1], *S. Pepe*[1]
[1]*IREA, CNR, Naples, Italy*

Volcanoes may deform as a consequence of several processes. Among these, there are flank instability and collapse; these may be induced, in addition to magma emplacement, by fault activity and the pressurization of a hydrothermal system. Modern geodetic techniques, as spaceborne interferometric synthetic aperture radar (DInSAR), allow the detection of centimeter-to millimeter-scale deformation of a volcanic edifice and are invaluable tools for monitoring and understanding the relations between deformation and magmatic activity.

Here we analyze the deformation of three volcanoes characterized by flank collapse through DInSAR technique: Etna, Piton de La Fournaise and Fogo.

Etna was erupting every ∼1.5 years over the last century. We show DInSAR results achieved in the last ∼20 years by exploiting ERS, ENVISAT, ALOS and COSMO-SkyMed satellite data, focusing on the deformation of the eastern and western flanks of the volcano before, during, and after the major 2001 and 2002–2003 eruptions and on seismic swarm occurred in 2010 on Pernicana fault.

Piton de la Fournaise present an eastern flank depression which is the scar of one of the most recent landslides. Recently, it has been extremely active, erupting 34 times between 1998 and 2011. We show deformation pattern by exploiting DInSAR Envisat and ALOS satellites from 2002 to 2010, focusing on 2007 eruption.

Fogo volcano is the active expression of the Cape Verde mantle hot spot. A new eruption started in the morning of November 23th 2014 inside the summit caldera. It took place from a fissure with two closely spaced vents on the southwest side of the Pico de Fogo. We show the potential and capability of Sentinel-1 satellite to image the deformation pattern related to this eruption and model the deformation source.

Joint Inter-Association Symposium

JV03a - JV3 Geophysical Imaging and Monitoring of Volcanoes (IAVCEI, IASPEI, IAGA)

IUGG-3028

Filling/emptyng of a shallow magma storage feeding the 26 october 2013 Etna paroxysm: Constraints from gravity and gps data

F. Greco[1], *G. Currenti*[2], *M. Palano*[2]
[1]*Istituto Nazionale di Geofisica e Vulcanologia, Catania, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania, Catania, Italy*

We present and analyze microgravity and GPS data collected on the summit sector of Etna volcano from September 2012 to October 2013, when several episodes of lava fountaining (paroxysm) occurred. We focus on the results of the measurements performed just three days before and three days after the 26 October 2013 paroxysmal event, when the New Southeast Crater produced a new paroxysm, almost six months after the previous paroxysm. Until July 2013, the mean gravity values remained mostly within 10 μGal with respect to the survey in September 2012. Instead, the gravity residuals for the July–22 October 2013 period was characterized by a positive gravity variation of about 40 μGal, with a wavelength of about 4 km centered in the summit zone. Ground deformation from July to 22 October 2013 was characterized by a general radial pattern of the horizontal displacements at the summit stations. Although the vertical variations are within their uncertainties, the overall pattern is consistent with an inflation process. The gravity variations between 22-29 October 2013, encompassing the paroxysmal event, exhibited a decrease up to 40 μGal, which compensates the previous gravity increase. During the same time interval ground deformation reversed, clearly indicating a slight deflation of the summit area. For the first time, this combined approach provides insight into the amount of gas-rich magma filling and empting a shallow magma storage before and after a paroxysmal event. The modeling of both gravity variations and ground deformation infers a source located at about 1 km a.s.l. These results reveal that this shallow magma storage experienced a complete filling/empting cycle with a roughly constant budget between stored and erupted magma during the paroxysmal event.

Joint Inter-Association Symposium

JV03a - JV3 Geophysical Imaging and Monitoring of Volcanoes (IAVCEI, IASPEI, IAGA)

IUGG-3407

Long-term volcano-magnetic effects associated with phreatic eruptions

T. Hashimoto[1]*, W. Kanda*[2]*, M. Utsugi*[3]*, M. Ichiki*[4]
[1]*Institute of Seismology and Volcanology, Faculty of Science- Hokkaido University, Sapporo, Japan*
[2]*Volcanic Fluid Research Center, Tokyo Institute of Technology, Gunma, Japan*
[3]*Institute for Geothermal Sciences, Graduate School of Science- Kyoto University, Kumamoto, Japan*
[4]*Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science- Tohoku University, Miyagi, Japan*

This study showcases the volcano-magnetic effects that have been observed at several Japanese volcanoes in recent years, with special attention to eruptions of phreatic manner, or those devoid of significant magmatic commitment. Looking at long-term (several years to decades) magnetic total field records at these volcanoes during inter-eruptive periods, localized dipolar changes around active craterlets with huge amplitudes are commonly recognized, indicating the sources are close to the ground surface. Interestingly, such magnetic changes progress in one-way. It suggests that the volcano-magnetic effects at such volcanoes take place not only at the time of eruptive events but also during inter-eruptive periods. Most of the exemplars here are characterized by demagnetization buildup during expanding unrest, while the case at Kuju, after the eruption in 1995, showed re-magnetization for almost two decades, being followed by a reversal into demagnetization finally in 2014. Integrating such specific examples together, it is likely that there is a long-term cycle composed of thermally-driven demagnetization during pre-eruptive periods and a re-magnetizing phase following an eruptive event. Another important feature at some of these instances is the intermittency in terms of their rate of change in coincidence with episodic acceleration in ground deformation. It implicates episodically triggered, or otherwise intrinsically repetitive, activation of a shallow hydrothermal system with subsequent demagnetization and pressurization. Further field observations combined with other records such as electrical resistivity, gas component, thermal discharge rate are necessary to better understand the detailed mechanism of such system and to forecast the timing of phreatic eruptions.

Joint Inter-Association Symposium

JV03a - JV3 Geophysical Imaging and Monitoring of Volcanoes (IAVCEI, IASPEI, IAGA)

IUGG-4265

Eruptive activity at Etna inferred through borehole strainmeters

A. Bonaccorso[1], G. Currenti[1], A. Linde[2], S. Sacks[2], A. Sicali[1]
[1]Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania, Catania, Italy
[2]Carnegie Institution, Department Terrestrial Magnetism, Washington, USA

In November 2011, the first two borehole strainmeters, dilatometers type with nominal precision of ~ 10^{-10} – 10^{-11}, were installed at Etna at ~180 m depth below the ground surface with distances from the summit craters of 6 (DEGI) and 10 km (DRUV), respectively. Significant variations in the strainmeter signals have been detected in temporal correspondence with the volcano activity. Since January 2011, the eruptive activity resumed at Etna producing a sequence of 44 lava fountain episodes through December 2013. Almost all the lava fountains had similar characteristics, lasting a few hours and feeding a lava flow that expands in the Valle del Bove depression with maximum lengths of 4–6 km.

During the events the high precision dilatometers detected negative strain changes with amplitudes of ~0.2 and ~1 μstrain at DRUV and DEGI, respectively, indicating medium expansion. Taking into account the volcano topography and the medium heterogeneity, a Finite Element Model was set up to accurately infer the source feeding the lava fountains from tilt and volumetric strain signals. The numerical computations indicated an elongated depressurizing source located at 0 km b.s.l., which underwent a volume change of ~2×10^6 m^3 accompanied by a compression of ~0.5×10^6 m^3 of the resident magma. This allowed to estimate an average erupted volume of ~2.5×10^6 m^3 for each event, which is in agreement with the mean total emitted volume calculated from field measurements and satellite data. The occurrence rate of the episodes and the fairly constant erupted volumes suggest that this shallow magma storage cannot accumulate large magma volumes and favors frequent short-term periodic eruptive events ensuing a balance between the refilling and the erupted magma.

Joint Inter-Association Symposium

JV03b - JV3 Geophysical Imaging and Monitoring of Volcanoes (IAVCEI, IASPEI, IAGA)

IUGG-0479

Piezomagnetic field produced by a spheroidal pressure source

Y. Sasai[1]
[1]*Tokai University, Institute of Ocean Research and Development, Shizuoka, Japan*

The piezomagnetic field produced by a spheroidal pressure source is presented. We follow Davis (1986), who combined Eshelby's (1957) elastic inclusion theory and Mindlin's (1936) half-space point force solution. The displacement field satisfies the boundary conditions rigorously at the ground surface, but approximately on the source body surface when it lies at a shallow depth. In case that the source body is located at a depth below the Curie point isotherm H (case III), the fundamental piezomagnetic potential or the Green's function for a point single force (Sasai, 1986) is applicable to the problem, which leads to an analytical solution. For a shallow source, in which the Curie point isotherm lies below the source (case I) or it intersects the spheroidal body (case II), the Green's function method is not applicable. We apply the representation theorem or the surface integral formula for the piezomagnetic potential (Sasai, 1991) to three surfaces enveloping the source body, i.e. (a) the ground surface, (b) the Curie point isotherm and (c) the spheroidal surface. For the sake of mathematical simplicity, we assume that the major spheroid axis is vertical or horizontal, not inclined. The contributions from (b) and (c) can be evaluated with the aid of high-precision numerical integral method.

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Joint Inter-Association Symposium

JV03b - JV3 Geophysical Imaging and Monitoring of Volcanoes (IAVCEI, IASPEI, IAGA)

IUGG-1360

The 2010 seismovolcanic crisis at Taal Volcano (Philippines)

J. Zlotnicki[1]*, Y. Sasai*[2]*, M.J.S. Johnston*[3]
[1]*CNRS, Observatoire de Physique du Globe-UMR6524, Aubières, France*
[2]*Earthquake Prediction Research Centre- Tokai University,*
Earthquake Prediction Research Centre, Shizuoka, Japan
[3]*US Geological Survey, US Geological Survey, Menlo Park, USA*

Taal volcano (Philippines) has continuously exhibited sporadic seismic crises, deformation and surface activity. Seismicity appeared again on Apr. 19, 2010 and sharply increased after Apr. 29. The crisis ended in March 2011. Since 2004, EMSEV Working Group (http://www.emsev-iugg.org/emsev/) and PHIVOLCS (http://www.emsev-iugg.org/emsev/) implemented multi-parametric monitoring stations for tracking the activity. The study collected observations of EM fields, thermal flux, seismicity, and ground deformation between 2007 and March 2011. The main signals were concomitant with the evolution of the crisis. Three periods of seismic activity, characterized by episodes of increasing then decreasing activity, occurred on Apr. 19 to Aug. 8, Aug. 8 to Nov. 18, and Nov. 18 to March 2011. The only available tiltmeter recorded three similar phases of deformation. Phase 1 can be divided in three parts - tilt down to the East from Apr. 19 to June 11 (Phase 1a), tilt down to the North from June 11 to July 13 (Phase 1b) followed by long-term deflation indicated by tilting back to the SW (Phase 1c). Phases 1a and 1b are consistent with an inflationary dike under the north rim of the main crater at about 5 km depth followed by activation of a secondary source at 1.5 to 2 km depth to the SE under MC. The total magnetic field showed a sub-nT decrease during phase 1, while it decreased by a few nT during phases 2 and 3. The latter can be explained as due to inflation and deflation of the shallow hydrothermal reservoir. Phases 1c, 2, and 3 reflect deflation of these deep sources. Phases 1c, 2 and 3 are clearly correlated with the largest amplitude electric signals recorded during the crisis, consistent with shallow activity inside the hydrothermal system after July 13, 2010.

Joint Inter-Association Symposium

JV03b - JV3 Geophysical Imaging and Monitoring of Volcanoes (IAVCEI, IASPEI, IAGA)

IUGG-1368

Autopsy of the signatures of the electric field related to July 8, 2000 Miyakejima eruption (Japan)

J. Zlotnicki[1]*, M. Uyeshima*[2]*, Y. Sasai*[3]
[1]*CNRS, Observatoire de Physique du Globe, Aubières cedex, France*
[2]*Earthquake research Institiute- The University of Tokyo,*
Earthquake research Institiute, Tokyo, Japan
[3]*Earthquake Prediction Research Centre- Tokai University,*
Earthquake Prediction Research Centre, Shizuoka, Japan

Miyake-jima volcano (Japan) erupted on July 8, 2000. After 1995, It was monitored by several electromagnetic methods. Smooth seismicity started on June 26 at 1830 LT. A dyke of SW direction grew up and ground deformation started at 21LT with the occurrence of large earthquakes. Then, dykes propagated outside to the West of the Island producing in the morning of June 27 a small submarine eruption. From June 27 to July 4, dykes and large earthquakes moved northwestwards. Volcanic seismicity recovered on July 4 and the eruption started on July 8 at 1820 LT. Then, several major phreatic explosions and expels of plumes occurred during the next months.

We will trace back the main electric signatures and their changes after 1999. In particular, we will focus on time series of the telluric field.

Stations located on SW (MYS) and NE (MYN) eruptive axes were recording the telluric field and the summit station (OYL) both the horizontal telluric and magnetic fields components. Data were recorded at 60 sec interval.

Oscillations in the electric field, up to 20 mV/km, appeared during the preceding days. At MYS, they were increasing till about 0230LT on June 27 when sharp spikes of 175 mV/km in amplitude began. This sequence lasted 2h30 and new oscillations reappeared. Oscillations were also observed at MYN after spikes at MYS have disappeared. In addition to the remarkable signals recorded at MYS and MYN on July 4 and related to the refocusing of activity on the volcano, both stations exhibited huge variations of several hours duration after July 7 (~1330LT). Signals reached more than 300 mV/km in amplitude. These signals attenuated on July 8 before the summit collapse. Results show that electric signals may appear before ground deformation, and seismicity in this case.

Joint Inter-Association Symposium

JV03b - JV3 Geophysical Imaging and Monitoring of Volcanoes (IAVCEI, IASPEI, IAGA)

IUGG-2245

Magnetic evidence of magmatic intrusions during the March 1998 La Fournaise and the 2002-2003 Etna eruptions

R. Napoli[1], *J. Zlotnicki*[2], *G. Currenti*[1], *A. Sicali*[1]
[1]*Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo-Sezione di Catania, Catania, Italy*
[2]*CNRS, Observatoire de Physique du Globe- Clermont-Fd-, Clermont-Fd-, France*

Monitoring the magnetic field at volcanoes can give valuable information on the dynamics of eruptions. The modifications of magnetic properties of rocks, induced by hydrothermal activity and magma dynamics, generate a wide variety of signals, as piezomagnetic, thermomagnetic and electrokinetic effects. The characterization and modeling of these signals is a key issue for understanding and discriminating the source mechanisms. Etna (Sicily) and La Fournaise (Réunion) are active volcanoes on which electromagnetic studies have been performed and have offered good cases study to advance the comprehension of the volcanomagnetic effects origin. Total magnetic field variations in the order of a few nanoTeslas have been mostly related to the migration of magma towards the surface both at Etna and at La Fournaise. We focus the analysis on the March 9, 1998 La Fournaise and 2002-2003 Etna eruptions. In both cases, we apply the WebGIS application GEOFIM (GEOphysical Inverse/Forward Modeling), which models both magnetic and tilt data to provide a coherent interpretation and description of the magmatic intrusions. GEOFIM quickly provides a first-order estimation of source characteristics leading to better constrain their location, depth, volume, and mass. The specific magnetic and deformation signatures of these intrusive events are highlighted in accordance to the similarity of the eruptive activities. The results contribute to image the spatial-temporal evolution of magma propagation even in situations of very fast emplacement and, hence, could be exploited for early warning purposes.

Joint Inter-Association Symposium

JV03b - JV3 Geophysical Imaging and Monitoring of Volcanoes (IAVCEI, IASPEI, IAGA)

IUGG-4106

Shallow structure of Solfatara Volcano revealed by joining 2D seismic reflection and electric profiles with CO2 and soil temperature measurements

P.P. Bruno[1], V. Di Fiore[2], G. Festa[3], M. Gresse[4], S. Maraio[5], I. Nazzaro[6], J. Vandemeulebrouck[4]
[1]The Petroleum Institute, Dept. of Petroleum Geosciences, Abu Dhabi, United Arab Emirates
[2]CNR, Ist. Ambiente Marino e Costiero, Napoli, Italy
[3]Università di Napopli "Federico II", Dip. di Fisica, Napoli, Italy
[4]Université Savoie, Institut des Sciences de la Terre, Grenoble, France
[5]Università Alma Mater Studiorum, Dip. Scienze Biologiche Geologiche e Ambientali, Bologna, Italy
[6]INGV, Sede Irpinia, Grottaminarda AV, Italy

The MedSuV - RICEN project includes a series of geophysical and geochemical experiments carried out within Solfatara Volcano, with the aim of studying changes in the properties of the medium at small scales through repeated high-resolution multi-parameter observations over time. The investigated area, (Solfatara), is the most active volcano of Campi Flegrei Caldera, Italy, and it is presently characterized by an intense hydrothermal shallow activity, which results in fumarolic emission and a gas release of approximately 1,500 tons per day.

We present here the preliminary results from two very-high resolution seismic reflection and electric resistivity profiles that were acquired in the crater along coincident positions in May and November 2014, along with CO2 flux and surface temperature measurements. The reflection profiles provide the first high-resolution seismic images of Solfatara crater, depicting a slightly asymmetrical structure, whose bottom is found at about 400 ms TWT. Seismic data also show distinctive anomalous amplitudes in at least two narrow areas, which may be indicative of gas escaping along pre-exisiting sub-vertical fault and fractures. The assumed degassing pathways intersect a strong horizontal reflector at about 100 ms TWT and reach the surface of the crater. Moreover, both electric and seismic data suggest the presence of low- resistivity dome shaped structure, buried in the centre of the volcano at a minimum depth of 50 m and matching with a high C02 and high soil temperature at surface.

Our results will provide a solid framework to constrain the near-surface geological interpretation of such a complex area and to better understand and relate temporal changes of the other measured parameters to the shallow geological structure of the crater.

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IUGG-4940

On temporal variation of SP spatial distribution on Miyakejima Island before and after the 2000 summit eruption

M. Uyeshima[1]*, J. Zlotnicki*[2]*, H. Hase*[3]*, K. Aizawa*[4]*, Y. Yamaya*[5]*, T. Koyama*[1]*, Y. Sasai*[6]
[1]*the University of Tokyo, ERI, Tokyo, Japan*
[2]*OPGC, CNRS-UMR6524, Clermont-Fd, France*
[3]*GERD, GERD, Tokyo, Japan*
[4]*Kyushu University, Graduate School of Science, Shimabara, Japan*
[5]*AIST, Institute of Geology and Geoinformation, Tsukuba, Japan*
[6]*Tokai University, EPRC, Shimizu, Japan*

We performed repeated SP surveys on Miyakejima volcanic island in the Izu-Bonin arc, before and after the 2000 summit eruption. Before the eruption, stable W-shape anomaly was detected in 1991, 1995, 1996 (Sasai et al., 1997) and the stability was also confirmed by long baseline electrical potential difference monitoring from 1997 to 2000 (Sasai et al., 2002).
After the eruption, we performed repeated SP surveys in the island, on the southern survey line (from the southern coast to the summit) in 2001, and not only on the south line but also on the northern line (from the northern coast to the summit) in 2005 and 2011, and on the central ring road which connects the south and north lines in 2012.
The long baseline observation detected enhancement of the electrical potential by about 150mV at SSW flank of the summit, coincident with the intense summit eruption on 18, Aug., 2000. This enhancement was confirmed by the subsequent SP survey in 2001: at altitudes from 300 to 600m, where minimal potential of -600 to -500 mV compared with the potential near the coast had been detected in the 1990-s surveys, the electrical potential was enhanced in comparison with that by the 1990-s surveys. We interpreted that this enhancement was related to intense volcanic gas emission from the southern edge of the central caldera, which was generated on 8 Jul., 2000.
However, the temporal variation of the spatial distribution of SP of the same trend was still detected in 2005 compared with the results in 2001, and still in 2011 compared with the results in 2005, although surface activities of the volcano is now getting the calmer. The potential enhancement probably indicates large-scale temporal variation of hydrothermal activity or that of subsurface electrical conductivity structure.

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IUGG-1094

Analyzing temporal changes by electromagnetic transfer functions at active volcanoes

B. Ladanivskyy[1], *J. Zlotnicki*[2], *V. Korepanov*[3]
[1]*Carpathian Branch of Institute of Geophysics- National Academy of Science of Ukraine, LVIV, Lviv, Ukraine*
[2]*CNRS, Observatoire de PHysique du Globe-UMR6524, Aubière cedex, France*
[3]*Centre of Institute for Space Research- National Academy of Science of Ukraine-National Space Agency of Ukraine, Centre of Institute for Space Research, LVIV, Ukraine*

Electromagnetic (EM) methods are useful for scanning changes in electrical properties of lithologies, hydrothermal systems, and geological discontinuities of volcanoes. We focus the presentation on magnetotelluric (MT) method applied to the monitoring of Taal volcano in the Philippines. This one abruptly erupts and gives rise to phreatic to magmatic eruptions accompanied by based surges. We consider two stations (DAK and MCL) located respectively on the northern flank and inside the crater. These stations sample data at 2 sec and 20 Hz. The period we consider corresponds to the long seismovolcanic crisis starting on April 13, 2010.

Time series of components were divided into 2 days sequences. The day under consideration was bracketed by the preceding half day and the consecutive one. Then a running time window was applied in order to smooth the transfer functions. Two approaches to MT data processing were applied. The first one was to consider a 'single station algorithm' and the other one was based on the use of a remote reference station. KAK Japanese geomagnetic observatory was used during application of the second protocol.

The day-to-day analysis shows a clear decrease of the apparent resistivity in relation with the seismovolcanic crisis, for periods of about 50 sec. Based on the records at the remote station, we can assume that the source of the changes takes place inside the volcano and the changes related to the 2010-11 seismovolcanic crisis.

For both stations on the volcano, MT transfer functions were computed on long time series, and inversion of MT curves was applied for estimating 1D conductivity

cross sections. Furthermore, we analyzed spectra of field components and of the residuals in the statistical estimation of transfer functions.

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IUGG-2422

3-D magnetotelluric studies of the actively deforming Aluto volcano, Ethiopia

F. Samrock[1], *A. Kuvshinov*[1], *J. Bakker*[1], *A. Jackson*[1], *S. Fisseha*[2]
[1]*ETH Zurich, Institute of Geophysics, Zurich, Switzerland*
[2]*Addis Ababa University, Institute of Geophysics- Space Science & Astronomy, Addis Ababa, Ethiopia*

We present results of a MT field survey that we carried out at Aluto volcano, Ethiopia. The area is situated along a central rift axis active faulting zone in the Main Ethiopian Rift Valley, and it is known to show remarkable unrest with reoccurring periods of uplift and setting. The deforming area spans around 10km x 10km. Aluto also hosts the only geothermal field in Ethiopia, which is currently exploited for energy production. We measured broad band MT data (0.001 to 1000 s) at 46 sites covering the extend of the volcanic complex (averaged site spacing 1 km) with the aims to get an image of the geothermal system and to identify the source of unrest.
We performed comprehensive 3-D inversions of the observed MT data using the ModEM code. The robustness of the models was tested by using different starting models, grids and inversion parameters. The recovered conductivity model corresponds well with the conceptual reservoir model for a high enthalpy geothermal system where an electrically high conductive cap layer overlies a more resistive body: Comparisons with well data indicate that the shallow conductor is related with a highly altered clay cap situated on top of the more resistive high temperature (> 300°C) upflow zone. The recovered 3-D conductivity model provides no significant evidence for an active deep magmatic system under Aluto, which is why we conclude that the source of unrest is most likely situated in the shallow hydrothermal system. 3-D forward modelling studies, which we performed with the aim to explain the tippers, suggest that the occurrence of melt is predominantly at lower crustal depths along an off-axis volcanic chain 40km west of Aluto and the central rift axis.

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IUGG-2614

Hydrothermal system beneath the Jigokudani valley, Tateyama volcano, Japan, inferred from AMT surveys and hot spring water chemistry

K. Seki[1], W. Kanda[2], T. Tanbo[3], Y. Ogawa[2], S. Takakura[4], M. Ushioda[2], A. Suzuki[1], Z. Saito[1], Y. Matsunaga[1]
[1]Tokyo Institute of Technology, Earth and Planetary Sciences, Tokyo, Japan
[2]Tokyo Institute of Technology, Volcanic Fluid Research Center, Tokyo, Japan
[3]Tateyama Caldera and Sabo Museum, Curatorial Division, Toyama, Japan
[4]National Institute of Advanced Industrial Science and Technology, Institute of Geo-Resources and Environment- National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

We carried out AMT surveys and the analyses of hot spring water in the Jigokudani valley (JV), Tateyama volcano, Japan. The JV was formed by repeated phreatic eruptions some 40,000 years ago, and has laminated lacustrine sediments that are located at the base of an extinct crater lake. Currently, the JV is an active solfatara field dotted with hot springs and fumaroles, and has experienced several anomalous events indicating the increase in volcanic activity. The objective of this study is to clarify the characteristic of electrical resistivity structure where multiple phreatic eruption events occurred, and to investigate the spatial relationship between subsurface structure and recent volcanic activity. We collected the AMT data at 25 locations in and around the JV, and estimated a 3D resistivity structure using the inversion code of Siripunvaraporn and Egbert (2009). Electrical conductivity, temperature and pH were measured in 50 hot springs, and chemical analyses were performed on representative 12 samples of those springs. Hot springs in the JV showed features of strong acid Cl-SO_4-type, and turned out to be derived from magmatic hydrothermal fluids because of the high ratio of Cl/SO_4 concentration. A highly conductive region with thickness of approximately 50m was detected beneath the most active geothermal field, and was interpreted as representing clayey sediments. A slightly resistive portion was present beneath this layer and hot spring water of this area showed high ionic concentrations, which suggests that there are high temperature gases of magmatic origin. A deep feature of 3D resistivity structure suggests that such magmatic gases are provided from east of the JV, which is consistent with the location of seismically inferred magma reservoir.

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IUGG-4731

Correlation between magma chamber deflation and eruption cloud height during the 2011 Kirishima-Shinmoe-dake eruptions

T. Kozono[1], H. Ueda[2], T. Shimbori[3], K. Fukui[3]
[1]Tohoku University, Department of Geophysics, Sendai, Japan
[2]National Research Institute for Earth Science and Disaster Prevention, Earthquake and Volcano Research Unit, Tsukuba, Japan
[3]Meteorological Research Institute, Volcanology Research Department, Tsukuba, Japan

Multiple observations of subsurface and surface phenomena during volcanic eruptions provide important information about eruption styles, eruption column dynamics, and magma plumbing systems. During the 2011 eruptions of Kirishima-Shinmoe-dake volcano in Japan, borehole-type tiltmeter data and weather radar data captured the subsurface and surface phenomena, respectively; the tiltmeters detected deflation of a magma chamber caused by migration of magma to the surface, and the weather radar detected changes in the height of the eruption cloud echo. In this study, we present a method based on the correlation between magma chamber deflation and cloud echo height to identify eruption styles. The method can detect whether a column-forming eruption is accompanied by magma migration from the magma chamber (e.g., sub-Plinian eruption), or not (e.g., Vulcanian explosion). By using well-correlated chamber deflation and echo height data, we found that even with a low discharge rate and strong wind during the Shinmoe-dake eruptions, the eruption column dynamics are well described by a one-quarter power scaling relationship between cloud height and magma discharge rate. In addition, we found a very clear correlation between the geodetic volume change of the magma chamber and erupted volume at the surface, which indicates that a stable magma plumbing system connecting the magma chamber and the surface did not change substantially during the eruptions. Our results show that a simultaneous monitoring of the magma chamber and eruption cloud based on tiltmeter and weather radar data is valuable for capturing the eruption dynamics in real time.

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IUGG-4817

3 Dimensional Magnetization Sructure of Aogashima Volcano using Vector Magnetic Aanomalies

N. ISEZAKI[1], *J. MATSUO*[2], *K. SAYANAGI*[1], *H. BABA*[1]
[1]*Tokai University, Institute of Oceanic Research and Development, Shimizu, Japan*
[2]*OYO International Corporation, Technical Section, Tokyo, Japan*

Measurement of magnetic anomaly vectors is absolutely essential to obtain magnetization structures of the magnetized body. Since 2008 we have developed a new magnetometer for measurement of vector magnetic field, called High Precision Magnetic survey System (HPMS), which can be used in various situations, for instance, in the deep-sea, on the sea surface, and in the air. In November 2014 we applied the HPMS as Deep-tow Three Component Magnetometer (DTCM) and Shipboard Three Component Magnetometer (STCM) for a marine magnetic survey around the volcanic island, Aogashima using Tokai University Vessel 'Bousei-Maru' . The Aogashima Island is an active volcanic island included in the Izu-Ogasawara volcanic arc. We have conducted heliborne magnetic surveys over the island in 2006 and 2009. The purpose of this marine magnetic survey was to add the vector anomalies to the heilborne data to clarify a fine 3D magnetization structure. In DTCM survey, a towing frame mounted with the HPMS ,an acoustic positioning (SSBL) and acoustic communication system was towed near the sea bottom using a wire rope. In STCM survey, the towing frame was fixed on the after-deck of the ship. Observed three components of geomagnetic fields **F**=(Hh,Hs,Hv) and gyro data (yaw,pitch,roll) are sampled in 10Hz. SSBL positions are fixed every 10 seconds. **F**, the vector in ship's coordinate (heading, starboard, vertical) is rotated to tne vector in Earth's coordinate (X,Y,Z:north,east,vertical down) using (yaw,pitch,roll). From (X,Y,Z), the IGRF fields are subtracted to get (dX,dY,dZ), three component magnetic anomalies from which 3D spaced 3 component magnetization of the Aogashima volcano is analyzed by solving the linear least square equation.

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IUGG-5560

Monitoring of volcanoes and geothermal processes using magnetotelluric time-lapse processing of electric and magnetic time series

P. Sailhac[1], *H. Larnier*[1]
[1]*Institut de Physique du Globe de Strasbourg- Université de Strasbourg/EOST- CN RS UMR 7516, Géophysique Expérimentale, Strasbourg, France*

Several geophysical and geochemical approaches can be used in the monitoring of volcanic activity. Magnetic and electric time series have been used to enhance fluid flows related to geothermal processes, especially because of electrokinetics phenomena (eg. works by Zlotnicki, Revil, Labazuy, Johnson, Jouniaux, or Ishido, among other). EM time series can also be considered in electrical conductivity imaging: by using the magnetotelluric method (MT) to give the so called MT impedance tensor related to the electrical conductivity of the subsurface. MT surveys have been used over many volcanoes and geothermal fields worldwide (eg. works by Wannamaker, Ogawa, or Caldwell among others). It is just about 15 years ago that MT started to be considered as a monitoring tool to enhance significative changes in the deep electric structures of the subsurface (eg. Wawrzyniak, Peacock, Ogawa, ..). Actually, the non stationarity of the geomagnetic activity is a tricky problem even when robust processing methods and uncertainty estimates are used (see Wawrzyniak et al. 2013 and discussion after Chave's comment). We have used an alternative method for MT data: we developped a processing based on the wavelet transform to get better resolution in time-frequency domain (see presentation by Larnier et al.). We have analysed long period electric and magnetic time series recorded on Piton de la Fournaise volcano prior, during, and after the 1998 volcanic eruption (Zlotnicki et al. and Wawrzyniak et al.): if using a daily time resolution, some variations appear that have not to be interpreted in terms of volcanic activity; choosing a time resolution of several days is necessary to improve estimates, and demonstrate the change in the electric structure when the lava comes up during the eruption.

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JV03p-040

Unrest before the 2012-13 Tolbachik fissure eruption in Kamchatka from local seismicity and GPS data

Y. Kugaenko[1]*, N. Titkov*[1]*, V. Saltykov*[1]
[1]*Geophysical Survey of RAS, Kamchatka Branch, Petropavlovsk-Kamchatsky, Russia*

We have analyzed the seismicity and surface deformation during several months before the 2012-13 Tolbachik fissure eruption, which began on 27 November 2012 on the southern slope of Plosky Tolbachik volcano in the Klyuchevskoy volcano group (Kamchatka). The acceleration of seismicity and earthquake migration to the surface correlate well with changes in the observed deformation patterns. The identified anomalies in seismic and GPS data before the eruption have similar durations of 4-5 months (July-November 2012) that support a genetic relationship, connected to magma rising from depth. These synchronous anomalies were interpreted as eruption unrest. The seismic anomaly comprises accelerated low energy level seismicity (mainly M=1.2-2.3) under Plosky Tolbachik volcano at a depth of less than 5 km. In the 2-3 weeks immediately preceding the eruption the rate of seismicity and the amount of radiated seismic energy exceeded the long-term average values (2000-2011) by more than 40 times. The deformation anomaly was recorded by displacement of the GPS points at distances from 20 to 60 km to the north of Tolbachik. The principal axis of the compressive strain was approximately directed towards the Tolbachik eruption site. The permanent GPS network detected radial compression and tangential stretching. The compressive strain reached about 10^-7 prior to eruption onset. Data recorded during this unrest episode of the Tolbachik volcanic zone will contribute to understanding of the reawakening of volcanic activity in this region and others worldwide with similar characteristics. This study was supported by RFBR grant 13-05-00117.

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JV03p-041

A large magmatic intrusion in the submarine edifice of Gran Canaria (Canary Islands) revealed by 3D modelling of aeromagnetic data

I. Blanco-Montenegro[1], *F. G. Montesinos*[2], *J. Arnoso*[3]
[1]*Escuela Politécnica Superior - Universidad de Burgos, Departamento de Física, Burgos, Spain*
[2]*Universidad Complutense de Madrid, Astronomía y Geodesia, Madrid, Spain*
[3]*Consejo Superior de Investigaciones Científicas, Instituto de Geociencias CSIC-UCM, Madrid, Spain*

Potential field anomalies can contribute to the knowledge of the early formation of ocean island volcanoes because they are capable of imaging their inner structure. In the volcanic island of Gran Canaria (Canary Islands), aeromagnetic data acquired by the Spanish IGN revealed an intense inverse magnetic dipole covering an area of about 80 x 40 km^2 to the NW, mainly offshore the island. We present the first 3D modelling of this structure, carried out with an inversion method based on a genetic algorithm. The method assumes that no information about the source is needed, but the intensity and direction of the magnetization must be known. Analysing the magnetic dipole, we obtained for it a declination D = 20° and an inclination I = –60°, whereas the ambient magnetic field is defined by D = −8° and I = 38° (IGRF). For the magnetic anomaly inversion, we built a source mesh made up of 10793 rectangular prisms with dimensions 2000 x 2000 x 1000 m^3 in the N-S, E-W and vertical directions, respectively, with depths ranging from the topographic/bathymetric surface to 16500 m bsl. We carried out the inversion for different magnetization intensities ranging from 1 to 6 A/m, and discuss the different possible models.

A large elongated body beneath the NW submarine edifice of the island is revealed, measuring about 60 km x 25 km, trending parallel to the isobaths and ranging in depth from the bathymetric surface until 6 to 10 km bsl, approximately. This body can be interpreted as a large magmatic intrusion emplaced during a period of reverse polarity of the Earth's magnetic field in the submarine stage of growth of Gran Canaria, with a volume nearly representing the 20% of the total volume of the island. We discuss the volcanological and tectonic implications of these results.

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JV03p-042

Three-dimensional resistivity structure around the active crater of Aso volcano

W. Kanda[1], *M. Utsugi*[2], *S. Takakura*[3], *H. Inoue*[2], *Y. Ogawa*[4]
[1]*Tokyo Institute of Technology, Kusatsu-Shirane Volcano Observatory, Gunma, Japan*
[2]*Kyoto University, Aso Volcanological Laboratory, Kumamoto, Japan*
[3]*National Institute of Advanced Industrial Science and Technology AIST, Institute of Geo-Resources and Environment, Tsukuba, Japan*
[4]*Tokyo Institute of Technology, Volcanic Fluid Research Center, Tokyo, Japan*

This paper presents a three-dimensional (3-D) electrical resistivity model around the active crater of Aso volcano using the audio-frequency magnetotelluric (AMT) data obtained during 2004-2005. The AMT data were collected at 43 locations on an approximately 300-m grid in and around the Nakadake crater, the summit of the central cone complex, and were already interpreted by two-dimensional models (Kanda et al., 2008). Over the past 80 years, all of the volcanic events within Aso volcano have originated from the 1st crater of Nakadake. The volcanic activity of Aso has showed a cyclic activity pattern: a crater lake is formed at a quiet period and a Strombolian eruption occurs at an active period. From November 2014, Strombolian eruptions have been observed at the 1st crater, which is considered to be a part of a similar activity cycle. This cyclicity of the volcanic activity implies that a specific structure that acts to accumulate the energy required to trigger eruptions develops at approximately the same location beneath the 1st crater. The objective of this study is to reveal such specific subsurface structure. As a result of 3-D inversion using the code of Siripunvaraporn and Egbert (2009), we have obtained the following features in the 3-D resistivity model. A highly conductive zone is present at depths between 100 and 300 m beneath the 1st crater, but unexpectedly the resistivity of the shallow subsurface around the Nakadake crater is not low in general. The low resistivity zone widely distributed at a depth around sea-level which was found in the previous studies is seen only beneath the northern half of the Nakadke crater including the 1st crater. We will discuss these features in connection with the variation sources inferred from other geophysical studies.

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JV03p-043

Atmospheric and ionospheric signatures of volcano reputations probed by FORMOSAT-3/COSMIC

J.Y. Liu[1], *T.C. Liu*[1], *C.H. Lin*[2], *C.H. Chen*[2]
[1]*National Central University, Institute of Space Science, Jhongli, Taiwan Republic of China*
[2]*National Cheng Kung University, Department of Earth Science, Tainan, Taiwan Republic of China*

Intense volcanic eruptions are often accompanied by hot dense gases and powerful explosive energy, which result in anomalous changes in the atmospheric temperature and disturbances in the ionospheric electron density. In this study, radio occultation (RO) observations of FORMOSAT-3/COSMIC (F3/C) are used to probe the temperature in the troposphere and stratosphere as well as the electron density in the ionosphere during the eruption of 8 volcanoes with VEI (volcano eruption index) of 4 in 2008-2011. Results show that 3 events yield significantly tropospheric warming but stratospheric cooling, 2 events reveal remarkably tropospheric cooling and stratospheric warming, and 1 event shows the mixture of the two. Temporal variations of longitude-altitude and latitude-altitude slices display that temperature anomalies induced by volcano reputations can be significantly affected by the background wind in the atmosphere. Meanwhile, the Hilbert-Huang Transform (HHT) is applied to analyze disturbances in the F3/C RO electron density profiles during the 8 event periods. However, the ionosphere can be easily perturbed by solar disturbances, magnetic storms, etc., and simply 3 out of 8 events revel that during/after the reputations, prominent fluctuations with wave length of about 350 km might appear in the topside of the ionosphere.

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JV03p-044

Multiparametric Volcano Monitoring System (MVMS) in Deception Island (Antarctica): Ground deformation, marine and terrestrial thermal anomalies and sea level variation.

M. Berrocoso[1], L. Peci-Sanchez[1], G. Prates[2], A. Fernandez-Ros[1], A. de Gil[1], J.M. Marrero[3], A. Garcia[4], R. Ortiz[4]
[1]Universidad de Cádiz, Facultad de Ciencias, Cádiz, Spain
[2]Universidade do Algarve, Instituto Superior de Engenharia, Faro, Portugal
[3]Volcanic Hazard and Risk Consultant, Volcanologia, Tenerife, Spain
[4]Instituto de Geociencias IGEO-UCM/CSIC, Volcanologia, Madrid, Spain

On Deception Island (South Shetland Islands – Antarctic Peninsula), every austral summer, volcano dynamics' monitoring is mandatory. During this season two research Stations operate and several tourist vessels enter Deception's flooded inner depression open to the sea. In the past, only seismicity was monitorized. Nowadays volcano monitoring is based on multi-sensor data. For this reason, a Multiparametric Volcano Monitoring System (MVMS) was designed and implemented in Deception Island, based on low cost, low power consumption, high data storage instruments, encompassing Electronic Distance Meters, Global Navigation Satellite Systems, soil temperature thermistors and tide gauges (bottom pressure sensors also with water temperature thermistors), and a reliable wireless communication system. The monitoring system also includes semi-automatic data processing packages developed to assist the volcano monitoring team at the Station where data is received. Ground deformation, marine and terrestrial thermal anomalies and sea level variations have been investigated and analyzed, providing an overview of the recent volcano dynamics detected on Deception Island.

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JV03p-045

Magma on the move, monitoring magma propagation in Iceland with GPS Geodesy

S. Hreinsdóttir[1], *S. Hjaltadottir*[2,3], *B. Ófeigsson*[3], *M. Parks*[2], *H. Fridriksdóttir*[2,3], *F. Sigmundsson*[2], *A. Hooper*[4], *T. Árnadóttir*[2], *V. Drouin*[2], *S. Dumont*[2], *R. Pedersen*[2], *E. Heimisson*[2], *K. Vogfjörd*[3], *K. Spaans*[4], *P. Einarsson*[2]
[1]*GNS Science, Tectonophysics, Lower Hutt, New Zealand*
[2]*University of Iceland, Institute of Earth Sciences, Reykjavík, Iceland*
[3]*Icelandic Meteorological Office, Research, Reykjavík, Iceland*
[4]*University of Leeds, School of Earth and Environment, Leeds, United Kingdom*

Continuous GPS (CGPS) measurements can be a very useful tool to monitor volcanic deformation. Pressure changes in magma chambers can result in measurable inflation or deflation and during unrest lateral and/or upward migration of magma can be mapped by interpreting together geodetic and seismic data. In 2010 and 2014 two significant volcanic eruptions took place in Iceland following a few weeks to months of complex magma propagation from the source to the surface.

In the twenty years preceding the 2010 Eyjafjallajökull eruptions periods of unrest, with sills forming under the volcano in 1994, 1999 and 2009, were documented with seismic and geodetic measurements. In early 2010 combined interpretation of far-field and near-field CGPS stations indicated that a deep magma reservoir under the volcano was feeding shallow intrusions and a dike propagating up toward the east flank of the volcano where a 300 m fissure started erupting on 20 March 2010.

On 16 August 2014 an intense seismic swarm started at the Bárdarbunga volcano, central Iceland. CGPS observations around the volcano showed simultaneous formation of a segmented dike over 45 km distance and a contraction of the magma chamber. Significant extension was observed at sites over 100 km ESE and WNW of the volcano and maximum widening of 1.3 m was observed between sites 25 km apart. On 29 August a minor fissure erupted in Holuhraun, northeast of Bárdarbunga, for a few hours. On 31 August the eruption started again on a 1.5 km long fissure.

During the two events the Iceland CGPS network was augmented with new CGPS stations, including a station on the ice covered Bárdarbunga volcano to document

the slow caldera collapse. The CGPS data were transmitted and analyzed every eight hours to monitor the situation near real time.

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JV03p-046

3D Velocity structure of the Katla volcano - Southern Iceland

Z. Jeddi[1], *A. Tryggvason*[1], *O. Gudmundsson*[1], *. IMO-SIL monitoring group*[2]
[1]*Uppsala University, Earth Science Department, Uppsala, Sweden*
[2]*Icelandic Meteorological Office, Division of Processing and Research, Reykjavik, Iceland*

The Katla volcano is one of the most active subglacial volcanoes in Iceland. As very little is known about its 3D structure, nine temporary seismic stations were installed by Uppsala University between May 2011 and August 2013 on and around the glacier Mýrdalsjökull covering the volcano. At the same time, due to the activity of Katla's neighbour in 2010 – the Eyjafjallajökull volcano – the permanent seismic network of the Icelandic Met Office (IMO) was increased to ten in 2011. Thousands of micro earthquakes have occurred within the region during this period and at least four different clusters have been identified: 1) the caldera region , 2) the western Godaland region, 3) a small cluster at the southern rim of Mýrdalsjökull (started in July 2011) and 4) a small cluster at the Eastern rim of the glacier. In order to define the 3D velocity structure, both P and S-wave travel times have been inverted simultaneously for both hypocenter locations and 3D velocity structure by using Local Earthquake Tomography (LET). The preliminary results show low velocities at shallow depth beneath the caldera region which can be related to geothermal activity, or possibly due to the occurrence of elevated temperatures. Even though we used high quality events with at least 7 phases for the inversion, the tomographic images as of yet lack the resolution to conclusively determine which processes cause the slow velocities. The events are very shallow and not well distributed in the area making tomography difficult. The concerns about the imminent eruption at Katla Volcano is the prime motivation for this study. A differential time tomographic method utilising differential travel time measurements will be applied on the same dataset to possibly improve the robustness of the images.

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JV03p-047

Geochemical, gravity and magnetic signals from the "Salinelle" mud volcanoes south of Mt. Etna (Italy)

R. Napoli[1], *F. Greco*[1], *S. Giammanco*[1], *G. Currenti*[1], *A. Sicali*[1]
[1]*Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo-Sezione di Catania, Catania, Italy*

Geochemical, gravity and magnetic surveys were carried out at the southern foot of Mt. Etna in the Salinelle mud volcanoes, where gas exhalations, mostly CO2 of magmatic origin mixed with hydrocarbon gases from shallow gas pockets, warm hypersaline waters and mud occur. The emitted natural fluids produce anomalies in many physical parameters, so as to permit the detection of their probable pathways through the crust. Soil CO2 effluxes and shallow soil heat fluxes were measured in a grid of 61 sites. The results indicate that higher diffuse emissions of CO2 and heat occur closer to the main water and mud vents, but significant gas/heat emissions occur also from the southernmost part of the surveyed area, some hundreds of meters south-east and south of the main vents. Microgravity measurements were also carried out using a Scintrex CG5 gravimeter, which provided an accuracy of 10 μGal. The residual gravity map reveals a significant negative gravity anomaly mainly in correspondence of the largest gas exhalations area and of the water/mud vents. During the magnetic survey more than 2,300 data were acquired by a GSM19 Overhauser effect magnetometer with 0.01 nT resolution. The total-intensity anomaly field is characterized by small magnetic anomalies with N-S direction surrounding the northern part of the area. Our multi-parametric survey revealed some small anomalous areas in the surroundings of the active mud volcanoes, defining secondary escape pathways for deep fluids that may represent local structural lines partly hidden/covered or partly sealed by deposition of minerals. Our study shows the importance of a multidisciplinary approach to the definition at a small scale of the geometry of channelized fluids rising within shallow hydrothermal systems.

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JV03p-048

Atmospheric-electric effect and thunderstorm activity of Shiveluch Volcano eruption on November, 16th, 2014

N. Cherneva[1], S.E. Smirnov[1], P.P. Firstov[2], R.R. Akbashev[2], B.M. Shevtsov[1], R.N. Sagitova[1], R. Holzworth[3]
[1]Institute of Cosmophysical Research and Radio Wave Propagation, FEB RAS, Paratunka- Kamchatka, Russia
[2]Kamchatka Branch of Geophysical Survey, RAS, Petropavlovsk-Kamchatskiy, Russia
[3]University of Washington, ED, Seattle, USA

Monitoring of the atmospheric electric field allows to detect an undersaturated eruptive cloud and to estimate them parameters. A seismic signal with the duration of about 20 minutes corresponding to an explosive eruption was registered on November 16, 2014. The meteorological observations were carried out near the Shiveluch volcano (48 km) twice per a day. At 12:00, a temperature stratification had two inversions at the heights of 9-10 km and 12 km, where wind velocities were 17 m/s and 11 m/s, correspondingly. In Kozyrevsk, which is 109 km from Shiveluch volcano, the positive anomaly of electric field with two maxima exceeding the background level 90 V/m was observed. If the anomaly is the effect from the eruptive cloud, then it is possible to estimate the velocity of eruptive formation, which is 17 m/s and 11 m/s. It means that ash propagation paths were formed at two heights where temperature inversions were observed (9-10 and 12 km). According to World Wide Lightning Location Network (WWLLN), on November, 16th, 2014, in 10 hour 19 mines on UT (local time 22 hour 19 mines) in the area of Shiveluch volcano, 3 lightning in radius about one kilometer to the south, east and north from the cupola of Shiveluch volcano were fixed. After 7 minutes, in 10 hour 26 mines, 3 lightning in a direction to south-west were. And in 10 hour 36 mines, approximately 4 km to west-south-west, the seventh lightning was observed. Grant FEB RAS and CRDF-14-007 N 16983. This publication is based on work supported by a grant from the U.S. Civilian Research and Development Foundation (RUG1-7084-PA-13) with funding from the United States Department of State.

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JV03p-049

The Unrest phenomenon at Mauna Loa volcano detected via multi-temporal and multi-platform InSAR measurements

S. Pepe[1], L. D'Auria[2], M. Bonano[1], R. Castaldo[1], F. Casu[1], C. De Luca[1], V. De Novellis[1], M. Manunta[1], E. Sansosti[1], G. Solaro[1], P. Tizzani[1]
[1]CNR, IREA, Naples, Italy
[2]INGV, Osservatorio Vesuviano, Naples, Italy

Mauna Loa is a basaltic shield volcano, located in in the Big Island of the Hawaii archipelago (USA), which rises over 4 km above sea and the first well-documented historical eruption occurred in 1843; most recent eruption occurred in 1984. After this eruption, the volcano entered in a phase of quiescence, interrupted by three main episodes of unrest. The latest episode began in April 2014 and continues to date, with a variable rate of inflation behavior. We investigate the ground deformation process affecting the Mauna Loa volcano from 2003 to 2014 by exploiting the advanced Interferometric Synthetic Aperture Radar (InSAR) technique referred to as Small BAseline Subset (SBAS) algorithm. The time series of Line-Of-Sight displacements derived from the multi-temporal and multi-platform SAR data were obtained using ENVISAT dataset, acquired by ascending and descending orbits over the 2003-2010 time period and COSMO-SkyMed images from both orbits in 2012-2014 time span. Moreover, we analyzed also SENTINEL 1A interferograms pairs obtained from both orbits acquired in 2014 – 2015 time interval. The final step consists in the inversion of the retrieved DInSAR results, in order to model both deep geological structures and magmatic sources to better understand the dynamics that drive on the volcano process. To characterize the geometry and the evolution of the volcano deformation source, we apply both forward and inverse modeling techniques. The former technique allowed defining roughly the geometrical parameters of the source, while the latter allowed retrieving its temporal evolution.
The obtained results have direct implication in the interpretation of the last unrest episode, providing a useful tool to aid the forecast of possible future eruptions at Mauna Loa.

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JV03p-050

Short-term gravity signal during major eruptions at Sakurajima volcano since 2012

S. Okubo[1]*, K. Yamamoto*[2]*, M. Iguchi*[2]*, A. Taketa*[1]*, Y. Tanaka*[1]*, Y. Imanishi*[1]
[1]*The University of Tokyo, Earthquake Research Institute, Tokyo, Japan*
[2]*Kyoto University, Disaster Prevention Research Institute, Kagoshima, Japan*

We have discussed long-term (timescale > several months) gravity change at Sakurajima volcano, which has been repeating Vulcanian eruptions frequently(500~1,000/year) since 2009 (Okubo et al., IAVCEI 2013). In fact, excellent correlations were found among the records of absolute gravity, ejected weight of volcanic ash, ground tilt, and infrasound air shock amplitude. The long-term gravity data were interpreted in terms of magma head height to explain the close correlation among the variables.
In this paper, we deal with rather **short-term** gravity signals based on continuous absolute gravity measurements since April 2012. After eliminating hydrological disturbances to the gravity field, we find several major eruptive events were associated with precursory short-term gravity decreases occurring over ~3 hours followed by quick recoveries lasting ~3 hours. The gravity signals occur in synchronization with the volcano's inflation/deflation as revealed by strain and tilt records, which strongly suggests that the gravity signals are due to either building-up of pressure within the volcano or mass transport in the conduit. Since similar precursory gravity changes were reported during the Vulcanian phase of the 2011 eruption of Shinmoe-dake volcano, Kirishima, Japan (Okubo et al., 2013), short-term precursory gravity changes might be universal to major Vulcanian eruptions.

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JV03p-051

Scientific and technological improvements of Etna's gravity network due to the installation of an iGrav™ superconducting gravimeter

F. Greco[1]*, D. Carbone*[2]*, A. Sicali*[2]*, A. Rappa*[2]
[1]*Istituto Nazionale di Geofisica e Vulcanologia, Catania, Italy*
[2]*Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania, Catania, Italy*

Over the last few decades, gravity measurements have been shown to be an effective tool to monitor and study active volcanoes. Precise in-situ gravity measurements have been performed at Mt. Etna volcano (Italy) to assess changes often close to the detection limit of the available instruments (less than ± 10 μGal). The study of these variation has allowed to better understand the underground processes related to volcanic activity. Different instruments, that represent the state of the art in gravimeters technology (a new generation of spring-based instruments plus absolute gravimeters), have been used to perform measurements along Etna's gravity network. We have also designed strategies to optimize the cost/benefit ratio of routine gravity monitoring of Etna, from both scientific and economic points of view. Here we report on the first installation of an iGrav™superconducting gravimeter (produced by GWR) at Etna. To complement Etna's network with this instruments implies an important step forward in the detection capabilities of the method, since the iGrav™ features a sub-microGal precision, is practically drift-free (instrumental drift rate less than 0.5 microGal/month) and totally insensitive to local changes in ambient parameters. iGrav™#016 was installed in September 2014 at the astrophysical observatory of Serra La Nave (southwestern flank of the volcano; 1740 m asl) and has acquired gravity data almost continuously even since, at a rate of 1Hz. The adopted strategies for effective management of iGrav™#16, the main features of the gravity data, compared with data acquired by spring gravimeters, and the possible relationships with the volcanic activity are presented and discussed.

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JV03p-053

Long-term versus short-term deformation processes at Mt. Etna volcano

G. Solaro[1], S. Pepe[1], M. Bonano[1], R. Castaldo[1], F. Casu[1], C. De Luca[1], V. De Novellis[1], M. Manunta[1], A. Pepe[1], E. Sansosti[1], P. Tizzani[1]
[1]IREA, CNR, Naples, Italy

Volcanoes may deform as a consequence of several geophysical processes that evolve at different spatial and temporal scales. In this work, we focus on Mt. Etna stratovolcano and we investigate the relationship between the deformation behaviours related to long- and short-term volcanic processes and the ascent of magma. Generally, at the long-term scale, the main processes are those responsible of the volcano deformation style (e.g., volcano spreading, sagging or basement extrusion) that can promote the evolution of deep dikes or pressurized reservoirs; on the other hand, the short-term mechanisms lead to unrest phenomena that may cause eruptions due to the shallow emplacement of magma batches. To discriminate between long- and short-term effects, we analyse a large Synthetic Aperture Radar (SAR) data archive acquired on Mt. Etna by several satellites during the past 20 years. In particular, SAR data collected by ERS-1/2, ENVISAT, ALOS, and COSMO-SkyMed platforms were independently processed through the SBAS-DInSAR approach to capture the long-term behaviour. Moreover, the short-term behaviour has been analysed by using TerraSAR-X and Sentinel-1A DInSAR data pairs, collected across the last paroxysm occurred on 28 December 2014. The preliminary analysis reveals a firm interaction between the structural surface deformation phenomena and the eruptive style of the entire volcanic edifice. This finding represents the base for future and extensive studies aimed at understanding the status of Mt. Etna and its evolution, particularly considering the forthcoming availability of SAR data continuously collected by the European Sentinel-1 satellite constellation.

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JV03p-054

The 2011 unrest at Katla volcano: Location and interpretation of the tremor source

G. Sgattoni[1,2,3]*, Ó. Gudmundsson*[2]*, A. Tryggvason*[2]*, F. Lucchi*[3]*, P. Einarsson*[1]
[1]*University of Iceland, Institute of Earth Sciences, Reykjavik, Iceland*
[2]*Uppsala University, Department of Earth Sciences, Uppsala, Sweden*
[3]*University of Bologna,*
Department of Biological- Geological and Environmental Sciences, Bologna, Italy

Katla volcano is one of the most active and threatening volcanoes in Iceland. It is partly covered by Mýrdalsjökull glacier and the last explosive eruption to break the ice-surface occurred in 1918. The current repose time is the longest known in history. Increased seismicity and a tremor burst were recorded on July 8-9th 2011, associated with flooding from the south east rim of the glacier and deepening of cauldrons on the ice cap. Moreover, new seismic activity started on the south flank. The question arose as to whether this episode relates to a minor subglacial eruption and the tremor was generated by volcanic processes or by the flood.
A network of 10 permanent and 3 temporary stations run by the Icelandic Met Office and Uppsala University was operating on and around the Katla caldera. Seismic data are being analysed to locate and interpret the tremor source.
Low frequency (1-5 Hz) tremor starting around 7pm on July 8th continued for about 24 hours. Pulses of tremor with varying amplitude and duration can be identified at all stations simultaneously. At around 4am on July 9th a separate tremor phase is seen at stations closest to Múlakvisl river, which concurrently flooded according to gauging stations. This suggests that this tremor phase was generated by the flood and the other tremor is related to other processes, most likely volcanic. Moreover, the amplitude distribution suggests multiple or distributed sources.
We use tremor amplitude and differential times from cross-correlation of station pairs to extract information about the source location. Multiple component correlation analyses and the time evolution of tremor attributes are further used to study the nature of the tremor source.
We acknowledge the Icelandic Met Office for access to waveform data.

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JV03p-055

The nature of unrest phenomena at Yellowstone Caldera discriminated via integrated modeling of remote sensing data and geophysical investigation

R. Castaldo[1], *P. Tizzani*[1], *M. Battaglia*[2], *A. Pepe*[1], *G. Zeni*[1], *R. Lanari*[1]
[1]*IREA, CNR, Napoli, Italy*
[2]*Università Sapienza, Scienze della Terra, Roma, Italy*

We investigated the 1997-2010 Yellowstone caldera unrest phenomena by using the advanced differential InSAR, precise leveling and gravity measurements. The analysis of the 1992-2010 displacement time series, retrieved by applying the SBAS InSAR technique, allowed the identification of three areas of deformation: (1) the Mallard Lake (ML) and Sour Creek (SC) resurgent domes, (2) a region close to the Northern Caldera Rim (NCR) and (3) the eastern Snake River Plain (SRP). While the eastern SRP shows a signal related to tectonic deformation, the other two regions are influenced by the caldera unrest. We removed the tectonic signal from the InSAR displacements and we modeled the InSAR, leveling and gravity measurements to retrieve the best-fitting source parameters. The performed analysis confirmed the existence of different distinct sources, beneath the brittle-ductile transition zone, which have been intermittently active during the last three decades. Finally, we interpreted our results in the light of existing seismic tomography studies. Concerning the SC dome, we highlighted the role of hydrothermal fluids as the driving force for the 1977-1983 uplift phenomenon; while for the 1983-1993 time interval the deformation source transformed into a deeper one with a higher magmatic component. Moreover, our results support the magmatic nature of the deformation source beneath ML dome for the overall investigated period. Finally, the uplift at NCR is interpreted as magma accumulation, while its subsidence could either be the result of fluids migration outside the caldera or the gravitational adjustment of the source from a spherical to a sill-like geometry.

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JV03p-056

Two decades of eruptive activity and associated magnetic signals: Popocatepetl Volcano (Mexico)

A.L. Martin[1], *G. Cifuentes*[2], *E. Gonzales*[3], *E. Hernandez*[2], *D. Negrete*[4]
[1]Instituto de Geofisica Universidad Nacional Autonoma de Mexico, Vulcanology, Mexico D.F., Mexico
[2]Instituto de Geofisica UNAM, Geomagnetismo, Mexico- DF, Mexico
[3]Instituto de Geofisica UNAM, Volcanologia, Mexico DF, Mexico
[4]Instituto de Geofisica UNAM, Volcanologia, Mexico- DF, Mexico

Popocatepetl volcano began erupting in December 1994and has continued since then with intermittent ash emission. In 1996, the first of a series of sequential crater domes was formed. Over 40 domes have grown following the explosive destruction of the previous ones. The time lapse between the formation and destruction of each dome varies from a few days to several years. Volcanomagnetic signals at Popocatepetl have been monitored in real time since 1997 with total intensity magnetic stations at 4000m asl. The volcano is 5452 m high but frequent explosions and their ejecta limit the access to the upper part of the volcano. The data from these stations is processed with the Teoloyucan base station (weighted differences) to subtract the external field effects and signals not related with the volcano. Negative anomalies have been associated with magma ascent into the crater and correlate with periods of harmonic tremor. Timing varies from one month to a few hours before the dome is visible in the crater. Most of the magnetic precursors are short term except for in 2013 when the descending trend lasted several months and in 2014 about two. A 17nT descent in august 2014 was correlated with hotter temperatures in the crater. Abrupt peaks and stepward increases were associated with explosions and dome crystallization.

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JV03p-057

Continuous magnetotelluric monitoring at geothermal site – application to Rittershoffen project, northern Alsace

Y. Abdelfettah[1,2]*, P. Sailhac*[1]*, H. Larnier*[1]*, E. Schill*[2]
[1]*Institut de Physique du Globe de Strasbourg- CNRS UMR7516, University of Strasbourg- Strasbourg- France, Strasbourg, France*
[2]*Institut fu¨r Nukleare Entsorgung INE- Karlsruher Institut fu¨r Technologie KIT, Karlsruher Institut fu¨r Technologie KIT- Karlsruher- Germany, Karlsruher, Germany*

Changes in fluid pathways in the subsurface of a geothermal project during stimulation and operation are typically inferred from micro-seismic monitoring. Micro-seismicity can provide information about where fractures shear and open, but neither on fracture connectivity nor on the fluid content. Electromagnetic methods are sensitive to conductivity contrasts and are typically employed as a supplementary tool to delineate reservoir boundaries. In 2014, a total of six MT stations (one permanent and five temporary) were installed from May 2014 until December 2014. The permanent station is located at RITT (Rittershoffen) and is synchronized with reference remote station located at Welschbruch observatory (about 85 km South from Rittershoffen), which it is still in operation. The temporary MT sites are located around Rittershoffen well; three stations had been installed South in the Betschdorf forest and two outside of it. Temporary sites recorded continuously for at least four days at each site before circulation operation started. The measurements at these temporary sites are repeated after termination of the circulation experiment. MT sample frequency for all stations is 512 Hz.
In this study, preliminary results obtained for monitoring of Rittershoffen geothermal site using magnetotelluric method will be presented and discussed. We are mainly interested for the frequency range between 0.1 to 10 Hz to record a significant signal, which may occur at the pumping and injection depths. The aim of this paper is to introduce the fieldwork achieved in 2014, the methodology and discuss the preliminary results obtained from observed data and probably from sensitivity analysis.