XIX Century Earthquakes in South America: What we can learn from Tsunamigrams

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ABSTRACT

Two large earthquakes took place in the later part of the XIX century in southern Peru and northern Chile, these are the August 13, 1868, and the May 9, 1877 (local time), events. Their estimated magnitudes are of the order of 9 rupturing contiguous segments of nearly 500 km each. Both of them accommodated the convergence between Nazca and South American plates producing large seafloor and coastal elevation changes generating significative tsunamis that affected most of the coastlines of the Pacific basin. Reported local runups reached 20 m. Both trans-pacific tsunamis were recorded at one tide gage in Fort Point, in the Presidio area of San Francisco Bay, California. Records at Sausalito (approximately 6 km away from Fort Point) for the 1877 event mimic the signal recorded at Fort Point. Here we report on the characteristics of these tide gage records and compare them to the recent record of the June 2001 Mw=8.4 earthquake that ruptured a fraction of the 1868 event. Numerical simulations of the tsunamis have been constructed. The area to the south of the 2001 event and north of Antofagasta –Tocopilla in Chile (17°S-22°S), has not been subjected to large earthquakes since the 1868-1877 sequence.

Key words: Tsunami, Historic earthquakes, Subduction zone earthquakes

PRESENTER'S BIOGRAPHY

Sergio Barrientos is currently the Scientific Director of the National Seismological Network of the University of Chile. Interested in the study of large earthquakes and the subduction process.

The Decision Matrix for Early Tsunami Warning in the Mediterranean Sea: is revision needed after the 2008 strong earthquake activity in Greece?

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ABSTRACT

After the generation of the large Indian Ocean 2004 tsunami a systematic effort started for the establishment of regional, national and local early tsunami warning systems in Europe under the co-ordination of IOC/UNESCO. Within this initiative an empirical matrix was developed as a tool supporting decisions about the tsunamigenic or non-tsunamigenic nature of a particular earthquake in real-time conditions. The decision matrix is based on the focal parameters of the earthquakes, that is the location of the earthquake epicenter (offshore or inland), the focal depth (shallow or intermediate depth) and the earthquake magnitude. The data set covers the instrumental period of seismicity that is about the last 100 years. The lower magnitude threshold required for the generation of an important tsunami is about 6. It has been found that offshore, shallow earthquakes have increasing probability for the tsunami generation with the increase of magnitude. However, during 2008 several strong earthquakes, both shallow and intermediate-depth, exceeding 6 in magnitude occurred in the Greek area and particularly along the Hellenic arc and trench system which is the most tsunamigenic in the European-Mediterranean region. None of them was reported to have produced even small tsunami-like sea-level disturbances. Therefore, we re-examine the empirical rules which compose the initial tsunami decision matrix under the light of the updated data set. We found that only minor change of the rules comes out and that for the time being there is no urgent need to revise the tsunami decision matrix adopted so far. Furthermore, from a smaller data set covering the post-1950 period we investigate an additional rule based on the focal mechanism of the earthquakes. As one may expect, a preliminary result indicates that focal mechanisms incorporating dip-slip component are the most prone for the tsunami generation although some characteristic examples of dip-slip events do not show this feature.

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2005-today: 24 hour monitoring of seismicity in Greece and daily analysis of the parameters of the earthquakes occur in the Greek region. *National Observatory Athens*.

c. Research interest

Marine Geophysics, Marine Seismology, Geographical Information Systems, Submarine Mass Failures, Tsunami Generation, Propagation, Runup and Hazard, Tsunami Risk Management on Coastal Areas, Calculation of Earthquake Parameters, Development of Geodatabase, Earthquakes along subduction zones.

Historical Significant Earthquakes, Volcanic Eruptions, and Tsunamis in Africa

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ABSTRACT

The National Geophysical Data Center (NGDC) global historical tsunami, significant earthquake, and significant volcanic eruption databases include events that range in date from 4350 B.C. to the present. The basic data in the historical event files include the date, time, location of the event, magnitude of the phenomenon (e.g. tsunami intensity, earthquake magnitude, volcanic explosivity index), and socio-economic information such as the number of fatalities and dollar damage. The tsunami database includes an additional table with information on the locations where tsunami waves were observed (e.g. runups, eyewitness observations, reconnaissance field surveys, tide gauges, or deep ocean sensors). An examination of the databases reveals that over 150 earthquakes have caused either deaths or significant damage on the continent of Africa. Ninety of these earthquakes resulted in over 250,000 fatalities. There are also several active volcanoes in Africa. The largest number of fatalities due to volcanic activity was in 1986 when over 1,700 deaths were caused by the release of a large volume of carbon dioxide from Lake Nyos in Cameroon. Further examination of the databases reveals that 40 events generated tsunami waves that were observed in thirteen different African countries from 23 B.C. to the present. The majority of these tsunamis were generated by earthquakes located either in the Mediterranean Sea, Atlantic Ocean, or Indian Ocean, except the eruption of Krakatau in 1883 and a few tsunamis with unknown causes. The highest runups observed on the African continent were from an earthquake in Morocco in 1773 that generated a 9 m wave in Tangiers and the 2004 Sumatra earthquake and tsunami that generated a 9.5 m wave in Eyl, Somalia. The 2004 Sumatra tsunami also caused 303 deaths on the east coast of Africa. Other deaths from tsunamis in Africa resulted from an earthquake and tsunami in 1365 in Algiers and an earthquake in 1820 on the Congo coast that generated a tsunami that drowned many natives in Angola. Additional statistics for Africa will be presented from the NGDC natural hazard catalogs.

Key words: Tsunami, earthquake, volcanic eruption, socio-economic

PRESENTER'S BIOGRAPHY

Paula Dunbar is the Hazards Team Lead and a physical scientist in the Marine Geology and Geophysics Division of the NOAA/National Geophysical Data Center (NGDC). She manages the archive and distribution of the historical tsunami event, significant earthquake, and significant volcanic eruptions databases. Ms. Dunbar has worked on GIS-based hazard assessment projects such as earthquake loss estimation and tsunami vulnerability analysis. Ms. Dunbar is a member of the IUGG Commission on Geophysical Risk and Sustainability (GeoRisk) and a member and Secretary of the IUGG Joint Tsunami Commission. GeoRisk studies the interaction between hazards, their likelihood and their wider social consequences as a result of the vulnerability of societies. The Tsunami Commission is an IUGG Inter-Association Commission responsible for international coordination of tsunami related meetings, research, field surveys and other tsunami related efforts. Prior to joining NGDC in 1991, she worked for the NOAA/Space Environment Services Center and the USGS/National Earthquake Information Center. Ms. Dunbar received a B.A. in Geography from the University of Colorado and a M.S. in Earth Sciences from Colorado State University.

Horn of Africa Surveys of the 2004 Indian Ocean Tsunami with focus on Somalia's Xaafuun Peninsula

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ABSTRACT

The 26 December 2004 tsunami severely affected a 700 km stretch of Somali coastline south of the Horn of Africa at a distance of 5,000 km from the epicenter of the magnitude 9.0 earthquake. The Puntland coast in northern Somalia was by far the area hardest hit to the west of the Indian subcontinent resulting in 298 deaths, extensive destruction of shelters, houses and water sources as well as fishing boats and equipment. In March 2005 the first UNESCO mission surveyed five impacted towns south of the Horn of Africa along the Puntland coast in northern Somalia: Eyl, Bandarbeyla, Foar, Xaafuun and Bargaal. This survey was complemented by a second UNESCO survey circling Yemen's Socotra Island to cover 12 villages in October 2006. The team measured tsunami runup heights and local flow depths on the basis of the location of watermarks on buildings and eyewitness accounts. Maximum runup heights were typically on the order of 5 to 9 m in northern Somalia and 2 to 6 m on Socotra. Most victims were reported along the low lying Xaafuun peninsula, which juts out 40 km into the Indian Ocean, forming the easternmost point on the African continent. The promontory is connected to the mainland by a 20 km long sand spit, which was widely flooded without overtopping. The fishing town of Xaafuun (English: Hafun) is believed to be the location of the ancient trade center of Opone, where ancient Egyptian pottery has been recovered by archaeologists. The largest tsunami death toll of 179 in a single town to the west of the Indian subcontinent was reported in Xaafuun, which was continuously settled for more than 2000 years. More than 50% of all tsunami fatalities west of the Indian subcontinent are concentrated along a 1 km stretch of Xaafuun coastline. The entire low-lying western part of Xaafuun was completely flooded by the tsunami with inundation distances exceeding 700 m. A total of 812 houses were destroyed, including 600 stone houses. The Italian-speaking vice council Mahad X. Said presented a unique and detailed description of the initial wave sequence based on the pillars of an aerial ropeway extending 1.5 km offshore. Before the 3rd and most powerful wave washed through town the water withdrew by 1.3 km to the 6 m offshore depth contour. The average velocity of the third wave between maximum drawback and impact on the town was estimated to approximately 11 m/sec. The eyewitness estimates of the arrival time concentrated around 9:00 UTC. Fortunately, the main tsunami waves arrived close to low tide during a receding tide. A tsunami arrival during high tide could have increased the runup heights by up to 2 m, depending on the location. An integrated development program implemented at Xaafuun involved local planning, partial relocation and reconstruction on higher ground.

Keywords: Tsunami, field survey, runup, Indian Ocean, Horn of Africa, Somalia, Yemen, 26 December 2004

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Mega Tsunami in the Indian Ocean as the Evidence of Recent Oceanic Bolide Impacts, Chevron Dune Formation and Rapid Climate Change

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The paper deals with physical and environmental effects resulting from impacts into the ocean by sizable comets, and the rates and risk associated with such cosmic impacts. Specifically, we investigate two sets of probable oceanic impact events that occurred within the last 5000 years, one in the Indian Ocean about 2800 BC, and the other in the Gulf of Carpentaria (Australia) about 536 AD. If validated, they would be the most energetic natural catastrophes occurring during the late Holocene with large-scale environmental and historic human effects and consequences. The physical evidence for the reality of these two impacts consists of several sets of data: (1) remarkable depositional traces of large water flooding (chevron dunes) found in southern Madagascar and along the coast of the Gulf of Carpentaria, (2) presence of crater candidates (29-km Burckle crater about 1500 km southeast of Madagascar which dates to within the last 6000 years and 18-km Kanmare and 12-km Tabban craters with an estimated age of 572±86 A.D. in the southeast corner of the Gulf of Carpentaria), (3) presence of high magnetic susceptibility, quench textured magnetite spherules and nearly pure carbon spherules, teardrop-shaped tektites with trail of ablation, other impact-indicators (quartz with 3 to 5 directions of straight, parallel fractures, concoidally fractured feldspar) and metallic drops with Fe> Cr> Ni and >1%Ni found by cutting-edge laboratory analytical techniques in the upper-most layer of core samples close to the crater candidates.

The allied problem to these climate affecting impacts is the problem of origin of chevron dunes that are V-shaped dunes widely developed in many parts of Indian Ocean coastline and in the Gulf of Carpentaria. Although some propose a wind-blown origin we have evidence in favor of their mega-tsunami formation. In southern Madagascar we have documented evidence for oceanic water run-up reaching 205 m with in-land penetration up to 45 km that is far beyond the run-ups of any historical tsunami. In the field study of these chevrons we found a number of features that are inconsistent with their wind-blown genesis, but well explained by flooding resulted from mega-tsunami waves coming from the areas with proposed crater candidates.

The results of our study show that substantive oceanic comet impacts not only have occurred more recently than modeled by astrophysicists, but that they profoundly affected Earth’s natural systems, climate, and human societies. If validated, they could potentially lead to a major paradigm shift in environmental science by recognizing the role of oceanic impacts in major climate downturns during the late Holocene that are well documented by different techniques (tree-ring anomalies, ice-shield and lake-bottom drilling and peat bog cores).

Tsunami impact on the African continent: historical overview

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ABSTRACT

The Global Historical Tsunami Database (GTDB), maintained by the Novosibirsk Tsunami Laboratory, that currently consists of about 2200 historical tsunamis occurred in the Word Ocean during the last 4000 years, contains only 20 historical tsunamigenic events that happened nearby the African coast in the time span from 1680 to present. Majority of these events occurred in eastern Atlantic and Mediterranean regions. The currently available historical data for the African continent are obviously incomplete. There is no doubt, for instance, that considerable part of the northern coast of Africa was affected by the large ancient tsunamis occurred in the eastern Mediterranean (e.g., 1628 BC Santorini, 365AD Crete or 1650 Aegean Sea events), but we do not have any witness reports on manifestation and impact of these tsunamis on African coast. All other parts of Africa do not have any nearby subduction zones and they are far away from any active plate boundaries. As a result, they are not exposed to an immediate threat of seismically generated regional and local tsunamis, but still at risk in case of large trans-oceanic tsunamis generated anywhere in the Atlantic and Indian oceans. The largest historically observed 16-meter run-up at the African coast was observer in Tangier, Morocco after the 1755 Lisbon earthquake. Almost 10-meter run-up was measured at the eastern coast of Somalia after the 2004 Sumatra tsunami. In addition to seismically and volcanically generated tsunamis, the African coast is subject for impact of local landslide-generated tsunamis that can occur near any part of the coastline, especially located nearby the mouths of large African rivers. In fact, historical chronicles tell about several cases of unusual wave run-ups observed in the area near Gulf of Guinea. Historical documents contains also several reports on tsunami-like events that occurred in the African lakes with the most recent case reported for the Lake Nyos, Cameroon on 21 August 1986, when a giant «bubble" of CO_2 gas came from the depth of the lake to the surface and generated destructive water waves that killed many people. The paper gives the analysis of availability and completeness of historical data on tsunami occurrence near the African coast and indicates the possible ways of filling the existing gaps in data.

Key words: tsunami, historical catalogs, risk assessment

PRESENTER'S BIOGRAPHY

Dr Viacheslav K. Gusiakov obtained his doctoral degree in 1974 from the University of Novosibirsk. He is working at the Department of Geophysics of the Institute of Computational Mathematics and Mathematical Geophysics), Siberian Division, and Russian Academy of Sciences in Novosibirsk, Russia. His area of expertise includes numerical modeling of tsunami, seismic and oceanographic data processing, geophysical databases, risk assessment and hazard mitigation. He served as Chairman of the IUGG Tsunami Commission (IUGG/TC) in 1995-2003. Being an internationally-acknowledged expert in the tsunami-related field, he has participated in international conferences and workshops as well as in biannual sessions of the IOC/UNESCO International Coordination Group for Tsunami Warning System in the Pacific (ICG/ITSU). V.Gusiakov is a member of the IUGG Tsunami Commission, the International Tsunami Society, the American Geophysical Union, and the Seismological Society of America.

The Cape West Coast Tsunami of 20-21 August 2008

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ABSTRACT

On 21 August 2008 the NSRI received accounts of unusual wave action along the Cape West Coast, startling boat-owners in harbours and causing flood damage at a shoreline factory in St Helena Bay. SANHO tide-gauge data from Luderitz (LB), Port Nolloth (PN), Saldanha Bay (SA), and Granger Bay (GB, Cape Town) reveal long-period (~15-60 min), tsunami-like waves affecting the entire coastline between Southern Namibia and Table Bay, beginning on 20 August and culminating in an extended attack during the morning of 21 August. At PN the largest wave occurred at 02:42 SAST with amplitude ~0.8 m and period ~42 min, superimposed on a high tide. The southwestern continental margin of Africa is known for large submarine slumps and gravity-slide faults that affect Tertiary-Quaternary strata, and also for associated gas-hydrate layers and mud-volcano structures. Hence, a large submarine landslide probably caused this tsunami, but short-period seismographic data from 7 southwestern stations in the CGS's South African National Seismographic Network (SANSN) reveal no local or distant earthquake that might have triggered slope failure. The 5-min atmospheric-pressure record from a SAWS automatic weather station at PN shows a remarkable fluctuation that correlates with the 3-min tide-gauge record in an inverse-barometer effect. At PN the onset of the atmospheric gravity wave and the first low-amplitude, long-period sea wave, occur synchronously at 05:15 SAST on 20 August. On this basis the observed disturbance is arguably an "edge-wave" or "meteo-tsunami" phenomenon with an atmospheric origin, unrelated to any submarine geological cause. Conversely, the atmospheric gravity wave may have been excited by the oceanic gravity wave (tsunami). In order to settle this question, analysis of the long- and very-long-period seismographic records from SANSN broadband instruments may yet resolve crustal motions characteristic of a "slow and silent" earthquake that is associated with - and diagnostic of the location and size of - a submarine landslide event (or episode of several discrete events). Continuous (30-s epoch) GPS data from 13 southwestern stations in the CDSM's TrigNet array is also available for kinematic analysis of N, E and Up motions over the period 19-22 August 2008. Preliminary modeling of a theoretical 15 km-long x 45 km-wide x 75 m-thick landslide, located at 1500 m depth in the Chamais Slump Zone west of PN with a down-slope displacement of 7.5 km, creates a similar signal in respect of amplitudes to those observed in the LB, PN, SA and GB tide-gauge records. However, a series of smaller slumps might be needed to explain the extended timing of the whole tsunami attack. Because the time-lag between a continental-slope landslide here and first tsunami wave at the coast is ~1-1.5 hours - and the main wave-train is further delayed, the near-real-time coordination of tide-gauge, barometric, (long-period) seismographic and GPS data, supported by scenario modeling of submarine landslides of different sizes at diverse locations, can provide the scientific basis for a future early-warning and disaster-mitigation system to safeguard human life and critical harbour (Cape Town, Saldanha) and nuclear-power station (Koeberg) infrastructure along this coastline.

Key words: Tsunami, southwestern Africa, submarine landslide.

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Late Pleistocene-Holocene turbidites in the Natal Valley: ~500 kyr record of tsunami on SE coast of South Africa?

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ABSTRACT

During the 1992 Russian-South African expedition of the R.V. Professor Logachev, Quaternary sediments in the submarine Natal Valley were sampled in ~3600-4000 m water depths by four large-diameter gravity cores, the longest core of 4.55 m. Three cores, consisting chiefly of planktonic foraminiferal ooze texturally ranging from mud to sandy mud, each contained a thin (<20 cm) layer of coarser sediment with erosive base, consistently lower carbonate values, and a very diverse benthic foraminiferal and shallow-water ostracod fauna, compared to a much less diverse bathyal or abyssal benthic fauna in the enclosing sediments. These thin coarser layers were evidently transported into the abyssal environment by turbidity currents. As a follow-up in 1996 the R.V. Marion Dufresne took a piston-core (MD962077, 35.54 m long in water depth 3781 m) in a zone of undisturbed sedimentation close to the previous core sites. Foram-bearing nanno ooze is interspersed with nine distinct quartzose silt and sand layers with an average spacing of 3 m. The lower four turbidites are finer-grained quartzose silts at depths of 34.3-34.4 m, 31.7-31.9 m, 28.8-29.0 m, and 25.6-25.8 m, i.e., about 0.2 m thick and a few meters apart. The top five turbidites are coarser-grained quartzose sands at depths of 20.8-21.0 m, 20.0-20.1 m, 19.2-19.3 m, 14.0-14.5 m, and 10.4-10.7 m.

In the dated, upper 24 m of the core, the acid-insoluble sand (AIS) fraction, plotted as a percentage of the unleached original subsample, is characterized by three narrow peaks of >50% AIS in Marine Isotope Stages (MIS) 13 (Interglacial), MIS 10 (Glacial) and MIS 8 (Glacial). Two minor (~5% AIS) peaks are found in MIS 13 and MIS 12 (Glacial). All five layers, rich in quartz sand, were also detected in the up-core plots of density, magnetic susceptibility and sonic velocity. The shallowest of the three major quartz-sand layers is found in a core depth of 10.5m (MIS 8), deeper than similar quartz sands found in the shorter Professor Logachev gravity cores. These five turbidites range in age from 510 and 485 ka in MIS 13, to 455 ka in MIS 12, 335 ka in MIS 10 and, finally, 250 ka in MIS 8.

The most likely triggers for the turbidity currents are large earthquakes (Nubia-Somalia plate-boundary-related), previously inferred as an explanation for the extensive, probably Pliocene–Pleistocene, major submarine slumps off the Wild Coast of South Africa, landward of the Natal Valley between Durban and East London. These episodes of continental-slope collapse were most probably accompanied by both turbidity flows to the abyssal plain and tsunami impacts along the adjacent Southern Africa coastline. Further systematic mapping of the extent and structure of the "Wild Coast Mega-slump" zone, the lateral distribution and thickness of the turbidite-hosting units in the nearby deep ocean basin, related to an attempt establish a coastal /estuarine record of Late Pleistocene-Holocene tsunami impacts, will be an important step towards better identification and assessment of risk from major earthquake and local tsunami in this region.

Key words: Natal Valley, piston core, turbidite layers, Holocene-Pleistocene, submarine landslide, tsunami, SE Africa

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Tsunami at Takoradi (Ghana, central West Africa) due to M_w 9.3 earthquake in Sumatra on 26 December 2004

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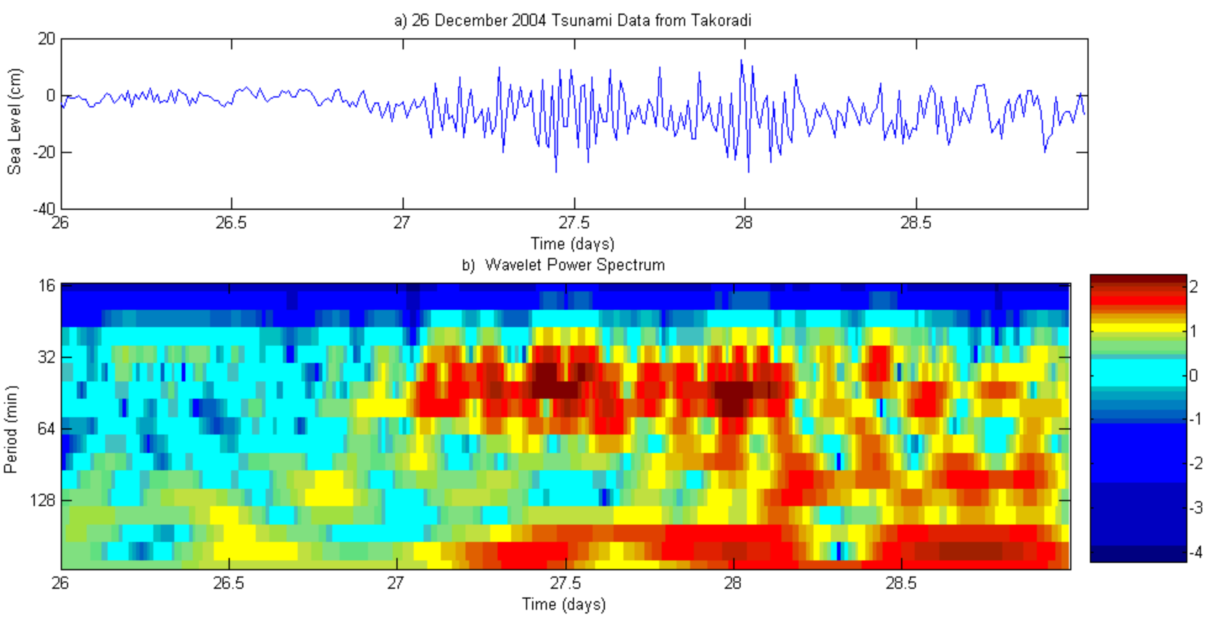
ABSTRACT

Under the cooperation of India, IOC/UNESCO and the Republic of Ghana, a digital tide gauge with 15-min sampling interval was installed at Takoradi Harbour in Ghana. The station started operation from 1 July 2004 as part of the Global Sea Level Observing System (GLOSS). Except South Africa, the Takoradi instrument was probably the only tide gauge working on the Atlantic coast of Africa in December 2004 and it clearly recorded the 2004 Sumatra tsunami. The tsunami wave arrived at Takoradi at 01:38 UTC on December 27, 2004, i.e. in 24 hrs 39 min after the earthquake. The dominant spectral energy at ~42 min. observed in the tsunami spectrum (computed for ~3-day segment) was considerably larger than that of the background spectrum (computed for ~87-day segment before tsunami). A wavelet analysis was used to track the



changes of tsunami frequency with time and to identify the specific frequency band of the energy concentration. The maximum spectral energy, observed from the tsunami arrival to ~04:00 UTC on 28 December, corresponds to periods ~29-58 min. Another bunch of maximum energy occurred at periods beyond ~159 min. The maximum trough-to-crest wave height was ~41 cm. Two distinct bursts of energy were evident in the record; the corresponding wave trains were separated by ~14 hr. The second burst, which probably was the result of focusing of reflected tsunami waves from certain regions of continental shelves or from the Mid-Atlantic Ridge, was larger in height by several cm. The continuous tsunami ringing was observed up to 31 December with gradual energy decay. Such long ringing was apparently associated with secondary signals reflected from continental borders or mid-ocean ridges. The prominent tsunami signal found in the Takoradi record indicates the sensitivity of West African coast to tsunami and points out to the importance of having high-quality sea-level stations on Africa's coastal and island locations for effective tsunami monitoring and possible warning.

Key words: Tsunami, wavelet analysis, Takoradi, West Africa, Atlantic Ocean

Establishment of a network of pressure and radar based Internet accessible real time reporting sea-level gauges on the Indian coasts

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ABSTRACT

The principal objective of the present research is enabling real/near-real time monitoring of anomalous sea-level oscillations (arising from tsunamis and storm surges) by establishing a network of fast-sampling and high-sensitivity sea-level gauges at selected locations on Indian coasts and islands. For this purpose, subsurface pressure based and downward-looking microwave radar based sea-level gauges have been designed and developed. The gauges have the capability to acquire wind-wave-smoothed sea-level data (5-minutes average) at fast sampling intervals (5-minutes) and upload a set of time-tagged dataset (previous date to current date) to an Internet server with the use of an inbuilt cellular modem and a network of existing cellular base-stations. Whereas satellite technology provides a sophisticated means of real-time sea-level data reporting, our preference for cellular-based data reporting stems from the ubiquity of cellular base-stations throughout the country, relatively small size of the cellular modem, and state-of-the art information accessibility at significantly low cost. The present gauge works on 12-volts battery which is charged through solar panels. The electronics and the modem are housed in a weather-proof housing and therefore, unlike conventional gauges which require a 'tide gauge hut', the present gauge works under open air environments. With the use of the present design, graphical displays of the measured sea-level, astronomical tide, and the residual (i.e., anomalous sea-level oscillations) can be viewed in real/near-real time from the Internet (http://inet.nio.org), updating at 5-minutes intervals. The Internet link displays a listing of sea-level gauge locations, any of which can be selected at a given time to view the trend of sea-level oscillations currently occurring at that site. Use of subsurface pressure gauges and the design methodology as described above has been found to be useful in the online detection and monitoring of even rather weak tsunami signals (due to M_w 8.4 earthquake in Sumatra on 12 September 2007) that arrived at Kavaratti Island (trough-to-crest wave height ≈5 cm), located in the eastern Arabian Sea in the Indian Ocean and at the coast of Goa (trough-to-crest wave height ≈30 cm), located on the west coast of India. Subsequently downward-looking microwave radar) based gauges (transmission frequency: 24 GHz; beam width: ±5°; measurement range: 30 m; accuracy: within ±1 cm incorporating cellular-based and Internet-enabled real-time reporting capability have been established at three stations on the west coast of India. The microwave radar gauges have been installed from coastal jetties and open water fronts with relatively lesser logistic problems. Our experiences with microwave radar gauges have so far been encouraging. However, we noticed that the measurements can get severely contaminated by man-made lapses such as anchoring of floating objects below the radar sensor. We note here that during anomalous sea states, floating objects can be brought below the radar by natural forces and this can be a concern unless the radar beam path is kept clear permanently by adequate mechanical means during installation. The latest development in the system design has incorporated low-power embedded Linux platform which allows maintaining accurate system clock using Internet network time protocol (NTP).

Key words: Tsunami, Internet-accessibility, real-time, pressure, radar

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Evidence of Tsunimagenic sources along the Algrerian margin

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ABSTRACT

In 2003 and 2005, two marine surveys(Maradja I and II) were conducted along the algerian margin in order to depict the structural pattern of this domain and to decipher the sedimentary processes which occurred in it. From the data analysis, several marine active structures were evidenced from west to east. They are in general reverse faulting as the Boumerdes fault, deepening towards the south demonstrating that the margin is reactived by the convergence process between Eurasia and Africa. Analysis of their characteristics (length, dip,…) demonstrate their ability to trigger tsunamis with both effects on the two European and African coastlines. The last Boumerdes of May 2003 event is the most significant example. Modelling of the effects of the Djidjelli tsunami of 1856 on the Algerian coast is presented. In order to model the impact of future events on the Algerian coast, we present here a review of the several seismic sources evidenced along the Algerian margin by the two surveys.

Key words: Tsunami, seismic sources, margin

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Prospecting a Sea-Level Network for Tsunami Warning in the Western Mediterranean basin

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ABSTRACT

In response to the 2004 Indian Ocean disaster, coordination groups for tsunami warning and mitigation systems have been set up by UNESCO; the Mediterranean Sea, where historical and recent tsunamis occurred, is one of the targeted basins. We focus on its Western part which is prone to undergo regional tsunamis, in particular caused by earthquakes along the North African coast, and examine which sea-level network could allow implementing a warning system for these events. Sea-level recording allows confirming or refuting the occurrence of a regional tsunami. Unfortunately, it is unsuitable to forecast the impact along the coasts close to the epicenter, which are hit too rapidly. Our approach is based on computation of travel times and modelling of wave propagation.

In the Western Mediterranean basin, such a system would be very challenging; small distances from potential seismic sources to impacted regions imply very short travel times and require rapid detection and warning processes. Moreover, because of their location and their small or moderate magnitude, the North Africa earthquakes are not prone to generate large tsunamis. Some of these seismic events can however trigger significant waves causing damage.

Taking into account the seismotectonic setting and the processing capacities, we examine the sea-level network that would most properly detect and measure tsunamis. The objective is to most efficiently notify an impending event, but avoiding excessive warnings. Moreover, cost is allowed for; sea-level recording requires substantial financial supports for equipments, implementation and maintenance, thus the warning system should operate with fewest sensors as possible. Our method first consists in deriving tide gages location from minimum travel times computed by ray tracing for the areas prone to be mostly affected. Then, using finite difference numerical modelling, the sensors spacing is evaluated such as the tsunami amplitude is properly measured: with a too sparse network, the maximal wave height may be underestimated.

The optimal network would be composed of about 17 coastal tide gages and 13 tsunameters located 50km far from the African shore and spaced 50 to 90 km apart. Taking into account delays of detection and transmission, time for warning increases roughly eastward from 5 to 25 min. 5 min is a very short time to evacuate people, and for the near-field areas, educational actions only could be carried out to encourage quick and appropriate reactions.

We developed our approach to design a sea level network, efficient and adapted to the Western Mediterranean, however it could be applied for other small and shallow basins.

Key words: tsunami, Mediterranean, warning system, tsunami travel times, modelling.

Towards a Regional Tsunami Warning System in the Gulf of Cadiz

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ABSTRACT

After the Sumatra event in December 2004, the UNESCO, through IOC, recognized the need for an end-to-end global tsunami warning system. The NEAMTWS Intergovernmental Coordination Groups was then established to cover the Atlantic, Mediterranean and Connected Seas area.

The Gulf of Cadiz is located at the eastern end of the Nubia-Eurasia plate boundary in the Atlantic and belongs to the NEAM region. This area has been the place of several tsunamis, like the well-known event of 1st November 1755. During the 20th century other smaller tsunamis were recorded in the area: the 25th November 1941, the 28th February 1969. The extensive occupation of coastal areas in the surrounding countries – Portugal, Spain and Morocco, the enormous influxes of tourists during high season and the large economic value of harbors and other coastal facilities increases the risk of tsunami impact.

Portugal due to its geographical location is the first country to be hit by a tsunami that is generated in the Gulf of Cadiz. This fact makes it the natural candidate to host a regional tsunami Warning system for this area that should be built on top of its National Tsunami Warning System (NTWS). In this paper we present the status of the ongoing implementation of the NTWS in Portugal:

i) The real time collection and processing of seismic data;
ii) The real time data acquisition and transmission of coastal sea-level data to the data collection centre;
iii) The software tools for the assimilation of seismic and sea-level data working and preparation of messages.

The purpose of the system is to issue to the Portuguese Civil Protection Authorities the first message based only on seismic information, after 5 minutes of the earthquake origin (i). The use of an extensive set of pre-computed tsunami scenarios allows the NTWS to inform also on the predicted arrival time and amplitude of the tsunami wave at pre-defined critical points along the coast. Next, using (ii) and (iii) the NTWS will be able to access in real-time the sea-level measurements and confirm, change or cancel the previous tsunami message.

Since only coastal tide-gauges are available the tsunami-warning message will not be effective for the coasts closest to the earthquake source. An effective tsunami warning system must rely on deep ocean measurements of sea level provided by DART-like buoys. We show in this paper the design of the future tsunami detection network, including the optima location of a minimum set of oceanic stations to account for source areas considered in the Gulf of Cadiz. When in operation, the Portuguese NTWS could send messages to other countries in the Atlantic, providing the services required by a Regional Tsunami Warning Centre.

The development of the Portuguese Tsunami Warning System is a joint effort between volunteer researchers from the following Portuguese institutions: Instituto de Meteorologia, Centro de Geofisica da Universidade de Lisboa, Instituto Hidrográfico, IGP and the European Joint Research Centre. These activities are funded by research projects: NEAREST and TRANSFER (6FP, EU) and by ERSTA (Portuguese civil protection).

Key words: Early Warning, Tsunami, Atlantic, Earthquake sources.

PRESENTER'S BIOGRAPHY

Luis Matias is a Seismologist that concluded his PhD in 1996 on the structure of the crust and upper mantle in Portugal mainland, as derived from deep seismic sounding profiles. His career has been dedicated both to Active and Passive Seismology where his main area of research is Seismotectonics. In collaboration with two other colleagues, Luis Matias received in 1996 the “Boa Esperança” Science prize in Portugal for their collective work on the Neotectonics and Seismotectonics in Portugal Mainland. He has been involved in almost all of the projects and scientific cruises that have investigated the Gulf of Cadiz area, looking for the definition and characterization of the geological sources that may generate big earthquakes and tsunamis in the area. He is currently a member of the Portuguese delegation the the ICG/NEAMTWS.

A report card on real-time long-period seismological algorithms in the context of tsunami warning

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ABSTRACT

We report on the performance of real-time estimators of earthquake source characteristics in the context of tsunami warning, especially for very large or anomalous events defying seismic scaling laws. The estimators include the improved mantle magnitude algorithm, the estimation of source moment using the body-wave algorithms M_{wp} in both the time and frequency domains, the slowness parameter Θ introduced by Newman and Okal, the high-frequency P-wave duration estimator $\tau_{1/3}$ introduced by Reymond *et al.*, and a possible magnitude scale based on the spectral amplitude of the *W* phase. The earthquakes considered are among the large sources ($M_0 > 10^{27}$ dyn*cm) from the past three years. Among them, the tsunamigenic events in the Solomons and Peru scale predictably, whereas the Santa Cruz event features a trend towards slowness, reminiscent of the 1980 source in the same region, and the 2006 Kuril event has a late (but not necessarily slow) source. By contrast, both the normal faulting 2007 Kuril source, the Moluccas and the Taiwan events feature high values of Θ, the former reminiscent of the outboard 1977 Sumbawa earthquake, and characteristic of intraplate earthquakes. These new data points generally uphold the deficiency of M_{wp} for sources exhibiting slowness or even a trend towards it, which should be a significant concern in the context of tsunami warning. By contrast, a magnitude based on the *W* phase satisfactorily scales most large or slow sources, while $\tau_{1/3}$ recognizes certain, but not always all "tsunami earthquakes".

Keywords: Tsunami sources; Real-time Seismology; Long-period Seismology; Tsunami Warning

PRESENTER’s BIOGRAPHY

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Tsunami hazard in the South Atlantic and SW Indian Ocean from large normal- and thrust-faulting earthquakes along the South Sandwich arc

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ABSTRACT

We examine the tsunami hazard posed by major earthquakes occurring at or near the South Sandwich Islands (SSI) subduction zone. While no large interplate thrust earthquake is known in the region, a number of historical events have been assigned magnitudes greater than 7. We present a detailed seismological study of the largest one, on 27 June 1929, for which we obtain a moment of 1.7×10^{28} dyn*cm, and a normal faulting mechanism expressing an internal tear of the South American plate at the northwestern corner of the arc. Similar, albeit smaller, normal faulting events are known along other sections of the arc in the modern (post-1963) catalogue. The tsunami hazard from the SSI is investigated by running numerical simulations on the high seas (excluding final inundation at the coastlines) for the 1929 earthquake and a number of sources inspired by its size. These include the recent normal events scaled up to the 1929 moment, and the improbable, but not totally impossible, interplate thrust event of a similar size. A common feature of all these models is the strong focusing of tsunami waves by the South Atlantic Ridge, the Southwest Indian Ocean Ridge, and the Agulhas Rise, resulting in amplitudes always enhanced in Ghana, Southern Mozambique and certain parts of the coast of South Africa. In addition, the 1929 geometry results in strong amplitudes (≈ 30 cm in deep water) off the coast of Brazil, where the tsunami should have been observed. In conclusion, this study documents the significant potential tsunami hazard to South Atlantic shorelines from earthquakes in this region, principally normal faulting events.

Keywords: South Sandwich Islands, Moment Tensor Inversion, Tsunami Hazard, Tsunami Simulations, South Africa

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2004 Sumatra tsunami surveys in the Western Indian Ocean and inferences for future tsunami hazard in region

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ABSTRACT

We compile the results of post-tsunami surveys carried out in 11 countries and territories extending form Oman to South Africa, along the Western shores of the Indian Ocean in the wake of the great 2004 Sumatra tsunami. Run-up ranges from unobserved (along certain parts of Madagascar) to 9 m (in Somalia). These variations can be attributed, in order of importance, to classical source directivity (explaining the huge inundation in Somalia), bathymetric focusing, near coastal bathymetry (responsible for scattered values along Madagascar), and finally local conditions (including the effect of extensive reef structures, *e.g.,* in Mayotte and Zanzibar). Numerical simulations carried out using the MOST code (and limited to the high seas, excluding run-up on beaches) reproduce the main trends observed in the survey of the 2004 tsunami, *e.g.,* the large amplitudes in Somalia, and variations across the Comoro archipelago. We also consider as sources mega-thrust earthquakes along the Sumatra subduction zone that can be reasonably expected in the aftermath of the 2005 and 2007 events, including a release of the strain accumulated on the 1833 fault, but remaining after the 2007 rupture (A), and a source (B) extending the former to the Sunda Straits. While (A) is expected to be largely comparable to the 2007 tsunami (and thus benign assuming similar tidal phases at the receivers), (B) would have an expected impact comparable to the 1833 tsunami, and in particular greater than in 2004 in the Mascarene Islands and in South Africa.

Keywords: 2004 tsunami, Tsunami surveys, Tsunami Hazard, Tsunami Simulations, East Africa

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Analysis of the 2004 Sumatra tsunami records for the coast of South Africa

by
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Abstract

There were eight tide gauges on the coast of the Republic of South Africa (RSA) operating at the time of the 2004 Sumatra earthquake and all of them recorded the tsunami waves quite clearly. The tsunami waves arrived at the east coast of South Africa in approximately 11–11.5 hours after the earthquake; then the waves hit the south coast (12-13 hrs) and the west (Atlantic) coast (13hr 20min – 15 hrs). At all sites, the first tsunami wave was positive. The maximum wave height (2.7 m) was recorded at Port Elizabeth. Significant waves were recorded by tide gauges on the Indian Ocean coast of RSA: 1.5 m at Richards Bay; 1.3 m at East London; and 1.6 m at Mossel Bay. Maximum wave heights on the Atlantic coast were much smaller, diminishing to 0.75-0.9 m at Simmons Bay, Cape Town and Saldanha, and 0.5 m at Port Nolloth. A noteworthy feature of all records was the very long (> 4 days) ringing time. Several distinct wave trains with typical durations of 12 to 24 hr appear in the records apparently due to multiple wave reflections from continental boundaries, including the Antarctic coast, the coasts of south and southeast Asia, and Western Australia. The spectra for the South African records were similar to those for other Indian Ocean stations. The most common spectral peaks, observed at several sites and most likely related to the source properties, are: 13-14 min; 37-38 min; 40-43 min; and 48-55 min. Low-frequency peaks are evident at some sites, specifically, 1.8 hr at Cape Town and Port Nolloth, 2.1 hr at Port Elizabeth, and 2.6 hr at Saldanha. The time-frequency *f-t* diagrams indicate very long (~2.5 days) high-energy ringing of broad-band tsunami oscillations for all stations, except Richards Bay (~1.5 days), the RSA station closest to the source area. The estimated energy decay time mainly increases with distance from the source from 17.4 hrs and 17.5 hrs in Port Elizabeth to 24.9 hrs in Cape Town and 25.8 hrs in Port Nolloth. The maximum energy was found to be concentrated at periods between 30 and 55 min; the long-period oscillations were found to decay slower than short-period oscillations.

The Great Sumatra tsunami of 26 December 2004 as observed on the coast of Africa

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Abstract

The megathrust Sumatra earthquake of 26 December 2004 (M_w = 9.3) generated a major tsunami that destructively impacted coastal regions of the Indian Ocean. The death toll from these waves is estimated to be more than 226,000 from 13 countries, including African countries such as Somalia, Kenya, Tanzania and South Africa that border the Indian Ocean. This was the first global-scale tsunami to occur during the "instrumental era" and was clearly recorded by a large number of tide gauges throughout the World Ocean, including the east and south (Indian Ocean) coasts of Africa as well as areas in the Atlantic Ocean such as Ghana and the Canarian Islands that are far remote from the source region. The large number of observations available for the event enabled us to investigate the propagation and transformation of the tsunami in the open ocean and to examine tsunami characteristics for both the Indian Ocean and Atlantic coasts of Africa in terms of the relative influence of the source and topography on the arriving waves. The 2004 Sumatra event indicates high tsunami risk for some areas of the African coast and the necessity of establishing a precise sea level network along the entire coast of Africa to provide continuous monitoring of tsunami waves and other marine hazards.

The Bulgarian experience in the EU tsunami projects TRANSFER and SCHEMA

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ABSTRACT

The TRANSFER (Tsunami Risk ANd Strategies For the European Region 2006-2008) and SCHEMA (Scenarios for Hazard-induced Emergencies Management 2007-2009) European Projects are targeted to the advanced research of the tsunamis (their generation, propagation, impact, possible early warning systems and scenarios for the population and infrastructure protection, etc.) threaten European coasts. The Bulgarian team in close cooperation with the other partners of both projects is responsible to the study of the phenomena in the Black Sea. As a new member state of the EU, Bulgaria appears as a periphery boundary of the Union to the influence of tsunamis to the European coasts. Collection of information and its interpretation, the data incorporation to the common data base, modeling, worst case scenarios, possible influences to the vulnerable structures and facilities and many other tasks are among the investigated topics. A cooperation work with the team of the University of Bologna investigating the recent tsunami case of 7th May, 2007 affected the North Bulgarian Black Sea coast, modeling of the tsunami energy generation by underwater slides and propagation of the waves and sea level changes, models of the most dangerous seismic sources and assessment of their tsunamigenic potential are among the priority tasks under execution. The vulnerability assessment, the risk analysis, the measures against the impact of tsunami, the incorporation of the satellite images to the hazards and risk assessment, the multihazard approach and its quantification are among the rest part of the tasks of the ongoing projects. The cooperation with other EU partners (as Greece, Romania, France, etc.) leads to the high effective results to the present and ancient observations of tsunamis and their transfer to the recent scientific numbers and models. The main aims of these projects are to supply the decision makers and societies with the respective scientific tool to decrease the negative impact of the tsunamis to the European coasts. The results are published in many papers, journals and presented to the respective national and international scientific events – conferences workshops symposia, etc.

Key words: tsunamis, European cooperation, projects

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Historical and Palaeo-record of Tsunami in Southern Africa-A Review

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The historical record of tsunami along the southern African coast and their sources are reviewed. Because of the relatively short historical record of tsunami, the database should be extended by investigations of palaeotsunami in the stratigraphic record. No systematic work has yet been conducted along this coastline, but a suggestion of a large tsunami from a Holocene bolide impact along the Madagascan coast is critically examined. It was found that the evidence cited for this event may have a more mundane explanation. Further possible evidence of Pleistocene and Holocene tsunami along the southern African coast is also discussed.

Key words: tsunami; southern African coast; palaeotsunami; stratigraphic record.

Discussion on the tsunami induced by the El Asnam (Algeria) earthquake of 1980 based on numerical modelling.

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On the 10th of October 1980, the biggest African instrumentally recorded earthquake of magnitude Ms=7.3 occurred near the city of El Asnam (northern Algeria) at about 60km from the sea. Some historical data and principally Spanish tide gage records reveal the arrival of long waves tens of minutes after the earthquake on five locations along the southeastern coast of Spain (Solovyev et al, 2000). This tsunami has been generally associated to submarine turbidity currents generated during the quake and due to slope sediment instabilities on the Algerian Margin, with regard to the 1954 event located in the same area (El Robrini et al., 1985, Solovyev et al., 1992). Within the framework of the European project TRANSFER which aims at constraining tsunamigenic sources and hazard zones in the Mediterranean Sea more particularly, tsunami modellings have been conducted in order to correlate the observed waves with a so-inland earthquake. The first results (Roger et al., EGU 2008) were encouraging since the Okada's deformation calculus used in our modelling code is able to generate a mini-tsunami which can propagate and be recorded along the Spanish coast. Since then many tests have been conducted constraining fault parameters of the El Asnam earthquake with the help of the rich existing bibliography, keeping in mind the field analysis. We use the Gebco 1' world bathymetric dataset to propagate the waves and digitized nautical charts to model the high resolution grid (10 m) of the Alicante Harbour, which has been chosen to compare numerical model results to historical data. Calculated arrival times, polarity and wave amplitudes are in good agreement with recorded data, especially for the sea level gage located in the harbour. Finally we stress the fact that earthquake-related tsunamigenic sources, for ruptures located several tens of kilometers onshore, thus implying a very localized offshore rupture, should also be considered for tsunami hazard assessment.

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Recent tsunamis that affected the Japanese coasts and evaluation of JMA's tsunami warning

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ABSTRACT

During the last two years (Oct 2006 to Sep 2008), Japan Meteorological Agency (JMA) issued tsunami advisories or warnings for nine events. Tsunami estimations in the advisories or warnings are considered appropriate for seven cases. No tsunami was confirmed for the other two cases, one of which was thought to be a quite peculiar case.

The November 2006 and January 2007 Kuril earthquakes, for which tsunami warnings were issued on the Hokkaido coasts, impelled JMA to improve its methods in estimating tsunamis. The JMA magnitude (M) was larger for the 2007 earthquake than the 2006 event, but other magnitude scales as well as the observed tsunamis were smaller. The long duration of these Kuril tsunamis were due to reflected wave at Emperor seamount chain. These features have become to be considered in the current JMA's system.

The Noto-hanto earthquake (M 6.9) on March 25 in 2007 generated a small (<0.3 m) tsunami. Tsunami advisory (expected height ~ 0.5 m) was issued in less than 2 min of the earthquake. On April 20, tsunami advisory was issued following an earthquake near Miyakojima, but no tsunami was recorded. The JMA magnitude was 6.7, but the moment magnitude (Mw) was 6.3 (cf. Global CMT catalog). It is a difficult case to evaluate the magnitude accurately as this is islands region. On July 16, the Niigata-ken Chuetsu-oki earthquake (M 6.8) caused moderate tsunami without any damage; the amplitude was up to a few tens of cm at most tidal stations while one station located nearby the source region recorded 1m. JMA issued tsunami advisory within 1 min of the earthquake. On August 2, following a shallow earthquake off southern Sakhalin coast (Mw 6.2), JMA at first did not issue advisory or warning because the estimations did not exceed the criteria for advisory. But a sea level fluctuation was observed at a few tide stations on the Japanese coast, then, JMA issued tsunami advisory for the northern coast of Hokkaido. The post-event analysis showed that the sea level disturbances recorded at Rumoi does not match with the numerical simulation, hence considered as meteorological origin. On August 16, for the great earthquake (Mw 8.0) off Peru coast, JMA issued tsunami advisory, based on the tsunami numerical simulation and actual tsunami data in Hawaii. The tsunami heights recorded on tide gauges were 0.2 m or less in Japan.

On May 8, 2008, an earthquake off Ibaraki (M 7.0) occurred and JMA did not issue tsunami advisory. Instead, JMA issued a tsunami forecast, which informed that the maximum tsunami height would be below 0.2 m and that such tsunami would not cause damage. Some tide stations recorded very weak tsunami, around 0.1 m. On Juy 19, an earthquake (M 6.6) off Fukushima prefecture caused tsunami up to 0.2 m. On September 11, a large earthquake (M 7.1) occurred off Tokachi, very close to the 2003 Tokachi-oki earthquake (M 8.0), and generated tsunami up to 0.2 m. JMA issued tsunami advisory messages for these two events.

Key words: tsunami. Tsunami warning system, Japan Meteorological Agency

PRESENTER'S BIOGRAPHY

Prof. Satake received B.S. and M. S. in Geophysics from Hokkaido University, Japan, and Ph. D., also in Geophysics, from University of Tokyo in 1987. He then spent two years as a Postdoc at Seismological Laboratory of California Institute of Technology, and fives years as Assistant Professor at Department of Geological Sciences, University of Michigan. In 1995, after the Kobe earthquake which caused more than 6000 casualties in Japan, he returned home to perform geological studies of earthquakes and tsunamis. In the last twelve years, he had been studying earthquakes and tsunami using both geophysical and geological methodologies at the Geological Survey of Japan. In January 2008, he moved to Earthquake Research Institute, the University of Tokyo. Dr. Satake is currently chair of tsunami commission of IUGG (International Union of Geodesy and Geophysics).

Hazard assessment at Vishakapatnam due to a Tsunamigenic earthquake in the North Andaman region

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The North Andaman arc is an active subduction zone which had generated several destructive Tsunamis in the past. The recent 26 December 2004 Sumatra-Andaman earthquake of magnitude Mw~9.3 generated the most destructive tsunami experienced by the humanity and caused severe damage to life and property all along the east coast of India. In this paper we have modelled a possible scenarios of Tsunamigenic earthquake in the North Andaman region. Tsunami wave propagation and inundation at Vishakapatnam due to this earthquake has been modelled. We find that the tsunami run up heights is around 3 to 4 m. The inundated distances too have been estimated and are seen to be around 1 to 2 km.

Scenarios of tsunami impact in the town of Alexandria, Egypt

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ABSTRACT

The Mediterranean coasts of Africa are known to have experienced strong tsunami impacts in history, and the tsunami hazard assessment along these coasts has been receiving increasing interest in the last years. In this study we focus on the area around the town of Alexandria, Egypt and our main purpose is to provide preliminary estimations of tsunami hazard in Alexandria by making use of scenarios built upon historical information and far-field tectonic sources. Indeed, tsunami catalogues indicate that the tsunami hazard in the Alexandria area is mainly related to far-field tectonic sources, and in particular to different sectors of the Hellenic Arc and with the Cyprean Arc thrust zones. The tsunamigenic earthquakes occurred on July 21, 365 (estimated magnitude 8.3) and on August 8, 1303 (estimated magnitude 8.0) are the two most famous historical events producing relevant destruction in Alexandria. In the framework of the EU-funded project TRANSFER, we develop a number of scenarios constructed by taking into account earthquakes of variable magnitudes occurring along different sectors of the two major aforementioned thrust zones. The simulations are carried out by means of the finite-differences model UBO-TSUFD, developed and maintained by the Tsunami Research Team at the University of Bologna, Italy. The UBO-TSUFD code solves the non-linear shallow water equations, including the computation of run-up, on nested grids. The results will be analyzed in terms of maximum expected tsunami wave heights along the coasts in the Alexandria area, of tsunami propagation times and characteristic wave periods. This study is a first step towards a full tsunami risk assessment for the town of Alexandria, which appears to be an urgent task due to the relevant population and population density, as well as to the key economic and touristic activities taking place in the area.

Key words: tsunami scenarios, numerical modeling, Alexandria, Mediterranean.

PRESENTER'S BIOGRAPHY

Stefano Tinti is full professor at the Department of Physics of the University of Bologna, Italy. He is the chairman of the Intergovernmental Coordination Group for the North-East Atlantic, the Mediterranean and Connected Seas Tsunami Warning System (ICG/NEAMTWS). He has been the coordinator of the two European projects called GITEC (Genesis and Impact of Tsunamis on the European Coasts) and GITEC-TWO (Genesis and Impact of Tsunamis on the European Coasts-Tsunami Warning and Observations). He is presently the coordinator of the ongoing European Union project called TRANSFER (Tsunami Risk And Strategies For the European Region), involving 29 partners throughout Europe.

Tsunami Forecasting Framework

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ABSTRACT

Over the last 60 years, public awareness of the tsunami hazard has surged following each destructive tsunami. However, awareness subsided dramatically several years after the tsunami. A similar cycle takes place in tsunami science. Intensified scientific attention immediately after a destructive tsunami is followed by the slow, but continuous decrease in scientific activities years following the tsunami. Scientific effectiveness is decreased as many new researchers rush into studying tsunamis without contemporary knowledge of state of science. Many of the same scientists abandon tsunami science, as the funding opportunities decrease, resulting in new science rarely preserved for the next destructive tsunami. This cycle leads to inefficiencies in research, which ultimately impedes advances in tsunami science, critical for developing saving-lives strategies. Many regions, like Africa, are left completely unprepared to tsunami threat due to the rarity of such events in the region. The 2004 Sumatra tsunami demonstrated that rare catastrophic events could be devastating for the unprepared coastlines.

One approach to this dilemma is to consider a well-maintained, robust integrator of the tsunami science, which we term a "tsunami forecast framework". New regional forecast systems, with advanced measuring and modeling technologies, represent tsunami state of the science and can serve as an integrated repository of tsunami science. A forecast system can assess all tsunami events, expanding the geographic coverage and number of tsunamis analyzed. A forecast system can maintain, preserve and expand the database of tsunami data, modeling technology, and assessment tools for tsunami forecast and warning. Such a framework, representing the collection of data and tools, will help to verify existing methods and evaluate new models and measurement technologies. The framework could also serve as a testbed for evaluating new scientific discoveries that can be readily plugged into the existing forecast framework for verification testing and future use. When globally coordinated, such a framework could maintain tsunami resilience even for areas, where tsunamis are extremely rare and supporting of functional regional tsunami forecast is financially impractical. In short, the forecasting framework can preserve and use the state of tsunami science between destructive tsunamis, thereby increasing research efficiency and scientific advances.

The paper presents the concept and examples of forecast framework and tools and its potential and current use for tsunami forecast, real-time assessments and hazard analysis for Indian, Pacific and Atlantic coastlines.

Key words: tsunami, forecast, numerical modeling, real-time measurements

PRESENTER'S BIOGRAPHY

Vasily V. Titov is Chief Scientist of the NOAA Center for Tsunami Research, the joint operation of NOAA's Pacific Marine Environmental Laboratory and the Joint Institute for the Study of the Atmosphere and Ocean of the University of Washington. He is also Affiliate Assistant Professor of the Earth and Space Sciences of the UW. He received his Ph.D in Coastal and Ocean Engineering in 1997 at the University of Southern California. His undergraduate degree is in Mathematics from the Novosibirsk State University. He published more than 50 papers on the subject of tsunami modeling and forecast. He has developed the MOST model that is now being use for NOAA's tsunami forecast and for tsunami studies in many countries.

Secondary Tsunamis Induced by Submarine Slope Slumping Triggered by Earthquakes in Tropical Countries

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It is pointed out by Hatori(1994) that there is a tendency that the magnitudes of tsunamis in tropical countries such as Indonesia and Philippines are one grade larger than those in the Japanese sea area. It is suggested that in many cases of earthquakes accompanied with tsunamis in tropical countries tsunamis are not only induced directly by the earthquakes but also induced secondary by submarine landslides. We discuss such several examples:

On February 17, 1996, a huge earthquake (M8.1) broke out in the north sea region of Biak Island, Irian Jaya, Indonesia, and the accompanied tsunami hit both the north and the south coasts of Biak Island. At several villages on the south coast of the Islands, the initial wave hit only five minutes after the main shock, while the expected arrival time of the first wave of the tsunami was 50 minutes after it. In this case, it is also suggested that a secondary tsunami induced by a submarine slope sliding triggered by the shaking of the earthquake was generated and reached the villages on the south coast about 45 minutes before the arrival of the first waves of the tsunami induced by the crustal deformation by the main shock.

In June 15, 1998 an earthquake of magnitude 7.0 occurred in the sea area north off Aitape City on the northern coast of Papua New Guinea, and more than 2,000 people were killed due to the accompanied tsunami. Sea water rose up to 15 meters above the mean sea level. This event also such a case that the magnitude of the accompanied tsunami was too large for the magnitude of earthquake, and moreover tsunami arrival time to the coast was too late for the theoretically predicted one. It was pointed out that a huge submarine landslide was induced by the main shock and the main part of the tsunami was generated by the landslide and not by the earthquake itself (Tsuji, 2001). In those two cases the secondary tsunamis were larger than the first tsunamis, which were caused by the crustal motion of the sea bed.

Key words: secondary tsunamis, tsunami magnitude, tsunamis of tropical countries, sea bottom slumping

PRESENTER'S BIOGRAPHY

Born in 1947 at Nara, Japan

Graduated from the Civil Engineering course, Faculty of Engineering, University of Tokyo in 1969

Finished the master course of the geophysical division, faculty of sciences, University of Tokyo in 1971

Obtained the title of PhD. at the University of Tokyo in 1982.

Researcher of the National Research Institute for Disaster Prevention in the period 1972 to 1986.

Associate professor of Earthquake Research Institute, University of Tokyo from 1986 till now.

The Puerto Rico Seismic Network Earthquake and Tsunami Information and Warning System

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ABSTRACT

Puerto Rico, a US Commonwealth, has a population of almost 4 million people. In 1867 and 1918 local M 7.3 earthquakes generated tsunamis that impacted the Virgin Islands and eastern Puerto Rico and Western Puerto Rico, respectively generating significant loss of life and property. Currently, 43 of its 78 municipalities have people living and working in the tsunami inundation zones, as well as critical infrastructure.

The Puerto Rico Seismic Network (PRSN) of the Dept. of Geology of the University of Puerto Rico provides earthquake and tsunami information and warnings within its Area of Responsibility (AOR) which includes Puerto Rico (PR), the US and British Virgin Islands (VI) and Eastern Dominican Republic (DR). As of 2008 it is staffed 24/7. Currently, the PRSN operates 25 seismic and 7 tide/weather stations in PR, VI and the DR. With funding from the National Science Foundation (NSF), 6 high rate GPS instruments have also been installed to complement existing joint broadband and strong motion seismic stations. The performance criteria is that within 5 minutes of an earthquake or tsunami event that could impact its AOR, the PRSN will issue reviewed bilingual (Spanish/English) informational, and when appropriate, warning products. The PRSN is working with its regional and international partners for implementing a Caribbean Tsunami Warning System (UNESCO IOC ICG Caribe EWS) which includes the establishment of a Caribbean Tsunami Warning Center by 2010. As part of these regional efforts, data from over 50 additional seismic stations, 12 additional sea level stations and 6 DART buoys in the Caribbean and Adjoining regions are also monitored and exchanged.

In addition to the monitoring and warning operations, the PRSN, in partnership with the State and Municipal emergency management agencies and the NOAA National Weather Service, offers on and off site education and outreach services. Since 2005 the PRSN has directly impacted over 50,000 people in Puerto Rico and the Virgin Islands. It is supporting the at risk municipalities to meet the requirements of the NOAA Tsunami Ready program. As part of the TsunamiReady efforts, in addition to the outreach activities, tsunami evacuation maps are prepared and distributed, warning reception and dissemination capabilities are upgraded and tsunami protocols are developed. Special materials have been developed for K-12 education and the tourism sectors.

Key words: Puerto Rico, Tsunami, Earthquake, Warning, TsunamiReady,

PRESENTER'S BIOGRAPHY

Christa G. von Hillebrandt-Andrade is the Director of the Puerto Rico Seismic Network of the University of Puerto Rico at Mayagüez and also Associate Researcher of its Geology Department. Her B.Sc. in Geology is from the University of Delaware (1984), while she received her M. Sc. in Geological Engineering from the Escuela Politécnica Nacional, Quito, Ecuador (1989). She currently chairs the Working Group I, Monitoring and Detection Systems and Warning Guidance of the UNESCO IOC ICG Caribe EWS, is Member of the Advisory Committee of the Caribbean Regional Association for the Caribbean Integrated Coastal Ocean Observing System (CARA) and a Director of the Seismological Society of America. Her publications and scientific and educational presentations focus on earthquakes and tsunamis in Puerto Rico and the Caribbean. She currently has funding from NOAA, the Government of Puerto Rico, USARCORP and NSF for earthquake and tsunami monitoring, warning and education and outreach activities.

Tsunami Hazard for Guadeloupe (French West Indies)

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Detailed analysis of historical data of tsunamis in the past 500 years in Guadeloupe (FrenchWest Indies), collected in different books, papers and sites is given. Totally, 11 events are selected as true and almost true. 7 tsunami events have been generated by the underwater earthquakes; 3 events - by the volcano eruptions, and one is a teletsunami. The geographical and temporal distributions of tsunami events are studied and some numerical simulations are presented. Numerical simulation of several historical tsunamis in the Caribbean Sea (1755 Lisbon trans-Atlantic tsunami, 1867 Virgin Island earthquake tsunami, 2003 Montserrat volcano tsunami) are performed within the framework of the nonlinear-shallow theory. Numerical results demonstrate the importance of the real bathymetry variability with respect to the direction of propagation of tsunami wave and its characteristics. The prognostic tsunami wave height distribution along the Caribbean Coast is computed using various forms of seismic and hydrodynamics sources.