
OS13A CC: 520 F Monday 1330h

Tsunamis

Presiding: **E Pelinovsky,** Institute of Applied Physics, Russian Academy of Sciences**; A Yalciner,** Middle East Technical University

OS13A-01 1330h

Predicted Tsunami Heights and Currents in Vancouver Island Harbours Caused by a Future Cascadia Subduction Zone Earthquake

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The 1700 great Cascadia earthquake (M=9) generated widespread tsunami waves that affected the entire Pacific Ocean and caused damage as far as Japan. Similar waves may be generated by a future Cascadia earthquake. We use several plausible rupture scenarios in numerical ocean model experiments to predict tsunami heights and currents in Vancouver Island harbours caused by such an earthquake. These scenarios include the rupture of the entire 1100-km length of the Subduction Zone and separate rupture of smaller northern and southern segments. We present the tsunami model results for several harbours including Victoria and Esquimalt harbours for these three scenarios. As expected, the more remote (southern) earthquake has a limited effect in the harbours. However, the other two scenarios produce very significant waves (up to 4.5 m) and strong currents (exceeding 10 knots) in Victoria and Esquimalt harbours that are located inside the Juan de Fuca Strait. The same models indicate that tsunami waves can exceed 10 m and currents can be at least twice as strong in various bays and harbours on the outer coast.

OS13A-02 1350h

Tsunami Generated By the Volcano Eruption On July 12-13, 2003 At Montserrat, Lesser Antilles

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Soufriere Hills Volcano, Montserrat, Lesser Antilles, has been undergoing a lava dome forming eruption since 1995. A major collapse of the dome occurred on 12-13 July 2003 and was accompanied by explosive activity. This was the largest dome-collapse to date at Soufriere Hills Volcano. The collapse was a prolonged event. Continuous pyroclastic flows began in the Tar River Valley on the eastern side of the volcano at 09:30 local time 12 July. From 10.45 onwards these reached the sea and at 18:30 the flows became larger and more energetic as the collapse progressively cut back into the hotter interior of the dome. The collapse reached its most energetic phase between 21.50 12 July and 0.50 13 July when a sequence of very large pyroclastic flows entered the sea and pyroclastic surges traveled up to 3 km across the surface of the sea. The climax of the collapse occurred at 23.35 when a very large pyroclastic flow impacted the sea and pyroclastic surges devastated 10 km^{2}2 on the NE flank of the volcano. A number of explosive events took place during this collapse, with the largest occurring at 23.52, which produced ash clouds to a height of 15 km. Various photos of this event can be found in the website of the Montserrat Volcano Observatory (http://www.mvo.ms). A field survey of the coastal area was conducted after the event by the staff of the Montserrat Volcano Observatory. A strandline of charred trees and other floating objects was found on the coast at Farm Bay (16.45'N, 62.09'W). The strandline is located about 100-200 m from the shoreline at a height of 4 m above sea level (eye estimates) approximately 2-4 km north of the mouth of the Tar River Valley where the pyroclastic flows impacted the sea on 12-13 July. Cyclone activity was high in September 2003 (Hurricanes Fabian and Isabel) and the strandline of charred trees may have resulted as from a tsunami related to the dome-collapse, as well from a storm surge. Taking into account the local character of this phenomenon, the tsunami origin is preferable. A tsunami was recorded in Guadeloupe (50 km south from Montserrat). According to witness reports, the tsunami wave arrived at Deshaies (northern part of Basse Terre Island) between 23.00 12 July and 0.01 13 July and scattered the boats near the mouth of the Deshaies River. The wave height is estimated to have been 0.5-1 m. The data of field surveys in Montserrat and Guadeloupe will be presented. The results of preliminary numerical simulation of tsunami propagation will be given also.

URL: http://www.mvo.ms

OS13A-03 1405h

Estimation of Tsunami Risk for the Caribbean Coast

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The tsunami problem for the coast of the Caribbean basin is discussed. Briefly the historical data of tsunami in the Caribbean Sea are presented. Numerical simulation of potential tsunamis in the Caribbean Sea is performed in the framework of the nonlinear-shallow theory. The tsunami wave height distribution along the Caribbean Coast is computed. These results are used to estimate the far-field tsunami potential of various coastal locations in the Caribbean Sea. In fact, five zones with tsunami low risk are selected basing on prognostic computations, they are: the bay “Golfo de Batabano” and the coast of province “Ciego de Avila” in Cuba, the Nicaraguan Coast (between Bluefields and Puerto Cabezas), the border between Mexico and Belize, the bay “Golfo de Venezuela” in Venezuela. The analysis of historical data confirms that there was no tsunami in the selected zones. Also, the wave attenuation in the Caribbean Sea is investigated; in fact, wave amplitude decreases in an order if the tsunami source is located on the distance up to 1000 km from the coastal location. Both factors wave attenuation and wave height distribution should be taken into account in the planned warning system for the Caribbean Sea. Specially the problem of tsunami risk for Lesser Antilles including Guadeloupe is discussed.

OS13A-04 1420h

Analysis of the Peruvian tsunami of June 23, 2001 recorded in the Pacific Ocean

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On June 23, 2001 a magnitude Mw = 8.4 earthquake occurred off the coast of southern Peru. This earthquake generated a widely distributed tsunami, which was recorded along much of the Pacific coast, including South America, Hawaii, and Japan. Most of energy of this tsunami propagated toward the westsouthwest in the direction of New Zealand and Australia; however, a portion of the energy also traveled poleward (to the north and south) along the American coast and, in particular, was recorded in California, Oregon, British Columbia and Alaska. High-quality records from different coastal locations enable us to examine the spectral parameters of the tsunami in detail. The general concept is that by comparative analysis of the event and the background spectra we can separate the source and topographic effects, and estimate the frequency distribution of the waves propagating along the shelf and across the ocean. The Peru tsunami source function' was associated with frequency bands: 0.01-0.2 cpm (periods 5-100 min) with peak values at 0.035-0.1 cpm (10-30 min). Remarkably, the reconstructed spectral characteristics of the source, based on measurements from opposite sides of the ocean, are in good agreement.

OS13A-05 1435h

Longterm tsunami forecasting and risk estimation for the coasts of Peru and northern Chile

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Data for all known tsunamigenic earthquakes and observed tsunami run-up from the Expert Tsunami Database for the Pacific (ETDB) are used to estimate tsunami risk for the coasts of Peru and northern Chile for zones bounded by 0° to 35°S latitude. Tsunamigenic earthquake estimates yield magnitudes of 8.52, 8.64, and 8.73 for return periods of 50, 100, and 200 years, respectively. Earthquake-based tsunami run-up and return periods are compared with those calculated from the National Geophysical Data Center Tsunami Database (NGDC), as well as with the other independent estimates. The problem of local tsunami-zoning is examined using a stochastic model for tsunami run-up distribution along the coastline.

OS13A-06 1450h

The Source Mechanism of 1939 Black Sea Tsunami

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The Black sea is surrounded by Turkey at South, Bulgaria, Romania and Moldovia at west, Russia and Ukraine at North, Georgia at East. The Great Erzincan Earthquake occurred on December 26, 1939 at 23:57 (GMT) in Turkey. This earthquake is remarkable not only because of its devastating casualties (39000), but also because of the tsunami generation in the Black sea [Richter, 1958]. The recorded epicenter coordinates (39.51oE, 39.80oN) was on land and approximately 60 km away from the south coast of the Black sea. The earthquake was shallow (26 km). The surface magnitude was 8 (maximal value for tsunami-generic earthquake in the Black Sea), and intensity of the earthquake was 11-12 [Nikonov, 1997]. Tsunami waves were observed at south coast of the Black sea near Fatsa, Ordu and Giresun towns in Turkey and recorded at North coast near Sebastopol, Yalta, Novorossiysk, Tuapse, and at East near poti and Batumi. The sea receded 50m, and then advanced 20m near Fatsa town. The sea also receded 50-60 m in Giresun, moreover in Ordu, the eyewitnesses at the harbor observed that sea initially was calm, then receded about 15 m. and returned its original position in 5-10 minutes [Altýnok and Ersoy, 2000]. The tsunami crossed the Black Sea and was recorded on tide-gauges in Soviet harbors with height 50 cm in Sevastopol and Novorossiysk, and 40 cm in Tuapse. The intensity of this tsunami can be considered as intensity III-V according to new tsunami intensity scale of [Papadopoulos and Imamura, 2001]. Since the epicenter of the earthquake is far from the sea, the source mechanism of this tsunami is uncertain. The wave might have originated by either directly from rupture, or by the secondary fault in the Black sea, or by a submarine landslide triggered by the earthquake. The available data of tide gauge measurements, and observations can be used to compare the model results with different source mechanisms and initial conditions. The initial wave with different assumptions of source mechanisms for 1939 event are used in simulation. The arrival times of the tsunami waves, the initial sign of the wave form, the wave period and the nearshore tsunami amplitudes are computed at selected coastal stations. The computed tsunami records at the coastal locations are compared with the available data. The comparison of the observational, instrumental and numerical data at the shore locations are used for analysis and comparison of the assumed source mechanisms. The probable source mechanism of 1939 Black sea Tsunami is also discussed. Altýnok, Y. and Þ. Ersoy (2000), Tsunamis observed on and near the Turkish coast. Natural Hazards, 21, 185-20. Nikonov, A. A. (1997), Tsunami occurrence on the coasts of the Black Sea and the Sea of Azov. Izvestiya, Physics of Solid Earth, 33, 72 - 87. Papadopoulos, G.A. and F. Imamura (2001), A proposal for a new tsunami intensity scale, Proceedings of International Tsunami Symposium 2001, Seattle, Washington, Aug. 7 -10, 2001, 569- 577. Richter C. F. (1958), Elementary Seismology, W. H, Freeman and Co., San Francisco, California, 1958

OS14A CC: 520 F Monday 1530h

Tsunami and Rogue Waves

Presiding: **E Pelinovsky,** Institute of Applied Physics, Russian Academy of Sciences**; E A OKAL,** Northwestern University

OS14A-01 1530h INVITED

M-TSU : From tsunameters to earthquake source

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We use tsunami records obtained by ocean-bottom "tsunameters" of the DART project to relate tsunami amplitudes on the high seas to the source of major earthquakes around the Pacific rim. Our approach is derived from the concept of mantle magnitude M sub m, developed by Okal and Talandier [1989], and exploits the possibility of working directly with tsunami signals on the high seas, unaffected by the later interaction of the wave with coastlines. Through a modification of the M sub m algorithm, we develop a tsunami magnitude M sub TSU, whose calculation is supported theoretically using normal mode theory. We analyze records of tsunamis from several major earthquakes including the 1994 Shikotan (Kuriles) and 2003 Rat Island events. We find that acceptable estimates of their seismic moments can be derived from tsunami spectral amplitudes at periods > 700 seconds. We are presently expanding this analysis to an enlarged database of records covering the past 10 years.

OS14A-02 1550h INVITED

Tsunamis and Tsunami Prone Mechanisms in Eastern Mediterranean

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There are numerous earthquakes and tsunamis that occurred in eastern Mediterranean and are documented in historical records. The fault zones around eastern Mediterranean basin are Hellenic Arc, North Anatolian Fault Zone (NAF), East Anatolian Fault Zone (EAF), Cyprus Arc, and Dead sea Fault. Hellenic Arc is a subduction zone of about 1000 km in length. It is the most active seismic region in Europe containing active volcanoes in historic times. The Hellenic Arc starts from the Peloponnesus passes from the south of Crete Island, goes at east side of Rhodes Island end enters mainland Anatolia around Dalaman. It has a roughly circular shape. The deepest region of the Mediterranean Sea is in between Rhodes and Dalaman near Hellenic Arc. The deepest region lies as a trench with the depth more than 4000 m depth, at the coordinates 28.7 oE, 35.7 oN, and with the size of 80 km in E-W direction and 60 km in S-N direction. At the centre of the Aegean sea there is a series of volcanic systems almost parallel to the trench and forming the internal arc (Milos, Antimilos, Antiparos, Santorini, Christiana, Colombus, Kos, Yali, Nisiros, etc). The North Anatolian fault is more than 1000 km-long, strike-slip fault. It starts near Erzincan Karliova, is roughly parallel to the Black Sea coasts towards W, enters the sea of Marmara at Izmit Bay and splits two branches. South branch lies at south of the sea of Marmara, North branch passes along the sea of Marmara towards Aegean sea. The East Anatolian Fault Zone starts near Karliova and goes to South and splits two Branches as Amonos Fault and Misis Fault. The Cyprus Arc starts in the Antalia Gulf and develops towards Cyprus. The link between the Cyprus and the Hellenic Arc and the link between the Cyprus Arc and EAF is still not described. The Dead Sea fault is a strike slip fault running in a N-S direction from the termination of the East Anatolian fault to the Red Sea. There are numerous earthquakes along the Dead Sea fault, but they recently do not exceed magnitude 4. The stronger earthquakes are more rare and always have magnitude lower than 6 and are mainly concentrated in the most internal zone of the Aqaba Gulf. In this study, the data about historical earthquakes, the distribution of their epicenters, the historical tsunamis in the eastern Mediterranean are presented. The fault zones, volcanic activities, probable submarine landslides, and their relation to the earthquakes and tsunamis are examined. The source areas and source mechanisms of historical tsunamis are analyzed. The probable source areas, expected source characteristics and tsunami prone mechanisms in eastern Mediterranean are discussed.

OS14A-03 1605h

Ocean-Scale Tsunami Propagation: Boussinesq Approximations.

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Tsunamis propagating over trans-oceanic distances can be significantly modified by effects of frequency dispersion, leading to (among other effects) alteration of wave fronts and wave packets, and changes in spatial distribution of wave energy due to alteration of ray patterns over complex bathymetry. In this presentation, we describe the theory and implementation of an ocean-scale tsunami propagation model in the Boussinesq approximation. The work focuses on the usual weakly dispersive, weakly nonlinear formulation of the classical theory. Working in spherical polar coordinates, we introduce a parameter which characterizes a horizontal wave packet length scale, leading to an aspect ratio which characterizes dispersion effects. Boussinesq equations are then obtained from the Euler equations with rotation included. Although the spherical coordinate model is aimed mainly at basin scale propagation problems, we describe an extension retaining several aspects of the formulation which would be more appropriate to local wave evolution either near the source or in the final runup stage, in order to obtain a more unified model. These effects include a representation of bottom motion, and a fully nonlinear treatment of surface conditions in order to represent large runup amplitudes during inundation. Numerical implementation of the code is described, and we discuss several examples of idealized and real-world applications.

OS14A-04 1620h

Freak Waves as a Result of Modulational Instability

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We have studied numerically the development of modulational instability for stationary propogating Stokes waves of a moderate magnitude, ($k_a = 0.15$), on a deep water. The spectral code method was applied to exact one-dimensional hydrodynamic equations, which describe the porential flow of an ideal fluid with free surface; this surface was conformlly mapped to the half plane. The equations were solved in a box with periodic boundary conditions containing as much as ten lengths of the leading wave. The total amount of spectral modes were varied between $3 \cdot 10^4$ to $1 \cdot 10^6$. In the initial moment of time, the exact Stokes wave was modulated by a small long scale perturbation. As a result, we observed an exponential growth of modulation, which was leading to the formation of a single freak wave. The freak wave grew up to the limiting amplitude of ($k_a \sim 0.45$); then, it demonstrated a tendency to an explosive formation of singularity.

OS14A-05 1635h

Model Simulations of Waves in Hurricane Juan

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Hurricane Juan made landfall at 0300 UTC near Halifax Nova Scotia. This was a category 2 hurricane with winds of 44 m/s, the largest storm to pass over these coastal areas in several decades. Associated high ocean waves were experienced in coastal waters, from Peggy's Cove to Sheet Harbour, growing to epic proportions on the Scotian Shelf, and exceeding the 100-year return wave based on the present climatology. As part of the GoMOOS program (Gulf of Maine Ocean Observing System, www.gomoos.org), winds from the USA Navy COAMPS (Coupled Ocean Atmosphere Model Prediction System) were used to evaluate and compare three widely-used third generation numerical wave models, SWAN, WAM and WaveWatch-III (hereafter WW3) for accuracy, with in situ measurements. Model comparisons consist of a set of composite model systems, respectively nesting WAM, WW3 and SWAN in WAM and WW3. We report results from the intermediate-resolution grid for Hurricane Juan. Wave measurements were made using four operational deep-water buoys (C44258, C44142, C44137, 44005), by a conventional directional wave rider (DWR) moored offshore from Lunenburg Bay, and also by two acoustic Doppler current profiler (ADCP) located (1) near an oil rig on Sable Island Bank, in relatively shallow water, and (2) near the outer boundary of Lunenburg Bay. We discuss the reliability of DWR wave data compared to ADCP wave data. We show that all models provide reliable hindcasts for significant wave height (Hs) and for peak period (Tp) for Juan, although a clear underestimation of Hs at the peak of the storm is evident, compared to observations. A feature in the COAMPS storm simulation is that the storm track appears to be slightly to the east of that of Quikscat scatterometer data. Comparisons between models and 2-dimensional wave spectra are presented. Preliminary results suggest that the recently released upgrade to the WW3 model shows slightly enhanced skill compared to the other models.

OS14A-06 1650h

Freak Waves: Physical Mechanisms And Experimental Data

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A review of physical mechanisms of the rogue wave phenomenon is given. The data of marine observations as well as laboratory experiments are briefly discussed. They demonstrate that freak waves may appear in deep and shallow waters. Simple statistical analysis of the rogue wave probability based on the assumption of a Gaussian wave field is reproduced. In the context of water wave theories the probabilistic approach shows that numerical simulations of freak waves should be made for very long times on large spatial domains and large number of realizations. As linear models of freak