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Instead, account must be taken of the potential for locally generated, essentially aseismic tsunamis; triggering of a warning system by anomalous tide gauge activity must be included in any warning system protocol. Other methods of evaluating and monitoring volcanic activity with potential to generate tsunamis will be discussed.

Emergent Tsunami Warning System for Puerto Rico and the Virgin Islands

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U.S. territories have been affected in recent history by two catastrophic tsunamis. On November 18, 1867, a MS 7.3 earthquake occurred in the Virgin Islands basin (MM VIII) which generated a tsunami with heights of 20 feet in Charlotte Amalie, USVI. On October 11, 1918, western Puerto Rico was affected when a tsunami with wave heights of up to 20 feet was generated by a 7.3 MS local earthquake (MM VIII–IX). Other tsunami sources have also been identified in the region.

Since 1993 meetings have been held, research has been carried out, projects have been funded, and proposals have been written to address this "forgotten hazard." As part of these efforts a tsunami warning system is emerging for the region. Protocols for responding to a tsunami emergency have been established by the Puerto Rico Seismic Network (PRSN), the U.S. National Weather Service (NWS), and the PR and VI Emergency Management Agencies. The IOCARIBE Group of Experts, the Pacific and Southern Regions of the USNWS, and the Pacific and West Coast/Alaska Tsunami Warning centers (PTWC and WC/ATWC) have also been actively involved. Seismic data and information, as well as the perceived ground shaking, are used to determine when a tsunami bulletin needs to be issued. For rapid determination and dissemination of earthquake parameters, the PRSN has developed programs as well as adapting others of the WC/ATWC (Early Bird; Whitmore, 2002). As a backup, and for regional and teleseismic tsunamis, protocols and procedures with NEIC, PTWC, and WC/ATWC are being prepared. Sea-level data and other tsunami scenarios need to be incorporated into the system. As a critical component, education, emergency response capabilities, and the characterization of the hazard are also being addressed. We believe that this emergent system will also benefit and can be expanded to include the wider Caribbean region.

The 1867 Tsunami at the Virgin Islands: Observations and Simulations

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The 1867 Virgin Island tsunami had a great effect on the Caribbean islands. A maximal tsunami height of 10 m was recorded for two coastal locations (Deshayes and Sainte-Rose) in Guadeloupe. The historical data of this event for the Caribbean Sea are discussed. The modeling of the 1867 tsunami is performed in the framework of the nonlinear shallow-water theory. Several possible locations of the tsunami source in the Anegada Passage between St. Thomas and St. Croix are examined. According to calculations the waves would be significant on the Virgin Islands and Puerto Rico (in almost the epicentral area), Antigua and Guadeloupe in the northern Lesser Antilles islands, and Grenada and Grenadines in the southern Lesser Antilles islands. Results of numerical simulations are in good agreement with available historical data.

New Procedures and Criteria for Tsunami Warnings in the Pacific

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The Richard H. Hagemeyer Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii will soon implement new procedures and criteria for issuing tsunami warnings in the Pacific. They are (1) magnitude criteria will be based on Mw rather than Richter Ms; (2) the threshold for issuing an expanding regional warning and watch will be raised from Ms greater than 7.5 to Mw greater than 7.8; and (3) a nonexpanding regional warning will be issued for Mw greater than 7.5 but less than or equal to 7.8. Mw for initial bulletins will be based on computations of Mwp. This will significantly reduce the elapsed time between earthquake origin and the initial tsunami bulletin since P waves travel to surrounding stations much faster than surface waves. Raising the expandin varn-ing/watch threshold from 7.5 to 7.8 will reduce the incidence of false larms while still providing a safety margin for any significant teletsunamis. A ing a fixed regional warning will catch many local/regional tsunamis withou over-warning.

Estimated Energy-to-moment Ratios Computed Routinely at PTWC: T ard a Routine Discriminant for Tsunami Earthquakes

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We present results of the calculation of energy-to-moment ratios fo arge teleseismic events at the Pacific Tsunami Warning Center, using the forn lism of Newman and Okal (1998). We seek to identify on a routine basis, an also in quasireal-time, the so-called "tsunami earthquakes", characterized by a on-ger tsunami excitation than expected from conventional magnitudes. The lgo-rithm is based on computing E^E, the estimated energy radiated into the P ave group, and theta = $\log_{10}(E^E/M_0)$. Tsunami earthquakes were found by Ne nan and Okal to feature a deficiency of 1 to 1.5 log units with respect to the a age value, theta = –4.9, predicted by seismic scaling laws.

For each event, individual values of theta, computed systematicall t a dozen stations, can be strongly scattered, but their average over stations ap ars robust. Most events fall between –4.5 and –5.5, with a mean value of –4. in excellent agreement with the data set studied by Newman and Okal. Also nd most importantly, no trend is found between theta and moment, which n-firms that theta is invariant with earthquake size; neither can we define a ear regional trend in theta values.

The Peruvian earthquake of June 23, 2001 is an interesting example f a complex event, which started with a very slow precursor, slowly buildin up moment release. An algorithm limiting the computation to the first 70 sec ds of source would give a deficient theta value of –6.4, while the inclusion o he main episode of strain release increases theta to –5.5, which expresses no r re than a trend toward slowness, as documented in other studies of this event.

The routine calculation of theta could be automated and this vari le should help provide additional insight into the difficult real-time proble of detecting and defining "tsunami earthquakes."

Far-field Tsunami Forecast Guidance Tools

GONZALEZ, F. I., TITOV, V. V., MOFJELD, H. O., NEWMAN, J. C., VENTURATO, A. J., EBLE, M. C., and DANTSKER, A., NOAA Center r Tsunami Inundation Mapping Efforts (TIME), Pacific Marine Environmen l Laboratory, Seattle, WA, 98115, frank.i.gonzalez@noaa.gov

The U.S. National Tsunami Hazard Mitigation Program (NTHMP) is led y the National Oceanic and Atmospheric Agency (NOAA), in partnership w 1 the U.S. Geological Survey (USGS), the Federal Emergency Managem t Agency (FEMA), and state agencies of Alaska, California, Hawaii, Oregon, a l Washington. A primary goal of the NTHMP is improvement in the speed, r -ability and utility of tsunami warnings. The NOAA Center for Tsunami In -dation Mapping Efforts (TIME) at the Pacific Marine Environmen Laboratory (PMEL) conducts R&D in support of this goal, in collaborati with NOAA's Tsunami Warning Centers (TWC's) and researchers and em gency managers in the five partner states.

Tools to provide operational forecasts of shoreline tsunami height a inland inundation are currently under development. The overall strategy is combine tsunami model simulations with real-time seismic data and tsuna observations acquired by NOAA's coastal tide gages and DART (Deep-oce Assessment and Reporting of Tsunamis) network through data assimilation a inversion methods.

There are significant challenges in meeting TWC operational requir ments—speed, accuracy, and user interfaces that provide guidance that is ea to interpret. Prototype tools have been tested, using historical tsunami dat The method, tools, test results, and operational implementation plans will b discussed.

Use of Hydrophones for the Detection of Submarine Landslides

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Submarine landslides have long been underappreciated as a source of tsunami. Recent studies of the 1998 tsunami in Sissano Lagoon (Papua New Guinea) and the 1946 Unimak Island (Alaska) tsunami have instigated a renewed interest in

this topic, as well as significant debate over the tsunamigenic capacity of submarine landslides. A lingering problem, however, is detection of these events. Landslides can occur with or without an accompanying earthquake and may occur in regions where earthquakes are uncommon and tsunami are not expected. Furthermore, such events may not generate a significant seismic signal, so they may not be identified in the seismic record. Hydroacoustic data collected by the Hawai'i Undersea Geo-Observatory (HUGO) and the Pacific Marine Environmental Laboratory (PMEL) show that submarine landslides can be detected at distances up to 5,000 km and can be easily distinguished from other acoustic signals such as earthquake T phases and biological noise. The landslides recorded by HUGO and PMEL are generated at the site where lava flows into the ocean at Kilauea volcano and occur up to ten times per day. The smallest Kilauea landslides generate hydroacoustic signals lasting 1–2 minutes, while the largest events may last for hours. Although hundreds of events were detected by HUGO, only the largest were also detected by the land-based seismic network operated by the Hawaiian Volcano Observatory, suggesting that hydrophones are particularly effective in monitoring these events. Landslide signals are found to be rich in high frequencies (20–1,000 Hz) and consequently are best identified when data are collected at high sample rates. The fact that signals are detected at great distances suggests that hydroacoustic detection of landslides could be a powerful tool in tsunami monitoring and modeling efforts.

A Comparison of Near-shore Tsunami Sources Offshore of Los Angeles and Orange Counties in Southern California

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The region offshore of metropolitan southern California is assessed to identify potential tsunami sources. Several tsunami sources have been identified including near-shore strike-slip and oblique-slip faults, submarine landslides, and uplifted areas associated with restraining bends on large strike-slip faults. The Method of Splitting Tsunami (MOST) model, a fully nonlinear shallow-water simulation with a moving shoreline algorithm, is then used to predict water motions and runup along the shoreline. The best avaliable topgraphic and bathymetric data were combined to produce a 3 arcsec (approx 100 m) computational grid, which is used in this study.

The results of the model show distinct difference in the runup signature between the different source models. Landslide-generated tsunamis create a narrow peaked distribution, while the near-shore seismic cases are much more regional in their effect with a wider, lower distribution. Results are also compared between different seismic cases where fault slip is distributed across several fault segments. When the computed runup is normalized by the amount of uplift, seismic sources across a range of sizes can be compared directly. Furthermore, plots of the normalized runup indicate areas that are susceptible to enhanced runup due to amplification and focusing.

Reconciling Source Areas Determined from Aftershock and Tsunami Data: The M 8.1 1952 Tokachi-Oki Earthquake along the Kuril Subduction Zone

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Tsunami records from the 1952 Tokachi-Oki earthquake (M 8.1) along the southern Kuril subduction zone are reexamined to determine the relationship between earthquake source regions derived from tsunami data and aftershock distributions. Using tsunami travel times alone, the previous estimate of the source region for this earthquake did not coincide with the aftershock distribution. The different source regions left unclear whether there is a continuing seismic gap between the 1952 rupture and rupture of a M 7.4 earthquake in 1973 which occurred along a segment adjacent to the 1952 rupture. In this study, the slip distribution for the 1952 earthquake is obtained by inverting 13 tsunami waveforms recorded in Hokkaido and Honshu. Our results demonstrate that the tsunami inversion yields a more accurate estimate of the earthquake source area, in agreement with the aftershock distribution, than estimates using only tsunami travel times. The stress-drop distribution is derived from the slip distribution using a depth-dependent rigidity function. Most of the aftershocks occurred in regions where the stress drop was lower than 4 MPa during the mainshock. Tsunami inversion results also indicate that a large amount of slip occurred east of the previously determined tsunami source area, suggesting that a portion of the interplate thrust near the trench ruptured during the mainshock. We also found >5 m of slip along the deeper part of the seismogenic interface, near an onshore region of high observed seismic intensity. This region, which also has the largest stress drop during the mainshock (19 MPa), had very few aftershocks. The revised tsunami source area is estimated to be about three times larger than the previous tsunami source area. Out of four large earthquakes with M~7 that occurred between 1952 and 1973, three were at the edges of regions with low slip during the 1952 event.

Thursday AM, 1 May 2003—San Gerónimo C
Seismic Safety of Dams
Donald Yule, Luis Suarez, and Lloyd Cluff

Comparison of Tectonic and Reservoir-induced Seismicity: Southern California and Northeast Brazil

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We compare small earthquakes occurring in two very different environments to investigate how variables such as depth and loading influence source processes. Small earthquakes (M < 3) are important as they bridge the gap between laboratory measurements of stick-slip sliding and large damaging earthquakes, and provide insights into the nucleation of unstable slip. Abercrombie and Leary (1993) noted that induced earthquakes appear to have lower average stress drops than tectonic earthquakes. We compare well studied earthquakes recorded at depth in the Cajon Pass borehole, southern California, with recordings of small earthquakes (M < 2.5) induced by varying water level in the Açu reservoir in northeast Brazil. The shallow depth of the reservoir-induced earthquakes (< 3 km), the short source-receiver distances (< 5 km), and the high Q of the Precambrian basement rock allowed high-frequency energy to be recorded by a dense surface network. The shallow depths also contrast with the depths of 10–20 km for the southern California earthquakes. An eight-station network at Açu recorded over 300 earthquakes beneath the reservoir between 1994 and 1997. They locate on northeast-trending faults and are consistent with strike-slip motion on these faults. Nascimento (2002) used a 3D groundwater flow model to show that the spatial and temporal distribution of seismicity is consistent with pore fluid migration on a small number of highly permeable fault structures. We use relative relocation methods to improve the resolution of the seismicity. We also calculate source parameters for these earthquakes using individual and relative methods. We compare our results with the deeper southern Californian seismicity to determine whether there are any significant differences in stress drop and energy radiation.

Seismic Analysis of Gravity Dams: The Effect of Valley Shape on Dam-reservoir Response

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Two special issues on the seismic response of gravity dams due to both the shape of the canyon and to the existing gaps between monoliths at the transverse contraction joints are discussed. One of them, associated with the 3D effects of the dam-reservoir system of the structurally independent monoliths while responding and interacting with the reservoir in the direction normal to the dam axis, is amenable to numerical analysis. The case of the Piedra del Aguila Dam, a gravity dam located in the southwest of Argentina with a maximum height of 170 m over the foundations, is presented and discussed. It is shown that in this case the shape of the valley produces significant amplification of the seismic response of the tallest monolith, as compared to an analysis carried out of the same monolith modeled as a plane dam-reservoir system.

The other effect to be discussed in the presentation is associated with the seismic response along the dam axis that leads to opening and closing of the gaps between the dam monoliths due to the variation of their flexibility within the valley cross-section. This effect may produce interactions and contacts between the adjacent monoliths that oscillate with different frequencies. To the authors' knowledge, such behavior, which is expected to be strongly nonlinear, has yet to be evaluated for this type of dam either by means of numerical models or by any other method of analysis.