TSUNAMI HAZARD ASSESSMENT USING SHORT-TERM INUNDATION FORECASTING FOR TSUNAMIS (SIFT) TOOL

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1. Introduction

The coastal areas of maritime nations have major socio-economic importance with their high population densities and important infrastructure. The 2004 Sumatra tsunami showed how a single devastating natural coastal hazard could easily put a toll on human life and economy of the affected nations. It emphasized the need for both advance planning and real-time operational forecast capability in order to mitigate losses in future events.

The NOAA Center for Tsunami Research has developed an operational tool called Short-term Inundation Forecasting for Tsunamis (SIFT) that can assimilate measurements of propagating tsunami wave trains, identify threatened regions, and set in progress numerical models that provide reliable real-time forecasts of the impact of the tsunami on specific coastal areas. While devastating events such as Sumatra 2004 are rare, the SIFT system also provides a capability for warning cancellation. This is a valuable service which can avoid the expense and loss of public confidence associated with unnecessary evacuations.

Underlying SIFT is a database of pre-computed tsunami propagation runs for discrete sections of the earth's subduction zones that are the principle locus of tsunamigenic activity. This database allows the generation of realistic simulations that can be used for coastal hazard assessment. The impact of a remote tsunami can be strongly dependent on local and basin-wide geometry, through wave refraction, reflection and interference. Only by a comprehensive study of potential sources can worst case scenarios can vulnerabilities be assessed and appropriate evacuation plans and structural design choices be made to further the goal of tsunami-resilient communities[1].

2. Short-term Inundation Forecasting for Tsunamis (SIFT) Tool

The SIFT tool was developed by the NOAA Center for Tsunami Research for real-time forecasting of actual tsunamis. It operates by combining real-time tsunami data obtained from the DART™ array and a set of nested numerical models to provide an estimate of tsunami arrival time and amplitudes. Method Of Splitting Tsunami (MOST)[2] is the tsunami model currently used by SIFT. Underlying SIFT is a database of pre-computed solutions for tsunami propagation based on unit sources, each 100x50 km in extent and with a seismic magnitude of $M_w = 7.5$ (Figure 1). When a tsunami wave train is detected by the pressure sensors of the DART™ array, the measurements are relayed in real-time via satellite to the Warning Centers. Here they are assimilated into SIFT to determine which linear combination of unit sources best matches the observations. The composite solution for deep-water propagation then provides basin-wide estimates of arrival times and identifies those coastal sites, if any, most threatened by the event.

When the projected impacts are sufficiently severe the second stage of SIFT can be initiated. The model runs available in the propagation database do not predict the non-linear details of near-shore evolution and inundation for a specific tsunami. Instead the composite solution described above is used to provide the boundary conditions for the nested models, referred to as a Stand-by-Inundation Model (SIM) that can provide such event-specific detail for threatened communities and is designed to run rapidly in real time. Speed is of the essence as many such SIMs may need to be run while the tsunami is transiting. To achieve speed of execution a SIM is a reduced-resolution version of the more detailed model possible under research conditions with the best available bathymetry. The SIM design process involves finding the optimum compromise between resolution and run-time that captures the main characteristics of the wave within the time constraints of operational usage.

3. Validation

The SIFT system has been validated with several historical event[2] and the two most recent Kuril events, namely 15 November 2006 and 13 January 2007 is presented. Although not part of the Tsunami Warning Center's operations, the SIFT system was exercised during both events and results at 12 currently available SIMs (Alaska, U.S. West Coast and Hawai'i) were compared with tide gage records. Comparison at Hilo SIM for the 15 November 2006 event showed good agreement with the first two tsunami waves (Figure 2). For the 13 January 2007 Kuril event, the Hilo, Hawai'i SIM showed a phase shift of 5.95 minutes and 69% higher for the first tsunami wave as compared with observed tide gage data (Figure 3). This is a relatively good comparison considering that SIFT was originally designed for normal thrust-fault earthquake and that the 13 January 2007 Kuril event was a reverse-thrust-fault earthquake[4].

4. Hazard Assessment

The initial effort for tsunami hazard assessment study is to determine the threat to the coastal community[5]. Credible worst-case scenarios based on historical or geological records of the region for both near- and far-field is crucial[6,7]. However, it is also important to know the tsunami wave characteristics and inundation extents for possible non-worst case scenarios most especially for near-field tsunamigenic sources. The availability of the validated SIFT system permits a more systematic evaluation of the hazard by generating a complete suite of tsunami scenarios. In addition, the impact of actual or potential alterations of bathymetry or near-shore structures such as breakwaters since the historical events can be assessed.

The process is illustrated by considering the hazard posed by a segment of the Aleutian subduction zone (sources A17-24, B17-24 in Figure 4) to O'ahu, Hawai'i The near-shore zone of O'ahu is represented by an array of points spaced at 2km along the 100m isobath (Figure 5). A combination of unit sources and slip distributions can be selected to generate the initial surface water level displacement due to different seismic moment, M_w. Here we investigate source scenarios corresponding to an $M_w = 8.0$ event emanating from either one or a combination of two unit sources

The non-uniformity of the hazard is evident in Figure 6 where the range of amplitude for the first arriving and overall maximum wave is drawn along the O'ahu coast. Apparently for sources in the section of the Aleutian subduction zone between Atka and Unimak Islands, the O'ahu shore near Haleiwa is most at risk from unit source B17. The next step would be to develop a SIM for Haleiwa and investigate the inundation associated with the worst case source region. Ultimately this information would assist state or local authorities for the region in land use zoning, and planning of evacuation routes and warning systems. Implementation of coastal structure building codes would lead to a Tsunami Resilient Community[1] in the study site.

5. Conclusions

The SIFT tool developed by NOAA Center for Tsunami Research is not only an operational tool that determines tsunami impact at specific coastal areas during an event but can also be used for hazard assessment studies. Originally designed for normal-thrust fault for the seismic source, it performed relatively well for a reverse-thrust fault as validated with the 13 January 2007 Kuril event.

Vulnerability of coastal communities due to a particular far-field or near-field tsunami sources are easily determined by combining unit sources to generate different seismic source scenarios. The range of the incoming simulated tsunami wave characteristics and inundation provides invaluable information for coastal state planners and emergency managers in building a more tsunami resilient communities.

References

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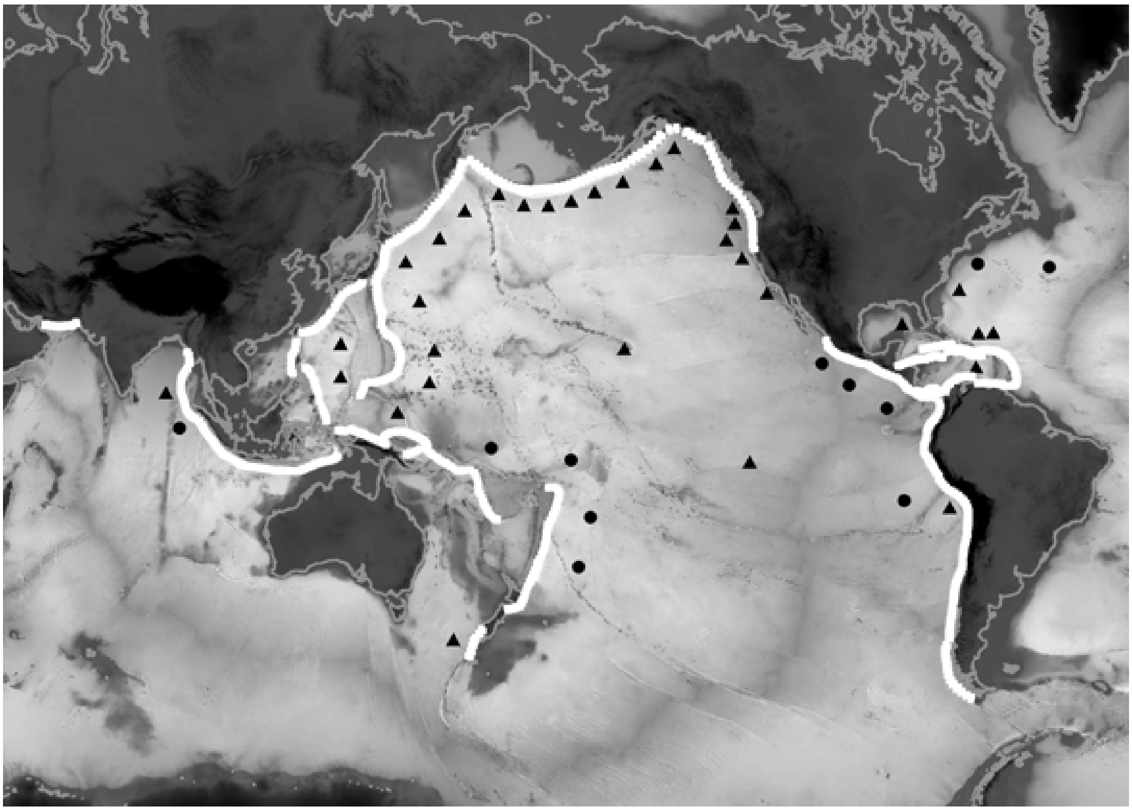

Figure 1. Global extent of unit sources (white squares) and DART™ array (▲deployed ●planned).

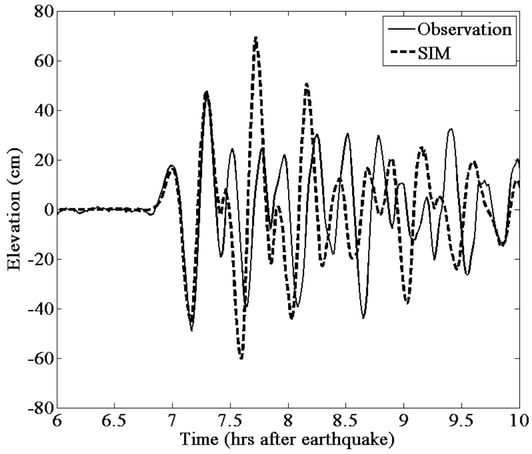

Figure 2. Comparison between observed water level and simulated SIM at Hilo for the 15 November 2006 Kuril event.

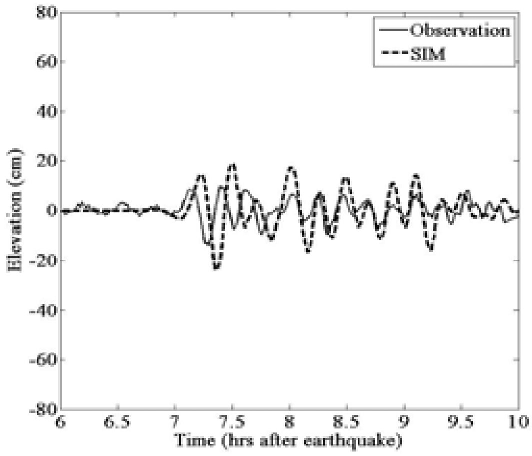

Figure 3. Comparison between observed water level and simulated SIM at Hilo for the 13 January 2007 Kuril event.

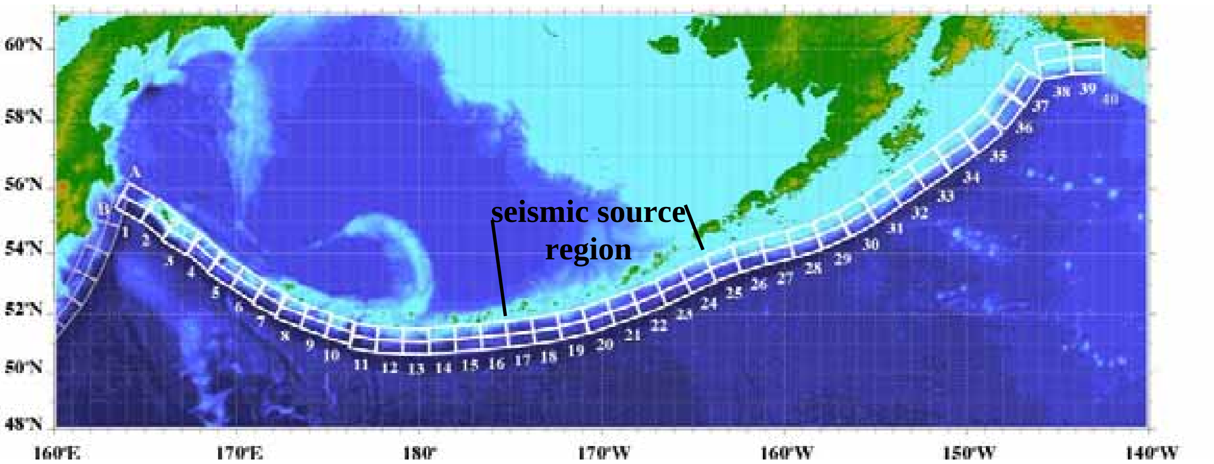

Figure 4. Aleutian Islands seismic source region for M_w=8.0.

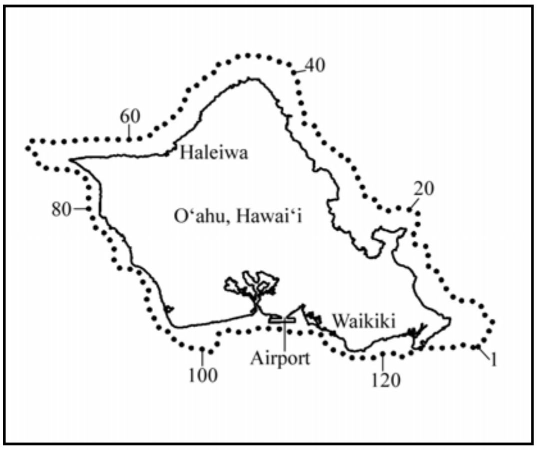

Figure 5. Numerical points spaced at 2km along 100m isobath at O‘ahu, Hawai‘i.

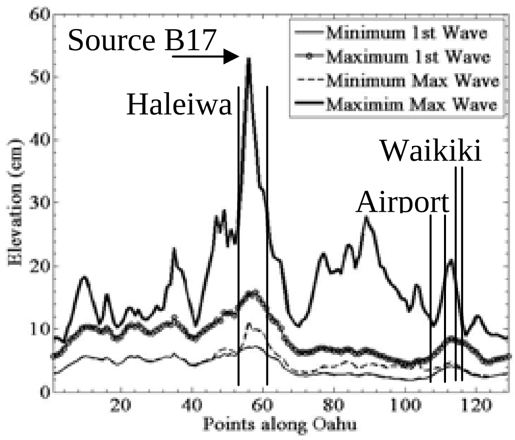

Figure 6. Tsunami wave height range of the first and maximum wave around O‘ahu, Hawai‘i for different seismic source with constant M_w (8.0) within the unit source range A,B – 17 to 24.