Combining measurements and models for real-time tsunami forecast

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Since the 2004 Indian Ocean tsunami, the most destructive tsunami in recorded history, worldwide awareness of tsunami hazard has peaked and global expansion of tsunami forecasting tools has made dramatic progress in both instruments and technology. Two of the most seminal advances in tsunami forecast since the Indian Ocean tsunami are: 1) the deployment of an extensive network of sensors to acquire deep ocean tsunami measurements, and 2) the introduction of real time numerical simulation as an vital tool in tsunami forecasting (Bernard and Robinson, 2009). To date, the number of deep-ocean tsunameters has grown from 9 in 2004 to 48 (Figure 1), forming a global tsunami monitoring network in the Pacific, the Indian Ocean and the Atlantic that is currently co-managed by multi-nations: Australia, Chile, Indonesia, Thailand and the United States. Since 2005, these tsunameters have detected 15 tsunamis generated by major earthquakes in the Pacific and Indian Ocean, building growing confidence of accuracy and reliability in far-field tsunami forecast (Titov, 2009). Japan has also installed six cabled Ocean Bottom Tsunami Meters (OBTMs), using the same sensor as the buoy-based tsunameters, to provide timely near-field tsunami forecasting for Japanese coasts since 1980s (Tsushima et al., 2009). The global implementation of these deep-ocean tsunami detectors has significantly accelerated the development and implementation of more accurate tsunami forecasting systems. Previous systems, relying on seismometers or coastal tide gages, had resulted 15 of 20 tsunami false alarms since 1949 (Bernard and Robinson, 2009). Currently, three tsunami forecast systems, developed by Japan (Kuwayama, 2006; Tatehata, 1997), Australia (Greenslade et al., 2007) and the United States (Titov et al., 2005; Wei et al., 2008; Titov, 2009; Whitmore, 2009) respectively, are monitoring worldwide tsunami activity for rapid forecast to minimize tsunami impact for at risk coastal communities. While the Japan and Australia systems are based on seismic data and propagation modeling, the United States is in the process of testing the next-generation forecast methodology that combines the real-time deep-ocean measurements with validated forecast inundation models (Synolakis et al., 2009) to produce real-time tsunami forecast for coastal communities.

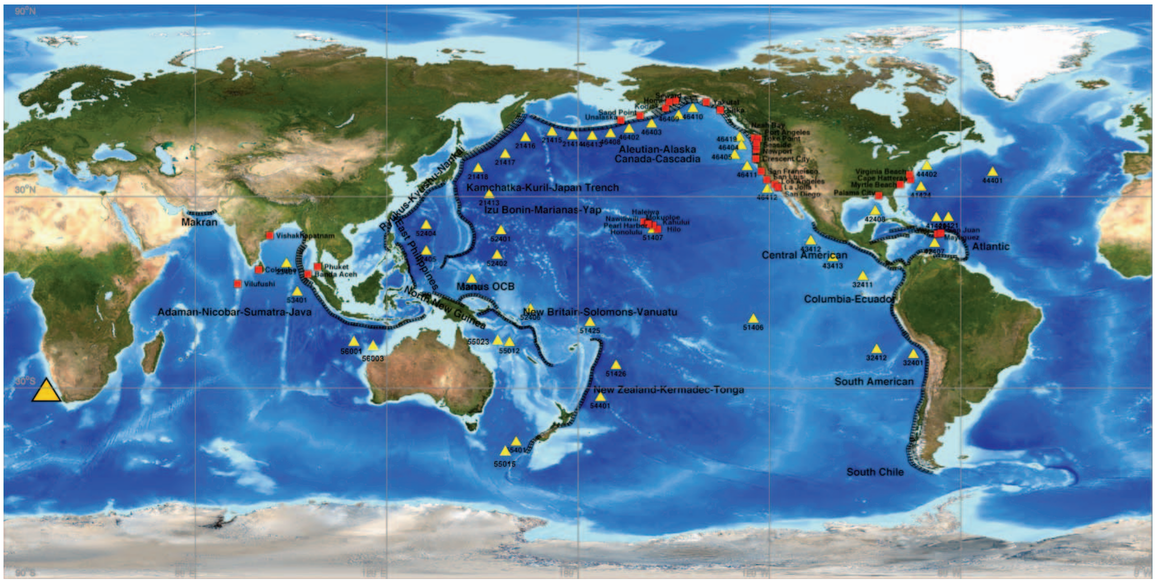

Figure 1. NOAA's tsunami forecast methodology, where ▲ = deep-ocean tsunameters; □ = forecast database of tsunami source functions; ■ = forecast models.

NOAA's tsunami forecast system utilizes a best fit between pre-computed tsunami simulations stored in a forecast database and real-time deep-ocean tsunami measurements provided by an array of tsunameters to constrain the tsunami source. This produces estimates of tsunami characteristics in deep water that can be used as initial and boundary conditions for high-resolution site-specific forecast models with nonlinear inundation computation, which are designed to simulate 4 hours of coastal tsunami dynamics in less than 10 minutes (Figure 1). The results are made available in real time to the Tsunami Warning Centers (TWCs) and to local emergency management to aid in hazard assessment and decision-making before the tsunami reaches at risk communities. NOAA plans to develop at least 75 high-resolution forecast models along the U.S. coasts in the next years, and 43 of them have already been developed and are now available for real-time forecasting. Since the 2004 Indian Ocean tsunami, the tsunami forecast system has been exercised for all 15 tsunamis that were detected and measured by the tsunameters, 12 in the Pacific and 3 in the Indian Ocean, demonstrating promising forecast accuracy, lead time, and coverage for far-field coastal communities. Several of these tsunami events will be presented to illustrate the forecast methodology, timeline, accuracy, efficiency, as well as lessons learned, of NOAA's real-time tsunami forecast system.

Although forecasting tsunami impact in the near field remains a challenge, the September 29, 2009 Samoan tsunami provided a first forecast test of the near-field tsunami impact using the new NOAA tsunami forecast system. It was the first event in which detailed, high-resolution tsunami inundation forecast model results were available for the impacted near-field areas before any other quantitative information had been obtained (http://nctr.pmel.noaa.gov/samoa20090929-local.html). The Samoan tsunami forecast results will be demonstrated to highlight the use of a tsunami forecast model to provide first justification of the real-time inundation forecast method and lessons for the use of inundation modeling in surveying and recovering from future tsunamis.

The essential components of NOAA's tsunami forecast system are deep-ocean measurements and numerical modeling. NOAA's system has produced excellent experimental forecasts for far-field tsunami impact, and showed significant potential for possible near-field forecast. When fully tested and implemented, NOAA's tsunami forecast system will not only enable accurate real time tsunami forecasts, but also will lead to more insights into tsunami dynamics and help address the challenge of creating tsunami –resilient communities.

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