September 2012

SeaSondes: The Ideal "Near-Field" Tsunami Observation Tool

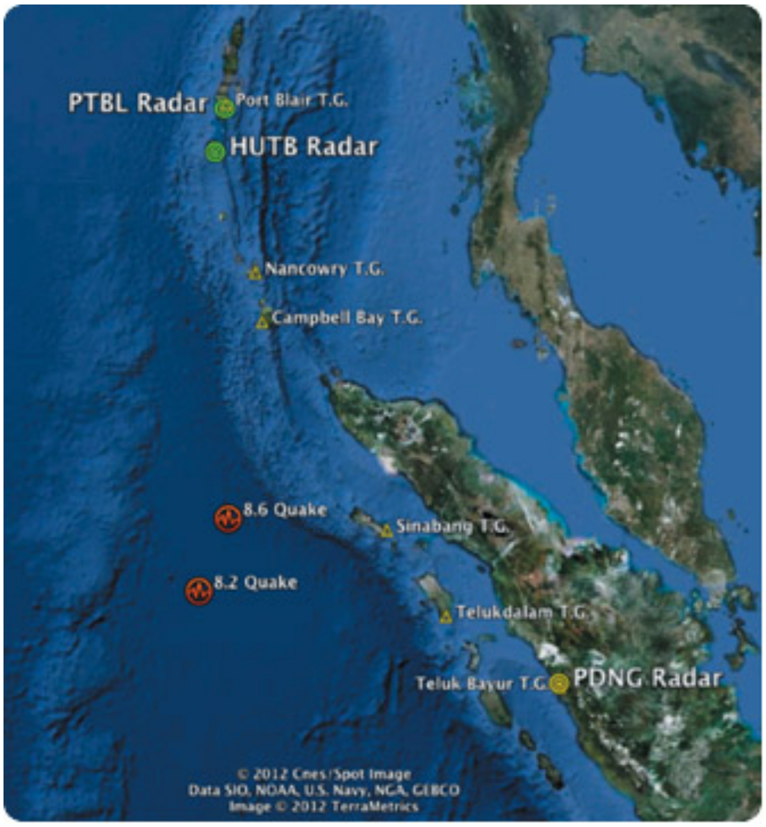
A special workshop at 2011 IEEE Oceans/MTS in Hawaii introduced and focused on a new term: ***"near-field" sensors*** at coastal areas that will be impacted by a tsunami. This is distinct from "far-field", which includes bottom DART-type pressure sensors and satellite altimetry, which observe hours before arrival at the coast. Data from the latter are used to refine the model forecasts, but are not enough. Near-shore bottom sensors or buoys in the coastal zone would not survive ravages of a passing tsunami. SeaSonde HF radars -- with no presence in the water -- are ideal and can observe before arrival. Tide gages are the other near-field sensor. But because they warn after initial impact, they provide only "upstream" information; this is not as useful as data at the impacted coastal point because of significant alongshore variation due to bathymetry. ***All information: seismic, far-field, model, and near-field (the latter including HF radar data) will prove invaluable in the evolving tsunami warning centers of the future.***

The discovery and publication by Barrick in 1979 that HF radars could detect a tsunami wave from its orbital velocity[1] lay dormant for 25 years until the devastating 2004 Banda Aceh event provided a "wake-up call." Although no HF radars were in place to observe that event, work began on hypothesizing the idealized tsunami current patterns one might expect to see from a single radar. It was recognized that the nearshore bathymetry would be a dominant factor that defined its surface signature. The problem lay in finding this tsunami pattern among the complex background flow constituents that these radars normally observe, and doing this rapidly with an automatic algorithm. This hypothetical pattern work gave way to reality after the March 2011 cataclysmic tsunami that wreaked havoc on Japan and whose strong waves were observed in the U.S. and South America. This time, over 20 SeaSondes were in place and able to record a trove of data that proved invaluable in creating the first HF radar algorithm ever that could detect the approaching tsunami signal offshore -- pulling it out of the background flows -- and provide an alert.

The algorithm that proved successful was based on the temporal characteristics of the tsunami wave rather than its spatial pattern; the latter will be added later. Damaging tsunamis have periods between 20 - 40 minutes. This separates them from wind-wave and swell motions, but is shorter than the 6-hour half-period of tides. However, normal spectral analysis methods require several periods to identify the desired peak, and this is too long to wait when lives are at stake. Therefore, to find the onset of this unique signature quickly among the other background flows, the algorithm we developed and demonstrated is based on the following:

- Running averages and standard deviations of radial velocity flows from the radar back in time are being continually computed in bands parallel to the bathymetry (depth) contours. Then we:
- Calculate a "velocity-deviation function" from this background as a product over several adjacent bands.
- Calculate a "velocity-increment function" as the magnitude change over three successive time steps of 2 - 4 minutes each.
- Calculate a "velocity-correlation function" over the three or four depth-oriented bands. This must then increase or decrease in at least three consecutive time steps.
- Finally, the above three "functions" are multiplied together to create our "q-factor", which -- when it jumps from quiescent by a significant amount -- becomes the "tsunami alert" that is transmitted to a national coordination center.

The above algorithm was tested offline but in a automatic manner on data from 14 SeaSondes for the intense March 2011 Japanese tsunami: in both Japan and the U.S.; and at different frequency bands[2]. In all cases, it detected the tsunami before it was seen at the coast by tide gages. And in all of these locations, the shallow shelf did not extend far offshore -- a particularly challenging scenario.
How does it work for weaker tsunamis? We had a chance to test this with an April 2012 magnitude 8.6 event in the Indian Ocean, followed by a weak 8.2 aftershock. [*See locator map*].



Locator map for April 2012 tsunami event in the Indian Ocean.

Recall that it is not the magnitude of the earthquake that dictates tsunami intensity; it is related to the nature of the plate motions. In these events, coastal tide gages recorded maxima less than a meter, and at the radar sites, only tens of centimeters. This was seen by the 13 MHz SeaSonde at Padang, Indonesia and two 5 MHz SeaSondes in the Andaman Islands belonging to India. A paper submitted August 2012 to Remote Sensing journal offers details of these detections[3].

Is this the end of our tsunami algorithm development? No. As with other tsunami sensors, analysis algorithms, and their mutual data fusion, they are in a state of flux and optimization. Our algorithm will see improvements in the following areas:

- The tradeoff between probability of detection and false alarms. You want the former to be as big as possible and the latter to be small. There is a "cost function" that describes this tradeoff. Never a false alarm carries a high cost of missing "the big event" and is unnecessary because other information (e.g., seismic) in a national tsunami fusion center will cull relevant alerts.
- The large velocity associated with the incoming tsunami is sensed by the radar. This will be converted to height through the spatio-temporal relations we developed, because height is the real killer.
- Although our recent experience shows the tsunami is detected before it arrives at the coast, we must refine this alert time more precisely. Again, the spatio-temporal tools to do this exist; we will develop and test them based on our past data observations.

[1] Barrick, D.E. "A Coastal Radar System for Tsunami Warning." Remote Sensing of Environment, Vol. 8, 353-358 (1979).

[2] Lipa, B., D. Barrick, S. I. Saitoh, Y. Ishikawa, T. Awaji, J. Largier, and N. Garfield. "Japan Tsunami Current Flows Observed by HF Radars on Two Continents." Remote Sensing, Vol. 3,1-17 (2011).

[3] Lipa, B. J., D.E. Barrick, S. Diposaptono, J. Isaacson, B.K. Jena, B.B. Nyden, K. Rajesh, T. Srinivasa Kumar. “High Frequency Radar Detection of the Weak 2012 Indonesia Tsunamis.”
Submitted to Remote Sensing in August 2012.

Background image: SeaSonde Remote Unit operating in Indonesia on coastal bluff.