ON THE FEASIBILITY OF TSUNAMI DETECTION USING SATELLITE-BASED SEA SURFACE ROUGHNESS MEASUREMENTS

B.D. Hamlington[1], R.R. Leben[1], O.A. Godin[2,3], V.G. Irisov[3,4]

1. Colorado Center for Astrodynamics Research, University of Colorado, Boulder, CO, 80309, USA.
2. Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, 80309, USA.
3. NOAA/Earth System Research Laboratory, Boulder, CO, 80305-3328, USA.
4. Zel Technologies LLC, Boulder, CO, 80305, USA

Observations of tsunamis in the open ocean are critical for developing early warning systems and improving our understanding of tsunami generation and propagation. An early and reliable assessment of an imminent tsunami threat requires detection of the tsunami wave in the open ocean away from the shore [1-3]. The wave amplitude of tsunamis in the open ocean, however, is small relative to the amplitude at the shore, making early detection a challenge. Current systems of detection rely on bottom pressure or variations in sea surface height. By complementing these systems with wide-area satellite observations of tsunami manifestations, we can potentially improve the accuracy and timeliness of tsunami forecasts, increase the advanced warning time and decrease the probability of false alarms [4-6].

While changes in the sea surface height (SSH) associated with tsunamis have been well documented [7-10], other manifestations of the tsunami signal in the open ocean have been detected in recent years. Tsunami-induced changes in surface roughness in the deep ocean were first observed in visible light and were given the name “tsunami shadows” [4,5]. Tsunami shadows appear as extended darkened strips on the ocean surface along a tsunami wave front. Formation of these “shadows” as areas with different root mean square (RMS) surface slope has been tentatively explained theoretically as a result of the air-sea interaction between the passing wave and turbulent wind near the surface of the ocean [11-13].

The effect of the tsunami on the radar backscattering strength was first detected from satellite altimeters during passage of the 2004 Sumatra-Andaman tsunami [13-14]. The Sumatra-Andaman tsunami is the first for which detailed SSH and radar backscattering strength measurements are available. While several publications were produced using the SSH measurements to study the properties of the tsunami including propagation and scattering [7-9], through statistical analyses, we have recently demonstrated that tsunamis cause noticeable changes in surface roughness and can thus be detected away from the shore using radar backscattering strength measurements [14].

Although four different satellite altimeters sampled the 2004 Sumatra-Andaman tsunami in the open ocean, the chances of sampling a tsunami away from the shore with a satellite altimeter are slim. Over 150 tsunami events have been documented by National Geophysical Data Center (NGDC) since the launch of the TOPEX/Poseidon satellite altimeter in 1992, but only a handful have definitive measurements of changes in sea surface height characteristic of a tsunami. The spatial and temporal coverage of satellite altimeters are not conducive for providing wide-area coverage of the ocean with the sampling time needed for an effective tsunami detection and warning system. However, given the recently proven ability to identify tsunami events in the open ocean from changes in the ocean surface roughness, orbiting radiometers and microwave radars, which have broad surface coverage across the satellite ground track, could potentially be used as the foundation for an early tsunami detection system.

Radar backscattering measurements from satellite altimeters are only currently available along one-dimensional lines traced by the nadir ground track. Two-dimensional images of tsunami-induced changes in sea surface roughness, however, could be obtained by using radiometers and microwave radars. Godin et al. [14] present a model for calculating the tsunami-induced changes in sea surface roughness, providing a factor directly related to sea surface height that corresponds to the modulation of background wind speed resulting from the passage of a tsunami. The ability to detect the tsunami from such a two-dimensional image is largely dependent on the variability and strength of the background wind field at the time of the tsunami passage. With a constant background wind of physically realistic magnitude, the tsunami-induced changes in sea surface roughness are apparent, as seen in Fig. 1A. The changes in sea surface roughness are computed from the model of Godin et al. [14] assuming a constant background wind of 3 m/s and using the SSH measurements taken by Jason-1 for the 2004 Sumatra-Andaman tsunami. However, when using the wind speeds calculated by QUIKSCAT on December 26th, 2004 (the day of the Sumatra-Andaman tsunami), the tsunami-induced changes are obscured by the variability of the background wind field, as depicted in Fig. 1B. Similar to the one-dimensional radar backscattering measurements provided by satellite altimeters for the 2004 Sumatra-Andaman tsunami, it will be necessary to find an appropriate method for filtering the data that will allow separation of the tsunami-induced signal from the background wind variability and measurement noise.

Although the feasibility of tsunami detection from changes in sea surface roughness has been proven using measurements from satellite altimeters, the practical issue of optimal retrieval of a tsunami signal from other sources of sea surface roughness measurements remains an open question. Use of radar backscattering strength measurements from satellite altimeters would be impractical for tsunami detection and early warning purposes because of the limited number of operational satellite altimeters. Even if the data could somehow be processed sufficiently quickly to be useful, the temporal and spatial coverage of nadir pointing altimeter measurements is unsuited for tsunami detection and warning. On the other hand, it is likely that tsunami-induced changes in sea surface roughness are observable with other types of space- and airborne sensors that sense sea surface roughness over much wider swaths. With this in mind, we explore the feasibility of using existing instruments and technology as the basis for a tsunami detection and early warning system. Furthermore, we compare our detection ability from changes in sea surface roughness with the ability for early detection from other manifestations of the tsunami in both the ocean and the atmosphere.

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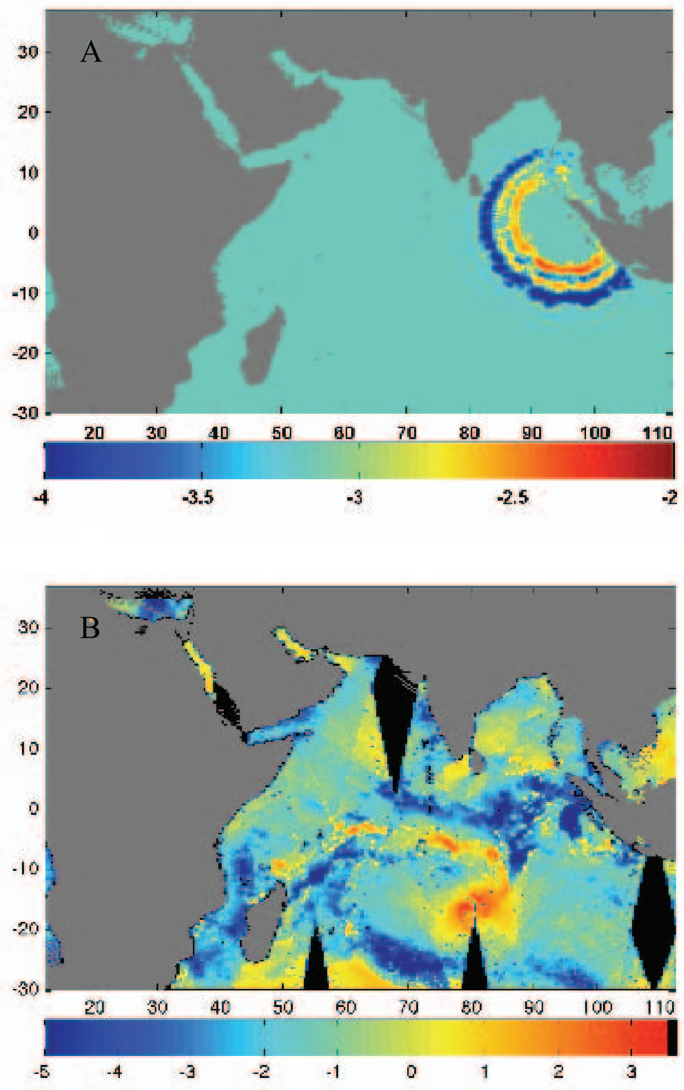

Figure 1. Using the model presented in Godin et al. [14], the two-dimensional field of radar backscattering strength is computed for A) a constant background wind of 3 m/s, and B) a background wind field obtained from QUIKSCAT on December 26th, 2004.