STATISTICAL ANALYSIS OF JASON-1 SEA SURFACE HEIGHT AND BACKSCATTERING DURING SUMATRA-ADAMAN TSUNAMI

V. G. Irisov, O. A. Godin, B. D. Hamlington, R. R. Leben, and G. A. Wick

The existing tsunami warning system is based primarily on registration of underwater earthquake events. Unfortunately this approach has intrinsic drawbacks: the relationship between quake force and tsunami intensity/propagation is complicated and not clear. Another approach relies on direct measurement of tsunami wave height by detection of pressure change near the bottom. Such a buoy network is expensive and provides sparse data. Observation of sea surface roughness variations caused by tsunami waves would provide important information complimentary to the traditional methods.

First mention of the tsunami-induced variation of surface roughness was reported in 1996 (Walker, 1996; Dudley and Lee, 1998). It was called a 'tsunami shadow' and manifested itself as dark strip along the tsunami front. It is clear that the currents caused by tsunami wave are too weak to explain direct modulation of surface waves, so another mechanism for the tsunami shadow was developed recently (Godin, 2003, 2004, 2005; Troitskaya and Ermakov, 2008). It is based on perturbation of air-sea interaction in the presence of large-scale waves, which results in noticeable changes of the effective near-surface wind. This effect is predicted to be much stronger compared with direct hydrodynamic modulation of surface roughness.

The first reliable simultaneous observation of sea surface height and surface roughness was made during the devastating Sumatra-Adaman tsunami in 2004. Satellite altimeters provide the sea surface elevation by measuring the time delay of the microwave pulse echo, reflected from the surface. At the same time the intensity of the backscattered signal is directly related to the sea surface roughness. The main advantage of this approach is that two independent measurements were done by the same instrument at the same place and time.

Among other spaceborne altimeters Jason-1 registered the strongest undulation of sea surface height (SSH) during the Sumatra tsunami. This can be explained by a favorable combination of flight track geolocation, pass time, and wave intensity. Along with SSH variations of about 50 cm, Jason-1 registered noticeable variations of nadir backscattering intensity at Ku- and C-bands, which we relate to surface roughness variations associated with the tsunami. Figure 1 shows corresponding dependencies of SSH and σ_0 versus latitude of the altimeter beam spot for the same pass 129 (the same geographical location), but for three different time intervals: before, during, and after the tsunami. Due to an orbital inclination of 66°, the equatorial segment of orbit projection onto the Earth surface, where the tsunami encounter occurred, is oriented primarily in the north-south direction.

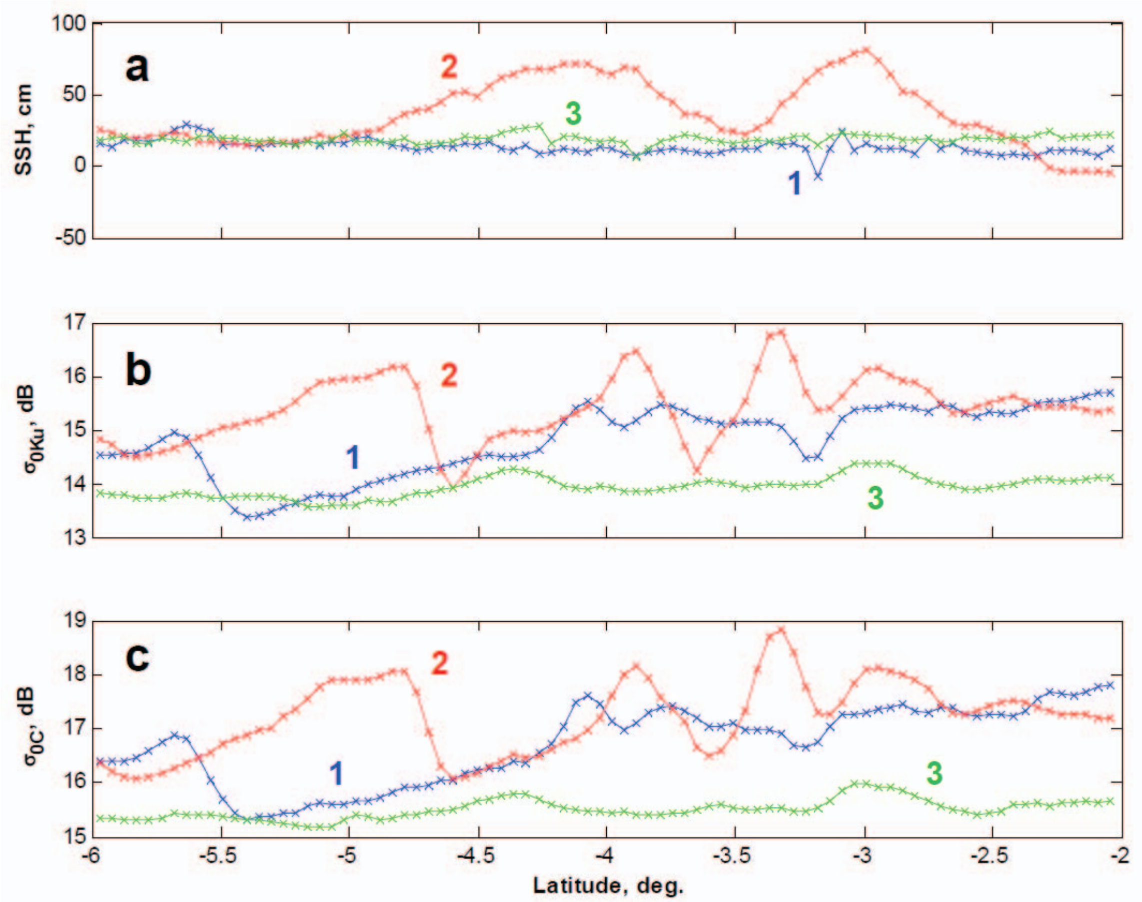

Figure 1. Jason-1 data for pass 129 obtained 10 days before (1), during (2), and 10 days after (3) Sumatra tsunami. (a) -- sea surface height, (b) -- Ku-band backscattering, (c) -- C-band backscattering.

SSH variations of 10-50 cm as well variations of σ_0 of 3-5 dB are not unusual for ocean altimetry. The main objective of the current work is to show that *simultaneous* variations of SSH and σ_0 on the given spatial scale of 30-100 km are extremely rare. For that purpose we examined five years of the historical record of Jason-1 observations. A spatial filtering algorithm was applied to randomly selected windows of approximately 3 degrees latitude centered in the range from 38° S to 8° N. We focused on the pass 129 where tsunami was detected. This way we avoid persistent variations of the altimeter data related to different geographical areas. All together about 1000 statistically independent data segments were processed. The algorithm was developed to calculate the total intensity of SSH and σ_0 variations and an integral measure of correlation between them within a certain spectral interval.

Figure 2 shows the results of the described test. The vertical red line on both panels shows the level of spectral measure of σ_0 variation (top) and spectral measure of correlation between σ_0 and SSH (bottom), corresponding to the tsunami event. The histograms show the distribution of the same values over a complete set of 999 randomly selected windows. The tsunami event was excluded from the background random set. One can see that σ_0 variations corresponding to tsunami are rare, but not exceptional.

About 1.7% cases show stronger variations than that observed during tsunami. At the same time the spectral measure of correlation between σ_0 and SSH shows an exceptionally high value for the tsunami. It is an argument in favor of our main hypothesis: a tsunami wave is accompanied by a noticeable variation of sea surface roughness – a tsunami shadow.

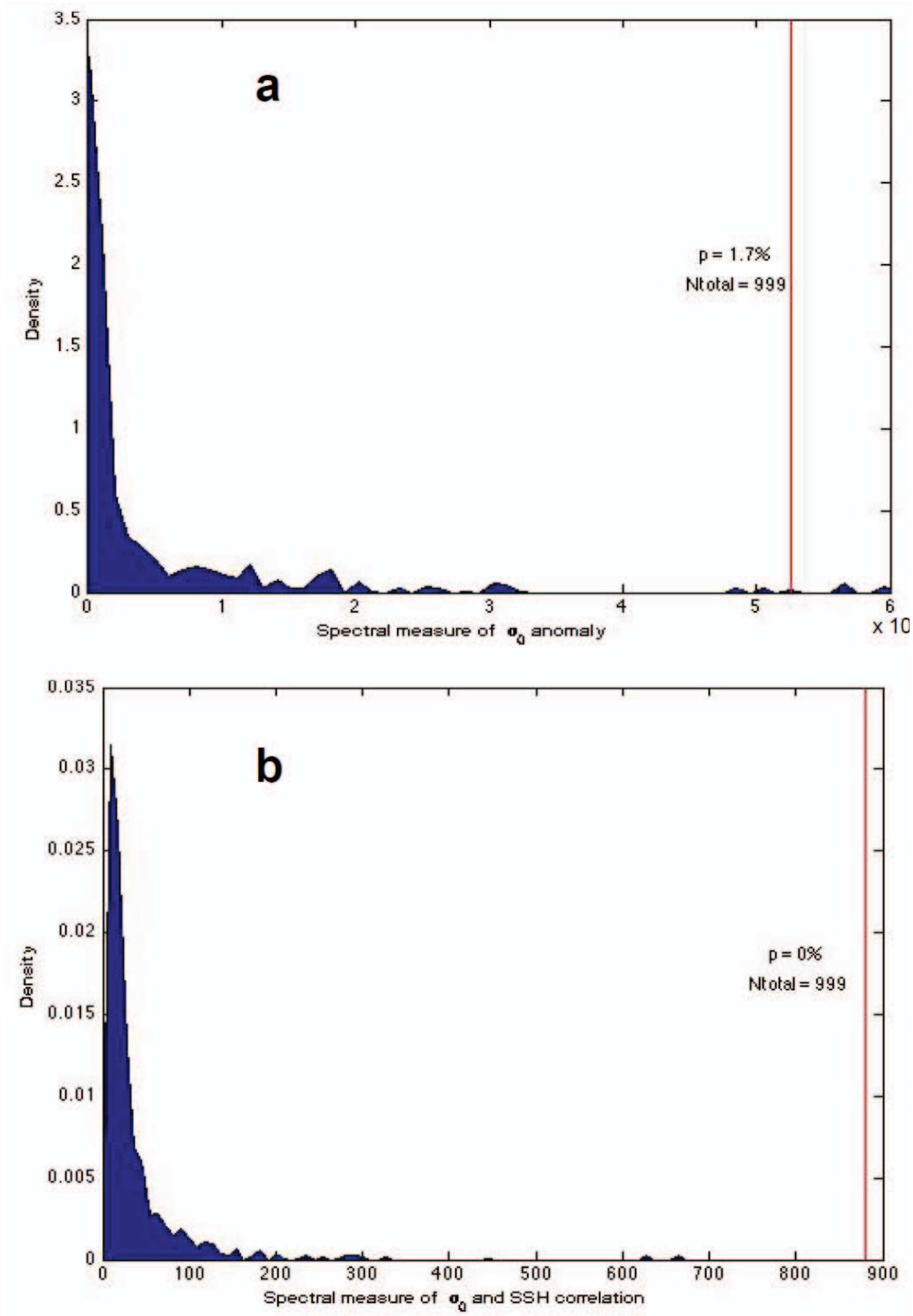

Figure 2. (a) -- randomization test of spectra measure of filtered backscattering (C-band), (b) -- randomization test of co-spectrum of filtered backscattering (C-band) and SSH variations.

Our team conducted another randomization test using a completely different algorithm based on measure of RMS and number of zeros crossings of σ_0 (Godin et al., 2009). It shows similar results, but we leave them beyond our presentation. The main conclusion of our analysis is that simultaneous variations of σ_0 and SSH of the spatial scale typical for Sumatra tsunami are extremely rare. It supports the theoretical explanation of tsunami shadow effect and opens an opportunity for tsunami detection by observing sea surface roughness modulation.

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