Japan Geoscience Union Meeting 2018

# Mechanism of volcanic tsunami earthquakes Part II: Tsunami analysis

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**1. Introduction**
Tsunami earthquake is a submarine earthquake generating disproportionally large tsunamis relative to its seismic magnitude [*Kanamori*, 1972, PEPI]. Torishima earthquakes are volcanic tsunami earthquakes with Mw=5.6-5.7, which repeatedly occur (approximately every 10 year) under a submarine caldera near Torishima Island, Japan. We here report results of tsunami analysis for the latest event on 2 May 2015 (JST). The overview of this project, including observations and mechanism of volcanic tsunami earthquakes, will be presented by *Fukao et al.* at this session.

**2. Tsunami observations**
Following the 2015 Torishima earthquake, tsunami waves were observed at several tide gauges on coast at such as the Izu-Bonin Islands. The waves reached the maximum amplitude of ~60 cm on Hachijo Island [*JMA*, 2015]. On the other hand, tsunami waves were also recorded by 10 station array of absolute pressure gauges deployed about 100 km away from the epicenter. The waves initiated with a small down-swing signal (~0.1 cm) and reached peak amplitude (1.5-2.0 cm) of a leading up-swing signal. We here analyzed tsunami waves generated by the 2015 Torishima earthquake, and modeled an initial sea-surface disturbance.

**3. Ray tracing for dispersive tsunami waves**
From the observations at the array, we picked up travel times of phases with different frequencies, and measured slowness directions by the plane-wave approximation. As a result, it is revealed that measured slowness direction varies as a function of frequency.

We developed a ray tracing method considering the dispersion effect, and attributed the frequency-dependent direction to the dispersion at deep water [*Sandanbata et al.*, 2018, PAGEOPH]. By comparing the observed and simulated values, the point source can be constrained within Smith Caldera with a radius of about 4 km. In addition, we back-projected the onset of tsunami waves with a measured slowness direction and travel time, and located its origin at the north part of the caldera rim. These imply that uplift accompanying the 2015 Torishima tsunami is inside and with a comparable size to the caldera rim.

**4. Tsunami source modeling based on the finite-difference method**
For precise tsunami source modeling, we performed tsunami simulations based on the finite-difference method [*Fukao et al.*, 2018, Sci. Adv.]. To simulate the tsunami propagation, the linear Boussinesq equations were solved with the tsunami simulation code, JAGURS [*Baba et al.*, 2015]. Because the source location was estimated within the caldera from a ray-tracing analysis, we assume a symmetric sea-surface disturbance composed of a central uplift and a small surrounding depression. We quantified the similarity between synthetic and observed waveforms at the array to find the best amplitude and radius of the central uplift. The grid search leads to a sea-surface uplift of ~1.5 m with a source size of 4.1 km comparable to the caldera size, which yields good agreement between the simulation and the

observation.

**5. Tsunami waveforms at the Yaene port on Hachijo Island**

By assuming the proposed model above, we computed tsunami waves at the Yaene port on Hachijo Island, where the maximum amplitude of ˜60 cm was observed. To calculate the synthetic tide gauge record in a complicated-shaped bay, we prepared fine bathymetry grid data and included the nonlinear effects on tsunami waves in the simulation. The simulated waveform well reproduces the observed waveform.

**6. Discussion and Conclusions**

The tsunami source model exhibits two properties of the sea-floor deformation. First, a large uplift concentrated within Smith Caldera implies a close association of the earthquake with some volcanic activity of the caldera edifice. Secondly, the modeled subsidence surrounding the caldera suggests that the event accompanied a notable subsidence, at least on the northeastern side of the caldera. Based on the tsunami analysis, a possible mechanism of volcanic tsunami earthquakes will be proposed by *Fukao et al.* at this session.

Keywords: tsunami earthquake, volcanic earthquake, submarine volcano, Smith Caldera, Sumisu Caldera, dispersive tsunami

 