Millimeter-scale tsunami of an M6 earthquake observed by the nearest-field pressure gauge array: a fault modeling and stress drop estimation

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Tsunamis associated with major (M > 7) offshore earthquakes are often recorded by offshore ocean-bottom pressure gauges and have been used to estimate the fault models and to understand the mechanics of earthquake faulting (e.g., Satake et al. 2013; Gusman et al. 2015; Heidarzadeh et al. 2016; Kubota et al. 2019). However, because the offshore stations were too few and remote from the earthquake hypocenters, it is challenging to record tsunamis due to moderate (M ~6) earthquakes with reasonable quality. To constrain the fault parameters for such moderate earthquakes, it is required to use stations near the source. Recently, a new, wide and dense pressure gauge network, called the Seafloor Observation Network for Earthquakes and Tsunamis along the Japan Trench (S-net), was constructed by the National Research Institute for Earth Science and Disaster Resilience (NIED) (Kanazawa et al. 2016). This network observed tsunamis with amplitudes of less than one cm associated with an Mw 6.0 earthquake off Sanriku on August 20, 2016, which occurred at the northern edge of the rupture area of the 1896 Sanriku tsunami earthquake (Kanamori, 1972; Tanioka & Satake, 1996). This study uses these millimeter-scale tsunami records to estimate the finite fault model and examines its relationship with other interplate earthquake phenomena.

First, we applied a band-pass filter with a passband of 100–1000 s to the raw records. When the traces were aligned according to the station locations, the westward propagation of tsunamis with the velocity of ~0.1 km/s could be recognized. The step-like signals were also observed at several stations near the epicenter. At the site S4N10, a station closest to the epicenter (~10 km), an abrupt pressure increase of ~20 hPa was observed. Takagi et al. (2019) examined records from the co-located accelerometer at S4N10 during this earthquake and found the sensor at S4N10 was rolled with a rotation angle of 5.72°. This suggests that these step-like signals are irrelevant to tsunami nor crustal deformation.

We then inverted the record to estimate the initial sea-surface height distribution (i.e., tsunami source). As a result, the tsunami source had a spatial extent of ~40 km and was located ~10 km to the west of the GCMT solution. In addition, when using only the remote stations (> ~100 km), the horizontal location was similar; however the initial height distribution was broader and the total volume of the displaced seawater was almost double. This suggests the horizontal location could be reasonably constrained only from the remote stations but the near-field data is essential to obtain the higher-resolution fault models, as pointed out by Inazu & Saito (2014) and Kubota et al. (2019).

We finally constrained the rectangular fault model with a uniform slip across the fault, based on the S-net tsunami data. We obtained a seismic moment $M_0 = 1.4 \times 10^{18}$ Nm (Mw 6.0) and a stress drop of $\Delta\sigma = 1.5$ MPa. The estimated stress drop value seems not so small as those of tsunami earthquakes such as the 1896 Meiji Sanriku earthquake (≪ ~1 MPa, e.g., Kanamori and Anderson, 1975) even if we consider the uncertainty of the stress drop estimation ($\Delta\sigma >$ ~ 0.7 MPa). We also found the estimated fault was unlikely to overlap with regions where slow earthquakes are active, such as low-frequency-tremors and very-low-frequency-earthquakes (e.g., Matsuzawa et al. 2015; Nishikawa et al. 2019; Tanaka et al. 2019).

This study demonstrated that the detectability of a millimeter-scale tsunami and the constraints on earthquake source parameters of moderate earthquakes are dramatically increased by the S-net’s new dense and widely distributed tsunami network. We expect that this new array records more tsunamis due to minor-to-moderate offshore earthquakes. This will enable us to elucidate the spatial variation of the stress drops, or mechanical properties, along the plate interface with much higher resolution than previously possible.

Keywords: S-net, Ocean bottom pressure gauge, Tsunami, Interplate earthquake, Fault modeling, Stress drop