Improving the constraint of the 2016 Off-Fukushima shallow normal-faulting earthquake with the high-coverage tsunami data from the S-net wide network: implication on the crustal stress in the overriding plate

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On November 22, 2016, an Mw 6.9 shallow normal-faulting earthquake occurred within the overriding plate off Fukushima Prefecture (12 km, GCMT). Although tsunamis associated with this event have been reported, they are observed only at the landward from the source and thus there might be a difficulty in constraining the tsunami source, in particular for its offshore side. In response to the 2011 Tohoku earthquake, a new offshore observation network, S-net, has been developed off eastern Japan (Aoi et al., 2020), and the S-net ocean-bottom pressure gauges (OBPs) clearly observed the tsunamis. Because the S-net station coverage is significantly high and some of them are located very close to the source, the constraint of the source of the Off-Fukushima earthquake will be significantly improved. We thus analyze the S-net OBP data to estimate the high-resolution fault model of the Off-Fukushima earthquake.
After processing the data, pulsive tsunamis with maximum amplitudes up to ~40 cm were recognized. We then estimated the tsunami source, with careful analysis to reduce the influence due to the instrumental noises related to the step and drift signals (Kubota et al., 2020JpGU). We obtained the tsunami source with one large subsidence region, which had narrower spatial extent and larger peak displacement than those previously proposed. We calculated the tsunami waveforms at the NOWPHAS near-coastal GPS buoys and wave gauges, which reproduced the observation very well even though they were not used for the inversion. This indicates that the S-net data dramatically improve the spatial constraint of the source.
We also estimated the slip distribution on the fault from the S-net OBP data. The main slip was concentrated in a region of ~30 km× ~20 km with average and maximum slips of ~300 cm and ~600 cm, respectively (Mw 7.1). Based on the shear stress change distribution on the fault from this fault model, we obtained an energy-based, or slip-weighted averaged, stress drop $\Delta \sigma_E$ (Noda et al. 2013) of ~14 MPa on the main slip area.
It has been reported that the normal-faulting seismicity within the overriding plate increased after the Tohoku earthquake, while reverse-faulting seismicity due to the horizontal compression by the subducting plate was dominant before (e.g., Terakawa & Matsu’ ura, 2010; Asano et al., 2011), and this change can be attributed to the switch of the stress regime from horizontal compression to extension due to the stress perturbation by the Tohoku earthquake (e.g., Hasegawa et al., 2012). Based on this interpretation, the deviatoric stress around this region is considered to mostly correspond to the static stress change by the Tohoku earthquake. However, the shear stress increase along the fault plane of the Off-Fukushima earthquake, by the Tohoku earthquake (Iinuma et al., 2012) is only ~2 MPa, which is significantly smaller than the stress drop inferred from the fault model. This shortage of the shear stress increase may suggest the deviatoric stress is locally large around the focal area. One probable interpretation is the local extensional stress is fundamentally developed at the shallowest surface of the plate around this region, probably related to its bending due to the force by the subducting oceanic plate (Hashimoto and Matsu'ura, 2006). This horizontal extensional stress may not exceed the crustal strength before the Tohoku earthquake, but the stress perturbation by the Tohoku earthquake enhanced the extensional

stress to provoke the normal-faulting seismicity. This study demonstrated that the use of the higher-coverage S-net OBP data will significantly contributes to improving the constraint of the fault modeling of the offshore earthquakes, which could not be achieved in the past when the S-net was not available. We expect that the S-net wide and dense OBP network will advance our understandings for ocean bottom seismology.

Keywords: S-net, Ocean bottom pressure gauge, Tsunami, The 2016 Fukushima earthquake, Intraplate stress regime

