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3D numerical simulation of the tsunami-generated electromagnetic field using non-uniform thin-sheet approximation

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A large (Mw=8.1) tsunamigenic earthquake occurred along the Kuril-Kamchatka trench on 13 January 2007. This event was of normal fault type (Ji, 2007; Yagi, 2007; Yamanaka, 2007; Lay et al., 2009) and was considered to be strongly associated with another tsunamigenic earthquake of thrust fault type that occurred on the landward slope of the trench on 15 November 2006. The 2007 fault geometry, however, was uncertain in the sense that the dipping direction (southeast or northwest) was not determined by previous reports so far (e.g., Yamanaka, 2007; Lay et al., 2009).

The 2007 tsunami propagated through the Pacific Ocean and was observed at many tide gauge stations, seafloor tsunami sensors and the Deep-ocean Assessment and Reporting of Tsunami (DART) system. Fujii and Satake (2008) estimated the slip distributions for this tsunami by waveform inversions and revealed insignificant difference between the two fault dips. Our seafloor electromagnetic (EM) station successfully observed tsunami-generated EM variations approximately one hour after arrival of seismic waves (Toh et al., 2011). The EM variations were generated by the coupling of the particle motion of conductive sea water with geomagnetic main field during tsunami passage. Some numerical simulations of the so-called motional induction process, viz., the tsunami dynamo effect, were conducted in two-dimensional (2-D) time domain (Minami and Toh, 2013) and three-dimensional (3-D) frequency domain (Zhang et al., 2014).

In this study, we introduced a 3-D non-uniform thin-sheet approximation proposed by McKirdy, Weaver and Dawson (1985). We newly developed a 3-D frequency domain code to calculate the tsunami dynamo effect, which was able to represent actual bathymetry by lateral conductance distribution within the surface thin-sheet without introducing many vertical grids in the ocean.

We applied this method to calculate the EM variations generated by tsunamis of the 2007 Kuril earthquake and estimated the slip distributions for both fault dips. As for kinetic tsunami propagation simulation, we used the linear Boussinesq approximation in order to reproduce subsequent phases after the tsunami first arrival. As for inversion, we used a non-negative least square method to fit the observed downward magnetic component as well as to avoid negative slips on the fault plane.

Our calculations indicate that the southeast-dipping fault model explains the observed downward magnetic component better than the northwest-dipping fault model. We also confirmed that the observed subsequent phases were produced by the frequency dispersion effect of the tsunami waves. The variance ratio (1.83) for the downward magnetic component by the two fault models was smaller than the critical F-value of 1.84 corresponding to 95% confidence level, although it passed the 90% confidence level. This may be attributed to too few observed data by the sparse sampling rate (2min). Use of more data such as the other tsunami-generated EM components can lead to determination of fault models with more accuracy. However, our calculation suggests that EM observations are sensitive enough to estimate the slip distribution on fault planes and can contribute to seismology.

Keywords: Tsunami, Dynamo effect