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Simulation of the tsunami-induced electromagnetic fields

Luolei Zhang[1]; Hisashi Utada[1]; Hisayoshi Shimizu[2]; Kiyoshi Baba[3]
[1] ERI, Univ. Tokyo; [2] ERI, University of Tokyo; [3] ERI, Univ. of Tokyo

It is well known that any motion of seawater in the geomagnetic field causes secondary electromagnetic (EM) field variations due to Faraday's law (e.g., Sanford, 1971; Tyler, 2005; Toh et al., 2011). There are a number of observations of such EM fields that were caused by the devastating Tohoku tsunami of 2011 not only on land observatories but also at some seafloor sites. Here we present a 3-D modeling result to simulate these observed fields. We apply a 3-D EM induction forward code in Cartesian coordinate system (Zhang et al., 2012) with non-uniform source term, which is based on the modified iterative dissipative method (MIDM). The source current distribution is predicted by the flow data calculated by a tsunami simulation (Maeda and Furumura, 2011) which solves Navier-Stokes equations in 3-D Cartesian coordinates. Flow data provided in the time domain are transformed to the frequency domain to calculate the source current distribution for the MIDM solver. The frequency domain solutions of Maxwell equations are then transformed back to the time domain to compare with observations. Comparisons in the frequency domain are also possible. Through such comparisons with accurate tsunami simulation results, EM observation may be used to constrain the tsunami source mechanism.

In the previous study (Utada et al., 2011), we estimated the tsunami-induced fields on land by applying Biot-Savart law (by ignoring the electromagnetic induction) to the same set of flow data and obtained qualitative agreement between observed and modeled fields. In the present study, we found that the present result generally gives smaller amplitude than the result of Biot-Savart calculation. This can be ascribed to the EM induction effect in the sea. We also found that the effect of the source current by the vertical motion, which was ignored in the previous study, can be comparable to that by the horizontal motion, especially in shallower water.

The water motion generates source current in the sea both of poloidal (with horizontal currents) and toroidal (with vertical currents) modes. Lateral heterogeneities (bathymetric variations and conductivity anomaly) would convert the toroidal to poloidal mode but the amplitude of converted mode is generally much smaller than that of originally poloidal mode. Therefore the source of the toroidal mode can be ignored in case of modeling observations on land. However, our numerical simulation shows that the effect of the toroidal mode may not be negligible for modeling seafloor observations, but only if the seafloor (of sedimentary layer) is very conducting. Resulting secondary horizontal magnetic field can be of comparable intensity to that due to the vertical motion. In such a case, the effect of these two sources would bias the estimation of the tsunami propagation direction by horizontal components of seafloor electromagnetic data, because the fields from these two sources are not parallel to the wave number vector. We also examined how the tsunami-induced EM field observations at seafloor constrain the conductivity of the shallower part of the seabed, which is difficult to resolve by using natural seafloor magnetotelluric signals. The poloidal mode signals are sensitive to the conductivity (the depth-integrated conductance) of approximately down to 30 km depth. Although the toroidal mode is sensitive to the integrated resistance of the sediment layer, separation of its weak effect from the dominant effect of the poloidal mode is difficult.