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津波によって海洋に励起される電磁場変動

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Tsunami-induced electromagnetic fields in the ocean

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Electric and magnetic (EM) fields are generated within ocean currents moving through the magnetic field of the earth, and the tsunami flow is also considered to generate EM fields in the ocean although its signal levels are very low. Recent advances in high precision measurements of EM fields enabled the seafloor measurements of the tsunami signals (Toh et al., 2011, Hamano et al., 2011, Ichihara et al., 2011). In order to extract useful information from the offshore measurements of tsunami EM signals and utilize them for the tsunami warning at the coast, we need an appropriate theory which relate the EM signals observed at seafloor to the tsunami parameters such as sea level changes, flow velocities, etc. The first comprehensive theoretical study of motional induction in the ocean was made by Longuet-Higgins et al. (1954). Since then, many investigations on the motional induction in the ocean has been accumulated (Sanford, 1971; Chave and Luther, 1990, Stephenson and Brian, 1992, Glatzman and Golubev, 2005, Tyler, 2005). However, most of these formulations use electrostatic approximation considering the effect of self-induction term is weak, and are applicable only to the low frequency oceanic flows such as tidal flows and not suitable for the tsunami flows, in which the phase velocities at deep ocean exceed 200 m/s. In the present paper, theory of the electromagnetic induction by the motional sources in the ocean is examined by taking account the self-induction term so that the theory can be applicable in the analysis of tsunami EM signals. In the present model, we consider tsunami motion in an unbounded ocean of constant depth, h, and electrical conductivity, s = 4 S/m, underlain by a semi-infinite layer with constant conductivity, which represent the crust and mantle below seafloor, and the surface of the ocean is in contact with an insulating air. By solving the induction equations with the boundary conditions at the sea surface and the bottom, we obtained the solution in the wavenumber-frequency domain. By using the shallow water approximation, i.e. water depth h is much smaller than the wavelength of the tsunami wave and assuming the induced magnetic field is much smaller than the ambient geomagnetic field, the vertical and horizontal components of the induced magnetic fields can be expressed as a function of sea level change, frequency, horizontal wave-number with the parameters of water depth h and the conductivity of the underlying semi-infinite layer. And, from the Maxwell equation, two horizontal components of the electric fields are obtained from the expression of the induced magnetic fields. Results of the present theoretical examination demonstrate that the observations of the three components of the magnetic field (bx, by, bz) and the two horizontal components of E-field (ex and ey) at a single seafloor station can reveals, (1) Variations of the sea level change associated with tsunami flows in time and frequency domains: (2) propagation direction of the tsunami waves; (3) frequency dependence of phase velocity of the tsunami propagation (i.e. dispersion relation), and (4) frequency dependence of the apparent electrical conductivity observed at the seafloor, which can be used to estimate the electrical conductivity structure under the seafloor. We will show that these theoretical relations are verified by the results of the first simultaneous observation of the tsunami-induced EM fields and the sea level change conducted in the French-Polynesia region.