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Initial motions of tsunamis detected by a seafloor geomagnetic observatory in the Northwest Pacific Basin

Hiroaki TOH[1*], Yozo Hamano[2]

[1]Graduate School of Science, Kyoto Univ., [2]IFREE, JAMSTEC

It has been long known that electromagnetic (EM) fields can be induced by motions of the conducting sweater coupling with the geomagnetic field (e.g., Faraday, 1832). This phenomenon is coined 'motional induction'. Earlier theoretical studies on motional induction in the ocean (Longuet-Higgins, 1949; Sanford, 1971; Chave and Luther, 1990) showed that the motionally induced EM field observed at the seafloor provides useful information of barotropic oceanic flows. On the other hand, detection of tsunami events in pelagic environments recently becomes very keen to warn tsunami assault at the shore. Differing from conventional tsunami sensors, ocean bottom EM fields can determine arrival directions and particle motions of tsunamis even by a single site observation, since EM measurements are essentially vector measurements. Recently, it was found, for the first time, that EM time-series from a seafloor geomagnetic observatory in the northwest Pacific Ocean captured clear signals of the tsunami-induced EM fields.

The seafloor geomagnetic observatory has been operated since August, 2001 (Toh et al., 2004; 20 06). The observatory has successfully provided seafloor EM time-series for slightly less than 2000 days so far with sampling rates of every one or two minute(s). On the other hand, the three years from the end of 2004 were found seismically very active in the Pacific region. The time period covered large tsunami earthquakes such as the great Sumatra-Andaman earthquake occurred on December 26, 2004 (Lay et al., 2005). Among the large tsunami earthquakes, we focused our analysis to a pair of earthquakes occurred successively on both sides of the Kuril Trench in November, 2006 and January, 2007 (Fujii and Satake, 2008) because they had opposite focal mechanisms.

The motional induction signals captured by the seafloor geomagnetic observatory turned out to have dominant frequencies of 1 and 3 mHz for the 2006 and 2007 tsunami events, respectively. The vector geomagnetic measurements also allowed us to determine the tsunami arrival direction. The estimated bearing of N322.7E was found in very good agreement with the direction to the epicenters. This is the first solid evidence for the presence of not only motionally induced electric field but also magnetic field. It has been argued that the motionally induced magnetic field tends to be masked by geomagnetic disturbances of external origin (Chave and Luther, 1990). This conjecture has led to observational focus on the seafloor electric field (Larsen and Sanford, 1985; Luther et al., 1991; Segawa and Toh, 1992; Nolasco et al., 2006) rather than the magnetic field. However, the motional induction signals reported here proved that the magnetic field cannot be neglected.

Another important property of the detected magnetic field is that it showed opposite responses to the opposite initial motions of the two tsunami events due to the opposite focal mechanisms. It was revealed that the 2006 event was associated with positive initial wave height while it was negative in 2007 (Fujii and Satake, 2008), which was clearly distinguishable by the opposite signs of the captured magnetic signal. This is very important information that can be made use of in terms of disaster mitigation, since the rise wave may become preemptive assault of large amount of water onto the shore. The rise and retreat tsunami waves can be discriminated from each other by seafloor EM observations, though conventional tsunami sensors are also capable of the distinction.