Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SEM36-02 Room:413 Time:April 30 15:30-15:45

Classification of tsunami dynamo phenomena in terms of ocean depths

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Conductive seawater moving in the geomagnetic main field drives an electromotive force and induces secondary electromagnetic (EM) fields. This effect is well known as "oceanic dynamo effect" and has been investigated for many years, especially for low-frequency phenomena such as tides and steady oceanic flows. However, it was recently found that tsunamis are also significant sources of the oceanic dynamo effect. Toh et al. (2011) reported tsunami-induced EM field data observed at the northwest Pacific seafloor EM station (NWP) at the time of the 2006/2007 Krill tsunamigenic earthquakes. Ever since, many events associated with the oceanic dynamo effect by tsunamis, hereafter called "tsunami dynamo effect", have been reported (e.g., Manoj et al. 2011; Suetsugu et al., 2012; Ichihara et al., 2013). To explain the tsunami dynamo effect, most of the preceding studies adopted analytical approaches in the frequency domain (e.g., Tyler, 2005). However, it is difficult to understand how EM fields are generated by tsunami propagations, although analytical solutions are very useful and handy.

In order to understand the tsunami dynamo effect more physically, we compared analytical solutions and results of numerical simulations using solitary waves, and revealed that tsunami dynamo phenomena can be classified according to the influence of the diffusion term in the induction equation for the magnetic field. In tsunami dynamo phenomena, the ocean depth has a dominant influence on the diffusion term. When the ocean depth is shallow enough, the diffusion term is large and comparable with the source term, while the self-induction term is small. In this case, the self-induction effect cannot attenuate the magnetic field induced by the coupling of the oceanic flows (v) and the geomagnetic main field (F), namely v×F. We can understand this case mostly by the Ampere's Law. On the other hand, when the ocean depth becomes deeper, the self-induction effect gets larger and reduces the amplitude and causes delay in phase of the magnetic field induced by v×F. Especially for the ocean depth deeper than 5000 m, the amplitude is attenuated to approximately 70 percent and the phase is delayed by more than 70 degrees compared with the magnetic field due to v×F, which can be understood by analogy with "Frozen Flux". As for the case of the tsunami dynamo phenomena reported by Toh et al. (2011) as well as Minami and Toh (2013), we can regard the phenomena as the self-induction dominant case because the ocean depth at the observation site, NWP, is approximately 5600m. This is consistent with the fact that sea level changes observed at the two DART sites in the vicinity of NWP are in phase with that of the vertical component of the magnetic field observed at NWP. In addition, our analysis using analytical solutions revealed that magnitudes of the tsunami-induced magnetic field have maximum peaks around the ocean depth of 2000m, when the tsunami height is fixed to 1m. This is because the self-induction and the diffusion effect, which vary differently according to the ocean depth, balances around that specific depth. These results are important because they enable us to predict how EM fields are induced by tsunamis in a variety of ocean depths, even though the number of observed examples of tsunami dynamo phenomena is limited at present. It is possible that our results are applied to tsunami early warning or mitigation of tsunami hazards in the future.

In the presentation, we will report the methodology of our classification of tsunami dynamo phenomena and discuss how tsunami-induced EM fields vary according to the ocean depth. We will also discuss how the ocean depth influences on the recently found initial rise (Minami and Toh, 2013) in the horizontal magnetic component observed prior to tsunami arrivals.

Keywords: tsunami, dynamo, solitary wave, seafloor observation, finite element method