Magnetic fields generated by tsunamis: Case studies on the 2009 Samoa and 2010 Chile earthquake tsunamis

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Abstract

This study focuses on examining the potential applications of the tsunami magnetic field to tsunami early warning, which includes the sensitivity and early arrival of the tsunami magnetic field to the tsunami sea level change in addition to the accuracies of both propagation direction and wave height estimated by the tsunami magnetic field, using the world's first simultaneous observation of tsunami magnetic field and tsunami sea level change data at the time of the 2009 Samoa and the 2010 Chile tsunamis. The world's first simultaneous observation was contained in a seafloor array data consisting of Site SOC1 through SOC9 (Suetsugu et al., 2021) acquired in the south Pacific Ocean around Tahiti (the TIARES area). Advanced three-dimensional (3-D) simulations of the tsunami velocity and magnetic fields for both events have been conducted as well.

In Chapter 1, the thesis started with the research history of motional induction phenomena in the Earth's ocean in order to characterize the tsunami magnetic field. The tsunami magnetic field has a large potential for tsunami early warning. To obtain an insight on

application of the tsunami magnetic field to tsunami early warning, the thesis investigated the advantages and disadvantages of the tsunami magnetic field for tsunami early warning based on the observed data of the 2009 Samoa and 2010 Chile tsunamis.

In Chapter 2, the thesis first presented the data processing methods for obtaining the tsunami signals from the observed sea level change and magnetic field data. By applying the precise deconvolution and a band-pass filter to the observed sea level change data as well as a combination of the external field correction and band-pass filters for the magnetic field data, the tsunami sea level change and magnetic signals of not only the larger 2010 Chile tsunami (Mw 8.8) but also the smaller 2009 Samoa tsunami (Mw 8.1) were successfully extracted from the observed data. The observed magnetic signal of the 2009 Samoa tsunami proved that the tsunami magnetic signals have a ~1-centimeter sensitivity to the respective sea level change. Second, this study examined the estimates of the tsunami propagation directions by the tsunami magnetic field. The results indicated that using the horizontal components of the tsunami magnetic field, the tsunami propagation directions can be estimated 2~4 minutes after the tsunami wave arrival at each observation site (we call it as 'the single station method' hereafter). It was also illustrated that the accuracy of the single station method is subject to change by the noise in the observation. On the other hand, fitting to distinct peaks of arbitrary tsunami magnetic components was found to give more reliable direction estimates, although this method ('the array station method') needs more time than the single station method since it requires all peak times over the whole array. Third, using the simultaneous data of both tsunami magnetic field and sea level change observed at SOC8, the phase lead of tsunami vertical component, b_z, was confirmed. The first arrival of tsunami b_z was ahead of the corresponding sea level change by 34 and 69 seconds for the 2009 Samoa and 2010 Chile tsunamis, respectively, which can be converted into phase angles smaller than 70 degrees implying that they fall in either 'the self-induction dominant case' or 'the intermediate case' according to Minami et al's (2015) classification. However, the initial rise in tsunami horizontal component, b_h, was not detected clearly in the observation. Finally, the accuracy of the sea level changes calculated from tsunami b_z and b_h by comparing them with the observation at SOC8. The results clearly showed that the conversion was very accurate, which means that the converted sea level changes from the tsunami magnetic field can be another (i.e., new) source of tsunami data.

In Chapter 3, the thesis conducted 3-D simulations of both tsunami velocity and magnetic fields for the 2009 Samoa and 2010 Chile events in time domain. In the simulation of tsunami velocity field, it was found that the existing tsunami source models cannot explain the observation in the TIARES area. This study, therefore, introduced modifications of amplitude and arrival time to the simulated results for both events so as to fit the very first arrivals, and the modified simulation results agreed with the observation much better. The same modifications were also applied to the simulated tsunami magnetic field taking advantage of the linear relationship between the complex amplitude of tsunami sea level change and magnetic field. The modified tsunami magnetic simulation agreed well with the observation in the TIARES area. It implies that the major source of simulation error lies in the insufficient tsunami source models. Then, using the modified tsunami magnetic field, the initial rise in tsunami b_h was further investigated in order to clarify the reason why we could not identify clear initial rise signals in the TIARES observation. The examination suggests that the initial rise in tsunami b_h of the 2009 Samoa event was too small to recognize, while that of the 2010 Chile tsunami is marginal although the possible initial rise signal in tsunami b_h of the latter event was clearer than the former both in observation and modified simulation. Unfortunately, however, the complex dual-peak structure of its first arrival obscured the presence of the initial rise signal.

In Chapters 4 and 5, the thesis discussed and summarized the results of the present study. In general, this study has shown that the tsunami magnetic field has not only enough accuracy for tsunami early warning but also sufficient ability of earlier detection of tsunamis. Because it is possible to estimate, in quasi real-time in principle, the tsunami wave height as well as the propagation direction, the tsunami magnetic field can be a powerful tool for global tsunami early warning. The converted tsunami sea level changes from the tsunami magnetic field may give a set of new and useful data for constructing better tsunami source models.