Observational and theoretical waveforms of electromagnetic signals generated by the motional induction effect before the arrival of seismic waves

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Earthquake ruptures and consequent ground motions generates variations in the electromagnetic (EM) field by means of variety of conversion processes in the Earth's crust. The generated EM signals are referred to as seismo-EM signals. Some of the earlier works have reported seismo-EM signals that are observed prior to the arrival of seismic waves [e.g. Iyemori et al. 1996 (JGG); Honkura et al. 2002 (EPS); Okubo et al. 2011 (EPSL)], which are sometimes referred to as "early seismo-EM signals". Theoretical calculations have been conducted to identify the generation mechanisms of the observed seismo-EM signals assuming some of candidate conversion mechanisms including the electrokinetic effect [Haartsen and Pride 1997 (JGR)], the motional induction effect [Gao et al. 2014 (JGR)], the piezomagnetic effect [Yamazaki 2016 (GJI)] and the piezoelectric effect [Ogawa and Utada 2000a (PEPI), 2000b (EPS)]. However, definitive answers have not been obtained, particularly for the case of early seismo-EM signals.

The objective of this work is to compare theoretical time-series of seismo-EM signals arising from the motional induction effect with observational one by means of simple numerical models. In an earlier work, Gao et al. [2014] consider the same problem by assuming uniform full-space model with analytical solutions. Their results imply that theoretical early seismo-EM signals in this situation are far smaller than observed ones. In the present work, I consider a model composed from conductive half-space that represents the Earth's crust and another half-space that represents the air as an insulator. In frequency domain, governing equations in this situation are reduced to ordinary differential equations by applying the Hankel transform, which can be solved analytically. Seismo-EM Solutions of the original equations are then obtained after the inverse Hankel transform. Time-series of seismo-EM signals are then obtained after the inverse Fourier transform.

The comparisons between observed and theoretical seismo-EM variations are performed for two cases: one is the phenomena observed at the time of 1999 Izmit earthquake, Turkey [Honkura et al. 2002], and the other is that observed at the time of 2008 Iwate-Miyagi earthquake, Japan [Okubo et al. 2011]. Early seismo-EM signals observed for these two earthquakes have different characters. For the case of Izmit earthquake, signals appeared only after seismic waves reach close to the observational site. In contrast, for the case of Iwate-Miyagi earthquake, EM signals emerges just after the onset of seismic ruptures. Numerical calculations assuming the motional induction effect reasonably account the feature of signals for the Izmit earthquake, but do not account that for the Iwate-Miyagi earthquake.

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