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Piezomagnetic signals just after the occurrence of seismic events: some examples of 2-D calculation

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Electromagnetic (EM) field observations may detect occurrences of earthquake. Several mechanisms convert seismic waves to variations in EM field. Variations in EM field generated near the seismic sources are possibly detected before the arrival of seismic waves because EM waves propagate the speed of light. This means, observations of EM field potentially improve the usefulness of earthquake early warning systems, which are conventionally based solely on observations of seismic waves.

The piezomagnetic effect is likely an important mechanism in terms of an application to the earthquake early warning by EM observations. The piezomagnetic effect describes changes in the magnetization of ferromagnetic minerals. Mathematical treatments to calculate changes in the magnetic field generated by the piezomagnetic field, referred to as the piezomagnetic field, have been developed [e.g. Sasai, 1991, Bull. Earthq. Res. Inst., Utsugi et al., 2000, GJI] to provide constraints on changes in the stress field accompanying with tectonic events. Although focuses of many studies on the piezomagnetic field are on the static problem, temporal variations in the magnetic field are also considered to be arisen by the piezomagnetic effect. An example of variations in the magnetic field, which likely generated by the piezomagnetic effect at the time of an earthquake but occurred prior to the arrival of the corresponding seismic wave, was reported at the time of the M.7.2 Iwate-Miyagi Nairiku Earthquake in Japan by Okubo et al. [2008, EPSL]. Okubo et al.'s result implies potential use of the geomagnetic observation as an approach to the earthquake early warning.

To promote the feasibility study of the piezomagnetic field observations as a tool of earthquake early warnings, we need to examine temporal variations of the piezomagnetic field corresponding to various kinds of seismic sources, because variations in the magnetic field observed before the seismic wave arrival may be less informative even if they can be detected. To make reliable calculations on this problem, we need to establish a calculation procedure to treat temporal variations both in the stress field and the EM field. Temporal variations in the magnetic field corresponding to time-development of the fault rupture was performed by Okubo et al However, their calculation may somewhat inaccurate. Their calculation was performed in a framework of static piezomagnetic field simulation, in which only near-field term of the displacement field is considered and velocities of seismic waves are assumed to be infinite. In addition, the effect of EM induction was totally ignored. We need to assess how the calculation result is altered when considering finite speed of seismic waves and the electromagnetic induction.

In the present study, we consider a rather simple two dimensional (2D) problem, consisting of an upper half-space representing the air, and a lower half-space representing a solid Earth with a uniform conductivity. The dislocation source is assumed to be two-dimensional, thus the displacement and stress field are also two dimensional. A rigorous solution of the EM field generated by time-varying sources aligned on a line (i.e. line source solution) has already given in the frequency-domain [Yamazaki, 2011, 2012, GJI]. The solutions are further converted to those in the time-domain. Line source solution EM fields generated by time-varying magnetizations with 2-D spatial distributions are obtained by integrating the line source solution.

As examples, two types of rupture and the generated stress fields are considered as the sources of the piezomagnetic field. One is a strike slip at the ground surface, and the other is a dip slip at a buried fault. Displacement fields corresponding to these sources are presented by a textbook in seismology [Aki and Richards, 2002]. Remarks of the results will be shown at the meeting.

Keywords: piezomagnetic effect, seismic wave, detection of earthquakes