Numerical simulation of ULF electromagnetic wave propagation in the lithosphere associated with earthquakes by using the WLP-FDTD method

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For decades, many papers reported that the Ultra Low Frequency (ULF) radiations associated with earthquakes were observed by magnetometers installed at the Earth's surface. Those mainly focused on detection of anomalies exceeding noises, or anomalous characteristics extracted from noises via signal processing. However, observed signals involve information of not only their source intensity, but also losses of media in which the ULF waves propagate, which should be taken into account. For this reason, numerical simulation of ULF propagation in the lithosphere is of importance.

In this study, we develop numerical simulation of the ULF propagation by using the weighted Laguerre polynomial finite-difference time-domain (WLP-FDTD) method with considering electrical properties of lithosphere, and investigate correlation between magnitude of earthquakes and the source current intensity of ULF radiation which is deduced from the numerical simulation.

The WLP-FDTD method solves electromagnetic fields by expanding solutions into weighted Laguerre polynomial series, discretizing computational region in space, and reducing the Maxwell equations into linear equations. This method is not a marching-on-time, but a marching-on-degree scheme, so that we can obtain more precise solutions by iteration even for responses over long time duration. The WLP-FDTD method showed several ten times less computational time than the conventional FDTD method.

We adopt Loma Prieta earthquake as a standard because the observation was performed over wide range of frequency bands so that frequency characteristics of the source current can be deduced. The conductivity distribution around the epicenter was obtained by the magnetotelluric measurement and it is implemented in the WLP-FDTD simulation.

Next, we calculate the source current intensity of earthquakes, such as Spitak EQ (1988), Biak EQ (1996), and Alum Rock EQ (2007), under the assumption that the frequency dependence of the source current is the same as one of Loma Prieta EQ. Especially, in Biak EQ the ULF signals are not detected directly, but the polarization analysis showed an anomaly associated with EQ. Therefore, we deduce that the Signal-to-Noise ratio of Biak EQ is approximately -3dB because the ULF wave at the observation point is less than noises, but is not much less. The conductivity is also taken into consideration in the simulation in each EQ, using MT measuments and bathymetry data.

From the above analyses, it is found that the relative intensity of source currents grows exponentially with the magnitude of EQs.

Keywords: Ultra Low Frequency electromagnetic wave, Weighted Laguerre Polynomial FDTD, Seismo-electromagnetics