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Estimation of induction effect on EM time series data by using MT frequency functions

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Introduction

There are many studies concerning precursory or co-seismic electromagnetic signals associated with earthquakes. In many cases, the signals are thought to be caused by piezomagnetic effect [1-4], or electrokinetic effect [5-8]. Recently, it has been reported that tsunami induced EM signals [9-11]. If an earthquake occurs during a period of geomagnetic storm coincidentally, the signals may be buried in the effect of induced fields, which seems to be difficult to detect them.

The 2011 Tohoku Earthquake (M9.0) occurred on March 11, 2011. We obtained electromagnetic time series data at the Tohoku region during the period from Dec. 2010 to Apr. 2011. Since the earthquake occurred during a geomagnetic storm unfortunately, we need to remove the effect of induced fields to enhance detectability of the signals. In the present study, we propose an estimation of induced fields in electromagnetic time series data by using MT frequency response functions. We also present the result of analyzing the data by using the method.

Method

In the MT method, fluctuation in the natural electric field E(ω) and magnetic field H(ω) in orthogonal directions are related through an impedance tensor Z(ω) as follows:

$$\begin{pmatrix} E_x(\omega) \\ E_y(\omega) \end{pmatrix} = \begin{pmatrix} Z_{xx}(\omega) & Z_{xy}(\omega) \\ Z_{yx}(\omega) & Z_{yy}(\omega) \end{pmatrix} \begin{pmatrix} H_x(\omega) \\ H_y(\omega) \end{pmatrix}, \quad (1)$$

where *x* and *y* correspond to northward and eastward directions, respectively. In the regular procedure of the MT method, the impedance tensor Z(ω) is estimated in the frequency domain.

Let us suppose that the impedance tensor Z(ω) is already estimated by processing of MT method procedure, we can simply obtain electric field E(ω) from magnetic field H(ω) by using equation 1. The obtained electric field E(ω) should be indicated the effect of induced fields in the frequency domain.

When we take admittance tensor $Z^{-1}(\omega)$ (inverse matrix of impedance tensor), equation 1 can be rewritten as follows:

$$\begin{pmatrix} H_x(\omega) \\ H_y(\omega) \end{pmatrix} = \begin{pmatrix} Z_{xx}(\omega) & Z_{xy}(\omega) \\ Z_{yx}(\omega) & Z_{yy}(\omega) \end{pmatrix}^{-1} \begin{pmatrix} E_x(\omega) \\ E_y(\omega) \end{pmatrix}, \qquad (2)$$

in the same way, we can also obtain magnetic field H(ω) from electric field E(ω) from equation 2. Since the equation 1 and 2 are in the frequency domain, the time domain electric field E(t) and the magnetic field H(t) data have to be converted to frequency domain data. The time domain data can be converted to frequency domain data by using Fourier transform algorithm as follows:

$$E(\omega) = \int_{-\infty}^{\infty} E(t) e^{-i\omega t} dt, \qquad (3)$$

$$H(\omega) = \int_{-\infty}^{\infty} H(t) e^{-i\omega t} dt. \qquad (4)$$

Frequency domain data can be converted to time domain data by using inverse Fourier transform algorithm as follows:

$$E(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} E(\omega) e^{i\omega t} d\omega, \qquad (5)$$

$$H(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} H(\omega)\, e^{i\omega t} d\omega. \qquad (6)$$

To obtain an induced electric field $E_{ind}(t)$ from observed magnetic field $H_{obs}(t)$ at any site, first, $H_{obs}(t)$ is converted to $H_{obs}(\omega)$ from equation 6. After the conversion, $H_{obs}(\omega)$ is converted to $E_{ind}(\omega)$ by using equation 1. Finally, we can convert the $E_{ind}(\omega)$ to $E_{ind}(t)$ from equation 5.

Induced magnetic field $H_{ind}(t)$ can be also estimated from observed electric field $E_{obs}(t)$ from 2, 3, and 6 in the same way. Since observed data is discrete and of finite length, we have to apply discrete equations to the real data when we operate those kinds of conversions.

Data analysis

The 2011 Tohoku Earthquake (M9.0) was occurred on March 11, 2011 at 05:46:18 UTC with the hypocenter located at 38.103ºN, 142.860ºE at the depth of 24km. MT continuous survey was conducted at MRM (Marumori town, Miyagi prefecture in Tohoku region) from Dec. 2010 to Apr. 2011. The data consists of five components (Ex, Ey, Hx, Hy, and Hz) with continuous 32 Hz sampling by using ADU07 system manufactured by Metronix Geophysics. Typical period range of the magnetic coil sensors is from

0.001 to 10,000 periods under fine noise-free condition. We apply a high-pass digital filter with cut-off period of 6,500s due to the coil sensitivity and background artificial noise situation of the site. The observed data quality at the site is not good at around 1s period. Thus, we resampled the observed data from 32 Hz to 4s sampling with an appropriate anti-aliasing filter. To check the result of analysis, we also used reference magnetic data at four JMA geomagnetic observatories (MMB, KAK, CBI, KNY). Since the reference magnetic data are measured in 1s sampling, the data also resampled to 4s sampling. MT Impedance tensor at the MRM was estimated by using the robust code of BIRRP [12].

To confirm the method, we show results on the day when geomagnetic storm was dominant. Comparing observed with predicted electric fields, we found that the predicted data explains the observed data very well for both electric and magnetic fields. These results imply that the estimation of the induced fields is successfully fulfilled induction and this method is very useful for the estimation of the effect.

Hx residual electric fields at MRM, KAK, and CBI do not show significant variations before the origin time of the earthquake. However, MMB show a positive rising anomalous variation of approximately 2 nT, and MRM show a negative obvious variation of approximately 4 nT at the earthquake occurrence time. The remarkable variation of each site of MMB and MRM starts from approximately 20 minutes before and continue to the arrival time of the earthquake. The variation at the MRM where the closest site of the epicenter of the earthquake shows the dominant, which suggests that the variations is thought to be a signal associated with the earthquake. Note that the predicted Hx from the electric fields at the MRM do not show such a significant variation, which implies that the variations appear in only magnetic fields that may be caused by piezomagnetic effect.

Conclusions

We attempted to estimate the effect of induced fields in the time series data by using MT frequency response functions. The estimations of induced electric and magnetic fields are successfully predicted by using the method. After correction of the effect of induced fields at the MRM and reference magnetic stations, obvious variations are detected before and after The 2011 Tohoku Earthquake. These results suggest that this method can be used as a powerful tool for detecting of signals associated with earthquakes on time series data.

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