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The Electromagnetic Observation and Inter Station Transfer Function Analysis before and after the 2002 Dyke Intrusion at Hachijo Island

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Abstract

There are many volcanoes and large earthquakes or earthquake swarms in Izu-Bonin Arc which stretches to the south in the Pacific Ocean. We have many electromagnetic observation systems in this area. In this study, we mention about the data observed at Hachijo Island. In August 2002, a dyke intruded in the N-S direction at a depth of 3 km beneath the Hachijo-Fuji, one of the volcanoes in Hachijo Island. The 3 components magnetic observation was performed in Hachijo Island by Hydrographic & Oceanographic Department of the Japan Coast Guard. To investigate the possible changes of electric conductivity beneath the Hachijo-Fuji, we analyzed this 3 component magnetic data before and after the dyke intrusion with the method of Inter Station Transfer Function (ISTF). We used data at Kakioka Magnetic Observatory as a reference station. The ISTF analysis provides the information on the difference of the electrical underground structure between the observation station (Hachijo Island) and reference station (Kakioka). We calculated monthly mean ISTF elements from 1998 to 2005. We used continuous wavelet transform instead of the conventional Fourier transform to promote accuracy in the calculation. As a result of analysis, we could not find obvious changes of ISTF components before and after the dyke intrusion in August 2002. The magnetic observatory was far (about 10 km from Hachijo-Fuji) to detect the influence of the dyke intrusion.

Introduction

Observations of the electromagnetic changes associated with seismic, volcanic and tectonic activities have been performed to clarify the generation mechanism and to be of useful to the monitoring of these activities. These studies were called "Seismo-, Volcano- and Tectono-Electro Magnetics". It has long been suggested that the electrical conductivity structure changes

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by seismicity and volcanism. The geomagnetic transfer function is a method to detect and verify such changes (Rikitake, 1966 ; Sano, 1980 and 1982). Yanagihara and Nagano (1976) reported the changes of geomagnetic transfer functions at Kakioka Magnetic Observatory over 10 years before and after the 1923 Kanto earthquake.

In the central part of the Japanese Islands, Izu-Bonin arc which stretches to the south in the western Pacific Ocean is one of the most active seismic and volcanic areas. Many electromagnetic observations have been performed intensively in this area, e.g. Izu Oshima Island (Yukutake, 1990) and Miyake Island (Nakagawa *et al.*, 1984 ; Utada *et al.*, 1984 ; and Sasai *et al.*, 2002). In Hachijo Island, the magnetic observation (total magnetic intensity and 3 component magnetic fields) has been performed since 1978 by Hydrographic & Oceanographic Department of the Japan Coast Guard (HJJ) (Fig. 1a).

In August 2002, there was a dyke intrusion in the N-S direction 3 km beneath the Hachijo-Fuji, one of the volcanoes in the Island (Kimata *et al.*, 2004). Fig. 1b shows the distribution of earthquakes in August 2002.

To investigate the possible changes of electric conductivity beneath the Hachijo-Fuji, we analyzed 3 component magnetic data observed at HJJ observatory before and after the dyke intrusion with the method of Inter Station Transfer Function (ISTF). ISTF is defined as the response function between two sets of three components of magnetic data at a observation station and reference station. We use magnetic data observed at Kakioka Magnetic Observatory, JMA as a reference station in this study. The ISTF analysis provides the information on the difference of the electrical underground structure between the Island and Kakioka. If there were any conductivity changes at HJJ, the ISTF would change before and after the dyke intrusion. In this paper, we calculated monthly mean ISTF between Hachijo Island (HJJ) and Kakioka (KAK) from 1998 to 2005.

In the conventional Fourier transform analysis, transient changes interfere the overall spectral properties and seriously degrade the accuracy

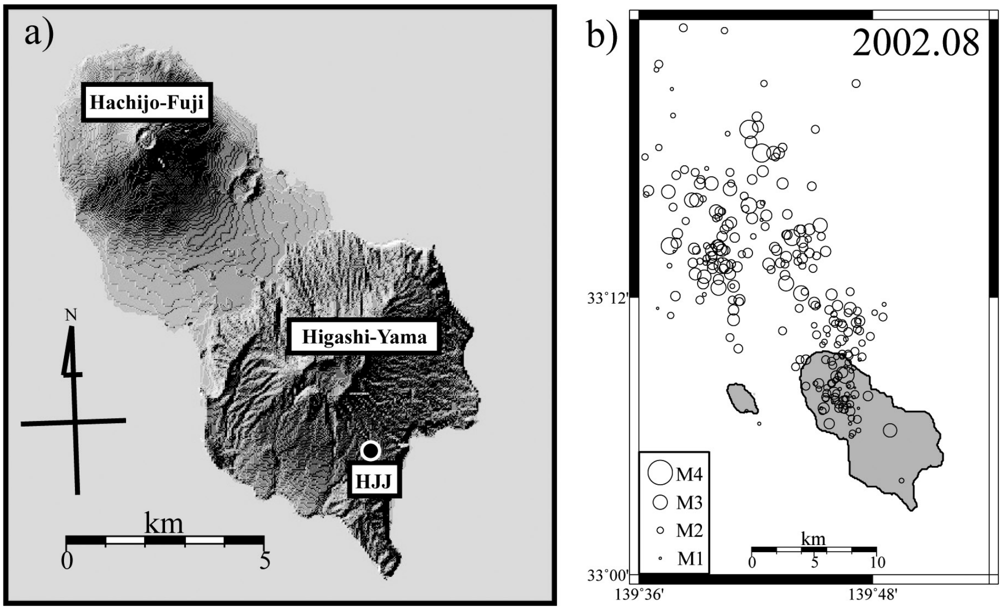

Fig. 1 a) Map of the Hachijo Island. HJJ indicates the magnetic observatory of Hydrographic & Oceanographic Department of the Japan Coast Guard.
b) Distribution map of earthquakes occurred around Hachijo Island in August 2002.

of the transfer functions. To avoid these effects, robust algorithms have been used since 1980s in the field of electromagnetic exploration (Egbert and Booker, 1986; Chave *et al.*, 1987). Harada *et al.* (2004) showed that the accuracy of the ISTF with continuous wavelet transform method was as high as that of robust estimations of transfer functions calculated by the Fourier transform method. Therefore, we used the continuous wavelet transform method in this study.

Method

The three components of geomagnetic field variations measured at a point can generally be expressed as ;

$$Z(\omega) = A(\omega)\cdot X(\omega) + B(\omega)\cdot Y(\omega), \tag{1}$$

where ω is the frequency, and $X(\omega)$, $Y(\omega)$, and $Z(\omega)$ are the Fourier coefficients of N-S, E-W, and up-down components of the geomagnetic field variations. $A(\omega)$ and $B(\omega)$ are called the geomagnetic transfer functions (Rikitake and Honkura, 1985). Short-term variations in the geomagnetic field are composed of the primary source field, secondary induced field and noises of various origins. The transfer functions depend on the underground electrical structure.

In the geomagnetic mid-latitude regions, including Japan, the geomagnetic field fluctuations originated in the upper atmosphere can be approximated by vertically incident uniform plane waves. Under this condition, the relationship of the geomagnetic field data observed at a site, and at the remote reference station may be expressed as follows (Harada *et al.*, 2004) ;

$$\begin{pmatrix} X_s(\omega) \\ Y_s(\omega) \\ Z_s(\omega) \end{pmatrix} = \begin{pmatrix} T_{xx}(\omega) & T_{xy}(\omega) \\ T_{yx}(\omega) & T_{yy}(\omega) \\ T_{zx}(\omega) & T_{zy}(\omega) \end{pmatrix} \cdot \begin{pmatrix} X_r(\omega) \\ Y_r(\omega) \end{pmatrix} + \begin{pmatrix} \delta X(\omega) \\ \delta Y(\omega) \\ \delta Z(\omega) \end{pmatrix}, \tag{2}$$

or

$$\mathbf{H}_s(\omega) = \mathbf{T}_{is}(\omega)\cdot \mathbf{H}_r(\omega) + \delta\mathbf{H}(\omega). \tag{3}$$

Here $\mathbf{H}_s(\omega)$ and $\mathbf{H}_r(\omega)$ are the Fourier coefficients of observed geomagnetic field data at a station and at the remote reference station, respectively. $\mathbf{T}_{is}(\omega)$ is the inter-station transfer function (ISTF), and $\delta\mathbf{H}(\omega)$ denotes the uncorrelated noise. The diagonal elements, T_{xx} and T_{yy}, indicate the complex-valued spectral ratio in each component between the two stations. If the incident wave and the underground structure are spatially uniform, the real components of the diagonal elements are 1.0. In actual case, the diagonal elements are not exactly 1.0, due mainly to structural heterogeneity, and the non-diagonal elements, T_{xy} and T_{yx}, have non-zero values. The elements, T_{zx} and T_{zy}, have the meaning analogous to the single station transfer functions, $A(\omega)$ and $B(\omega)$ in Eq. (1).

The ISTF is usually estimated using data taken when the ratio of $\mathbf{H}_s(\omega)$ to $\delta\mathbf{H}(\omega)$ is high, such as the nighttime data on days of high solar-terrestrial geomagnetic activity. The elements of the ISTF are determined by making use of the usual power-spectrum approach.

The mother wavelet is chosen according to the signal properties and the purpose of analysis. We chose the Morlet wavelet (Grossman and Morlet, 1984), because it has a simple relationship between frequency and scale. The Morlet wavelet uses the exponential $e^{i\omega t}$ as the basis function in combination with a Gaussian window function ;

$$\psi_0(t) = \pi^{-1/4} e^{i\omega_0 t} e^{-t^2/2}, \tag{4}$$

where the dimensionless parameters t and ω_0 express the time and frequency, respectively. This wavelet function meets the admissibility condition at $\omega_0 \geq 5$. The waveform of the Morlet wavelet ($\omega_0 = 5$) is shown in Fig. 2.

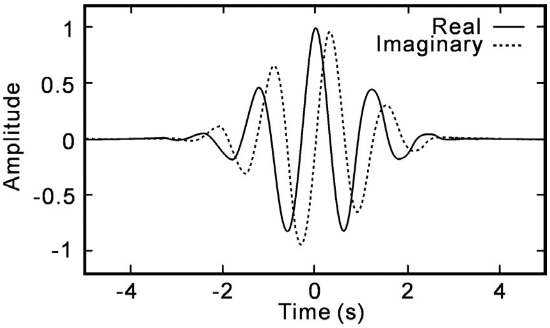

Fig. 2 The waveform of the Morlet wavelet ($\omega_0 = 5$ in Eq. [4]).

Result

We applied the wavelet method to the HJJ and the KAK data. We choose the high geomagnetic activity days (three hour $Kp \geq 5$) for every month. The number of such days was usually 3-5 per month. There were several months that had no significant storm. Nighttime 6 hours (from 21:00 to 03:00 LT) of the chosen days were segmented into consecutive windows with length which would contain enough number of data points to reduce the effects of isolated outliers.

The correlation function and the Inter-Station Transfer Functions were calculated for every chosen time-frequency window. Then, the windows with inter-station correlation function higher than 0.90 were selected because the transfer functions obtained from those windows were expected to be higher in accuracy. The final transfer functions of the month were the results of the least-square estimate from these windows.

Fig. 3 shows the six ISTF elements for each period of geomagnetic fluctuation. ISTF elements were well determined over the period range from 30 to 500 seconds.

Fig. 4 shows the time variation of ISTF elements from 1998 to 2005 in the periods of 30 seconds, 60 seconds, 120 seconds and 300 seconds. A dashed line shows the time of the dyke intrusion event, August 2002. We could not find obvious changes before and after August 2002.

Discussion

By using the wavelet algorithm, ISTF elements were determined with little error bars. For the periods longer than 60 seconds ISTF elements show almost constant value, which implies that there happened no large-scale changes in the electric conductivity beneath the Hachijo Island.

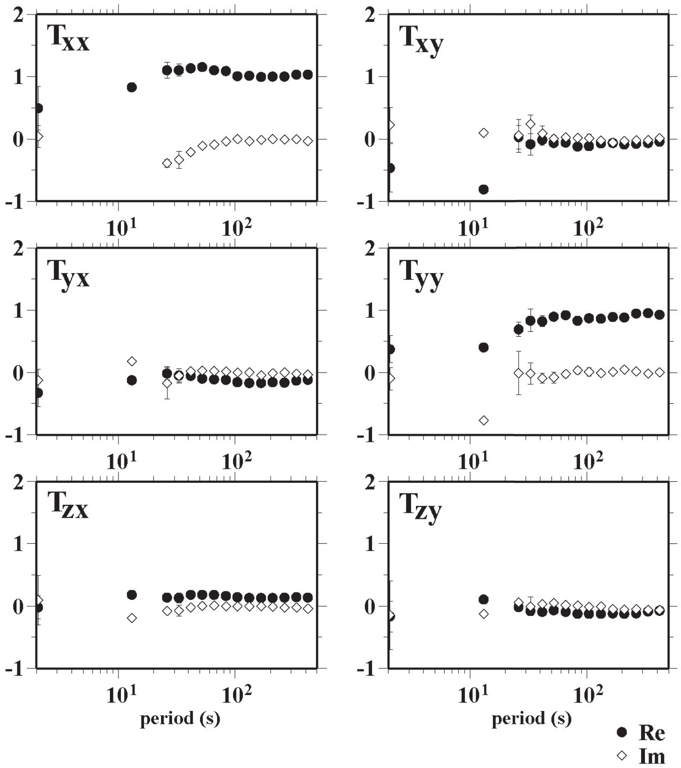

Fig. 3 The Inter-Station Transfer Function elements calculated between HJJ and KAK in August 2002.

Based on GPS and tilt-meter data, a model for crustal deformation was presented, in which a dyke of thickness 3 m intruded in the N-S direction at a depth of 3 km beneath the Hachijo-Fuji volcano. After several days, the thickness of dyke reduced to 1 m, which suggests that the intrusive magma moved away to the north (GSI and JHOD, 2002).

On the other hand, very strange extremely low-frequency earthquakes began to occur at the end of August. Its period is anomalously long, i.e. 7 to 12 seconds. A model for such an earthquake was proposed, which was an oscillating vertical magma sheet of 2 km by 4 km at the top depth of 2.6 km. Such very long period (VLP) events continued to occur for a few months in 2002 (Kumagai *et al*., 2003).

The piezomagnetic changes generated by such an intrusive dyke were computed. Since the dyke top was at a depth of 3 km from the ground surface, the computed total magnetic intensity changes are at

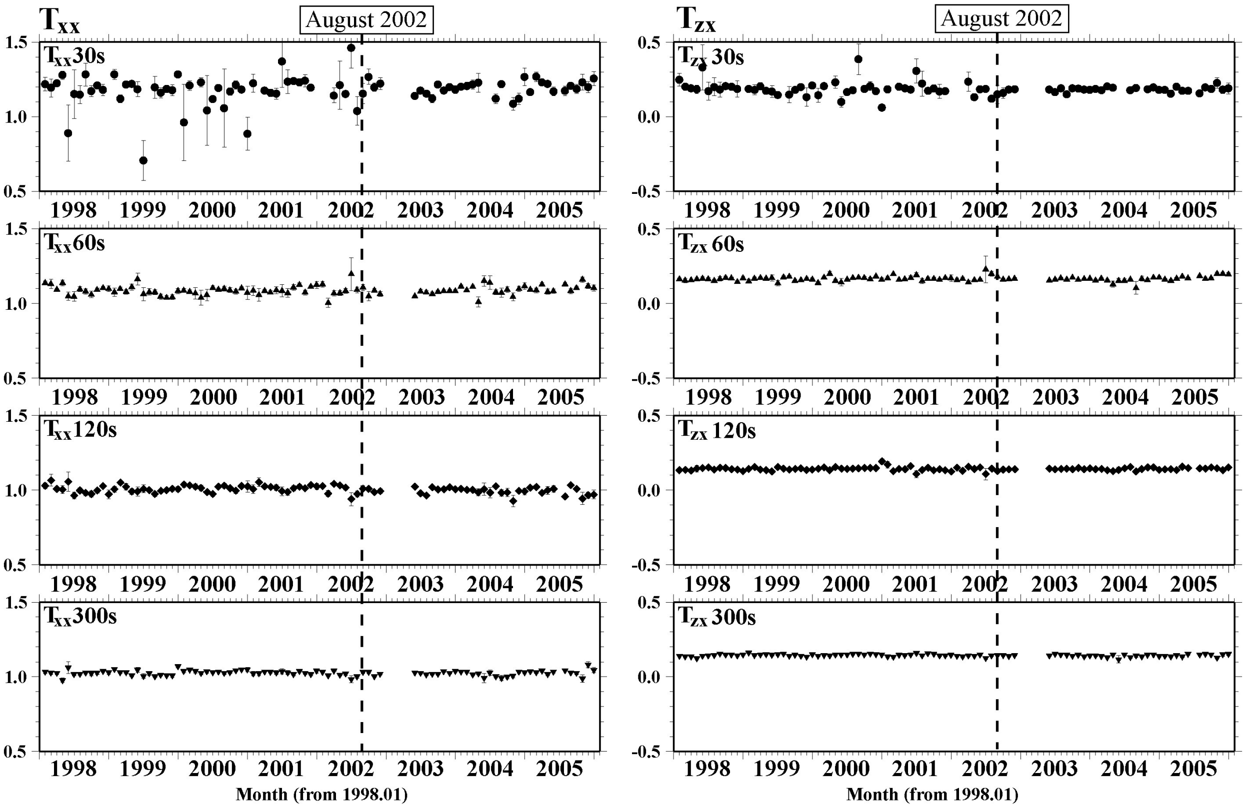

Fig. 4 The monthly variation of ISTF elements (left : Txx, right : Tzx) for each periods from January 1998 to December 2005. A dashed line indicates August 2002, when the dyke was intruded beneath the Hachijo-Fuji Volcano.

most less than 1 nT (Nagao *et al.*, 2006).

Therefore our result is quite reasonable because HJJ Observatory is located on the older volcano about 10 km away from the Hachijo-Fuji volcano.

Conclusion

We calculated ISTF with using the geomagnetic data observed HJJ and KAK before and after the dyke intrusion beneath the Hachijo-Fuji. In this calculation, we applied the wavelet algorithm to promote the accuracy of transfer function. Therefore, we could obtain ISTF elements with little errors.

The time variation of ISTF elements was almost constant value and we could not find obvious changes before and after the dyke intrusion. Many reports pointed that the size of the intruded dyke beneath the Hachijo-Fuji was not so large enough to affect the conductivity beneath all of the Hachijo Island. The magnetic observatory (HJJ) was about 10 km far from Hachijo-Fuji, therefore, we consider our result was quite reasonable.

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Literature Cited

Chave, A. D., D. J. Thomson and M. E. Ander (1987) On the robust estimation of power spectra, coherence, and transfer functions. J. Geophys. Res., **92** (B1), 633-648.

Egbert, G. D., and J. R. Booker (1986) Robust estimation of geomagnetic transfer functions. Geophys. J. R. Astr. Soc., **87**, 173-194.

Grossman, A., and J. Morlet (1984) Decomposition of Hardy functions into square integrable wavelets of constant shape. SIAM J. Math. Anal., **15**, 723-736.

Harada, M., K. Hattori and N. Isezaki (2004) Transfer function analysis approach for anomalous ULF geomagnetic field change detection. Phys. Chem. Eearth, **29**, 409-417.

Kimata, F., M. Irwan and K. Fukano (2004) Ground deformation at Hachijo Island, Japan on 13-22 August 2002 observed by GPS measurements and estimated dike intrusion model. Bull. Volcanol. Soc. Japan, **49**, 13-22.

Kumagai, H., K. Miyakawa, H. Negishi, H. Inoue, K. Obara and D. Suetsugu (2003) Magmatic dike resonances inferred from Very-Long-Period seismic signals. Science, DOI:10.1126/science.1081195.

Nagao, T., Y. Sasai, J. Izutsu, H. Hase, M. Harada, J. Zlotnicki and K. Onodera (2006) Ground-based electromagnetic monitoring of Hachijo-Fuji volcano, Japan. Abstracts of DEMETER International Symposium, Toulouse, France.

Nakagawa, I., Y. Sasai, H. Utada, Y. Ishikawa, S. Koyama K. Oouchi and T. Tokumoto (1984) Changes in total intensity of the geomagnetic field associated with the 1983 eruption of Miyake-jima volcano. Bull. Volcanol. Soc. Japan, Ser. 2, **29**, S101 (in Japanese).

Sano, Y. (1980) Time changes of transfer functions at Kakioka related to earthquake occurrences (I). Mem. Kakioka Mag. Obs. Suppl., **8**, 1-25.

Sano, Y. (1982) Time changes of transfer functions at Kakioka related to earthquake occurrences (II). Mem. Kakioka Mag. Obs. Suppl., **9**, 91-110.

Sasai, Y., M. Uyeshima, J. Zlotnicki, H. Utada, T. Kagiyama , T. Hashimoto and Y. Takahashi (2002) Magnetic and electric field observations during the 2000 activity of Miyake-jima volcano, Central Japan. EPSL, **203**, 769-777.

Rikitake, T. and Y. Honkura (1985) Solid Earth Geomagnetism, Terra Scientific Pub., 384p.

Utada, H., Y. Sasai, I. Nakagawa, S. Koyama, Y. Ishikawa and Y. Hamano (1984) Changes in the electrical resistivity associated with the 1983 eruption of Miyake-jima volcano. Bull. Volcanol. Soc. Japan, Ser. 2, **29**, S113 (in Japanese).

Yanagihara K. and T. Nagano (1976) Time change of transfer function in the central Japan anomaly of conductivity with special reference to earthquake occurrences. J. Geomag. Geoelectr., **28**, 157-163.

Yukutake, T. (1990) An overview of the eruptions of Oshima volcano, Izu, 1986-1987 from the geomagnetic and geoelectric standpoints. J. Geomag. Geoelectr., **42**, 141-150.

2002年ダイク貫入前後における八丈島電磁観測データのISTF解析

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要　旨

伊豆小笠原弧は日本でも有数の火山地帯であり，比較的大きな地震や群発地震なども多い場所である．この地域には数多くの電磁気的観測が行われている．本研究では八丈島で観測された地磁気データについて解析を行った．2002年8月に八丈島北部の火山である八丈富士の地下3 kmに南北方向にダイクが貫入しそれに伴う地殻変動が発生した．八丈島では海上保安庁水路部により3成分磁力測定が行われている．本研究ではダイク貫入前後の八丈島磁力データと気象庁柿岡地磁気観測所のデータを用いて，Inter-Station Transfer Function（ISTF）法を解析手法として，ダイク貫入の地殻変動に伴う地下の電気的構造の変化を調査した．

ISTF法は二点間の地下構造の違いを表し，我々は1998年から2005年までの1月ごとの代表的なISTFの値を求め,地下構造の時間的な変化を調査した．ISTFの計算においては従来のフーリエ変換ではなくウェーブレット変換を用いた．これにより，系統的な誤差を従来よりも小さく抑えることが可能である．

解析結果ではダイク貫入前後で目立ったISTFの変化，つまり八丈島観測点の地下構造の変化は認められなかった．これは八丈島観測点が推定されているダイク貫入の場所よりも10 kmほど離れており，またダイクの大きさも八丈島全体に影響を及ぼすほどではなかったからである．

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