ULF geomagnetic changes possibly associated with the 2008 Iwate-Miyagi Nairiku earthquake

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Abstract

Anomalous ULF geomagnetic field changes associated with earthquake is one of the most convincing and promising phenomena due to deeper skin depth. Since ULF signals associated with large earthquakes are weak, effective signal discrimination methods should be required. In this study, we investigate ULF geomagnetic changes possibly associated with the 2008 Iwate-Miyagi Nairiku earthquake based on spectral density ratio analysis, geomagnetic transfer function analysis, fractal analysis, and direction finding analysis. Geomagnetic data observed at Esashi, where the epicentral distance is about 47 km and Kakioka, the distance is about 317 km, and as a reference station have been analyzed. Wavelet transform have been performed for the spectral density analysis instead of FFT method. Before the earthquake, the variation of spectral density ratio, Sz/Sx and Sz/Sy, at the nearest station of Esashi exhibits an apparent increase from the trend. On the contrary, there are no corresponding significant changes at a remote station of Kakioka. The level of peak is beyond the 3 σ and its duration is 3 days. The lead time is about 3-4 weeks before the earthquake. At the periods from 3 to 105 sec, similar anomalous changes occurred. Results of transfer function analysis are similar. Fractal analysis and direction finding analysis have been also applied. The obtained fractal dimension and direction of arrival of ULF waves show the possible relation to the earthquake. These facts suggest the anomalous change is a possible candidate of earthquake-related ULF magnetic change.

1. Introduction

Recently, there are many reports on seismo-electro electromagnetic phenomena in a wide frequency range. Measurements of electromagnetic phenomena can be classified into three types; (1) passive ground-based observation, (2) active ground-based observation using transmitter signals, and (3) satellite observation.

Among of these observational methods, one of the most promising methods is earthquake related ULF (ultra low frequency, with frequency less than 1Hz) phenomena because of skin depth. ULF geomagnetic data observed at the ground are superposition of several signals. The most intense signals are geomagnetic pulsations. The next intense signals are artificial noises due to DC-driven train, factories and so on. The third signals are earthquake related signals. Earthquake related signals are very weak, so there have been developed several kind of methods for discriminating these signals from other signals; (1) spectrum density ratio analysis by means of the ratio of vertical component to horizontal component, (2) geomagnetic transfer function analysis, (3) mono- and multi- fractal analyses,(4) principal component analysis, (5) direction finding analysis, and so on [1].

So far, it is found that the detectable distance for anomaly is given by the formula $0.025R < M - 4.5$, where R is epicentral distance and M is magnitude [1]. In this paper, ULF geomagnetic data observed at Esashi station are analyzed, where the epicentral distance is about 47 km. Therefore, it is expected to detect some ULF anomalies before the day of the 2008 Iwate-Miyagi Nairiku earthquake. In this paper, the ULF geomagnetic changes associated with the 2008 Iwate-Miyagi Nairiku earthquake are presented based on the spectrum density ratio analysis using wavelet transform, transfer function analysis, fractal analysis, and direction finding analysis.

The 2008 Iwate-Miyagi Nairiku earthquake occurred at N39.03°, E140.89° on June 13, 2008 with magnitude M 7.2 and the depth is 8 km. The source mechanism is reverse faulting with (Strike, Dip, Rake) = (203°, 37°, 93°). The earthquake triggered landslide. Over 10 people died and about 450 people injured. Furthermore, several micro-earthquakes ($M < 1.4$) occurred about 40 minutes before the earthquake near the epicenter and three aftershocks with $M>5$ occurred on June 14, 2008 (M5.7 and M5.2) and June 16, 2008 (M5.3) .

The data observed at Esashi and Kakioka are used. The distances from the epicenter are 47 km and 317 km, respectively. At the nearest Esashi station, 3-component induction magnetometer is in operation by Geographical Survey Institute, Japan. The sampling frequency is 15 Hz. In this study, the data are re-sampled to 1Hz. As a reference, Kakioka data are adopted, where a 3 component fluxgate type magnetometer is in operation with 1Hz sampling by Japan Meteorological Agency. We analyze three years data from January 1, 2006 to 3, December 2008.

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2. Data Analysis

In this paper, spectral density analysis with wavelet transform is performed for detection of anomalous changes in observed data instead of conventional FFT. Because FFT analysis is not suitable for transient signals such as impulses. The concept of this spectral density analysis is based on the idea that signals associated with solar-terrestrial origins are likely to be plane waves with vertically incident. Therefore, there is no vertical component of magnetic field theoretically, while crustal origin signal from the underground current is considered to have a vertical component. This suggests that the spectral density ratio such as Sz/Sx and Sz/Sy shows a small or a certain value for the normal period. Here Sx, Sy, and Sz mean the spectral density at a certain frequency for north-south, east-west, and vertical component, respectively. On the other hand, the higher value of spectral density ration is expected in the active period of earthquake-related ULF electromagnetic phenomena. In this paper, Morlet wavelet is selected for a mother function. Morlet wavelet is defined by a sinusoidal function and a Gaussian window.

2.1 Spectrum density analysis

According to the previous reports, the possible anomalous changes are dominant in range of 10-100 sec. The results seem to be consistent. In order to investigate tendency of variation in power, 3 hours averaging is performed. In order to compare the seismic activity, Es index is introduced. It is the daily sum of local earthquake energy in terms of magnitude in the following formula.

$$Es = \log \sum_{1day} \frac{10^{4.8+1.5M}}{r^2} \qquad (1)$$

where M and r indicate magnitude of earthquake and hypocenter distance from Esashi station. In this paper, earthquakes with r < 200 km are selected from the earthquake catalog issued by Japan Meteorological Agency. At least there is no significant geomagnetic storm during the period of the anomalous enhancement appearance.

In order to investigate subterranean effects more clearly, the variation of spectral density ratio such as Sz/Sx and Sz/Sy at Esashi station is taken. It is found that spectrum density ratios increase apparently 35 - 20 days before the earthquake. In comparison with the variation at Kakioka (the reference station),

The variation of spectrum density ratio at Esashi reveals an enhancement before the earthquake and the seasonal variation. On the other hand, there is no clear seasonal variation in the ratio at Kakioka. The most important thing is there is no anomalous enhancement for the ratio at Kakioka before the day of earthquakes. The similar tendency is obtained in the Sz/Sx (and also for the periods of 3 -33 sec). These facts are highly suggestive of a local or an anomalous change at Esashi. However there are some increases of the ratio through the whole analyzed period. In order to eliminate the seasonal variation and examine singularity, the following normalization is performed;

$$\frac{S_z^*}{S_i} = \frac{S_z / S_i - \overline{S_z / S_i}}{\sigma}, i = x, y \qquad (2)$$

where S_z/S_i is ± 5 days running average, $\overline{S_z / S_i}$ is ± 30 days running average and σ is the standard deviation for 30 days data. We call S_z^* / S_i normalized spectrum density ratio hereafter and it is defined the threshold for anomaly using □. In this paper, the criterion of anomaly is set at +2σ. It is found that there exist two anomalies in the period of 10.41 sec and the anomaly 29 - 27 days before the earthquake has the highest value beyond 3 □ and the longest duration (3 days). Similar characteristics are obtained in the period of 52.48 sec and 101.95 sec. In fact, the anomaly appear in the period from 3 sec to 105 sec, although the range of analyzed periods is from 3 sec to 1060 sec. The anomaly before the earthquake is a wide-band frequency phenomenon. These facts are highly suggestive of a local or an anomalous change at Esashi and a possible candidate of earthquake-related ULF change.

2.2 Transfer Function Analysis and Fractal Analysis

It is known that the following equation is established among geomagnetic three components:

$$Z(\omega) = A(\omega) \cdot X(\omega) + B(\omega) \cdot Y(\omega) \qquad (3)$$

where X(□), Y(□), and Z(□) show NS, EW, and vertical components of geomagnetic fields. A(□) and B(□) are geomagnetic transfer functions [1]. These transfer functions have information on electric structure of underground. In this paper, we use wavelet transform instead of a conventional FFT as shown in spectral density ratio analysis. Data in

the period of 10.41 sec at Esashi and Kakioka have been investigated. The results are quite similar to those for spectral density ratio and it is found that the local phenomena around Esashi station.

We have also performed Detrended Fluctuation Analysis (DFA) as a fractal analysis [2] . Several days during the analyzed period show anomalous behaviors; that is the value decreases significantly. It means the appearance of additive high frequency noises.

2.3 Direction Finding Analysis

Furthermore, direction finding analysis based on Lissajous method and goniometer method has been performed the data which show simultaneous anomalies in spectral density ratio, transfer function, and DFA. The results indicate that direction of arrival (DOA) is only faced to the source region in the case of 25 days before the earthquake and DOAs for other cases directed to the normal back ground.

3. Conclusion

The ULF geomagnetic data observed at Esashi and Kakioka have been analyzed to detect any possible precursory signatures associated with the 2008 Iwate-Miyagi Nairiku earthquake. Spectral density analysis, transfer function analysis, DFA, and direction finding analysis have been performed. Before the earthquake, the variation of spectral density ratio and transfer function at the nearest station of Esashi exhibits an apparent increase from the trend. On the contrary, there are no corresponding significant changes at a remote station of Kakioka. After investigating the singularity of the increase using normalized spectrum density ratio, the enhancement is the most significant in intensity and duration for the all analyzed period. The level of peak is beyond the 3 σ and its duration is 3 days. The lead time is about 3-4 weeks before the earthquake. At the periods from 3 to 105 sec, similar anomalous changes occurred.

Together with transfer function analysis, DFA, and direction finding analysis, 25 days before the earthquake, all results show anomalous changes. Spectral density ratio and transfer function increase significantly and a value of DFA decreases. Results of direction finding suggest the signal coming from the future source regions. These facts suggest the anomalous change is a possible candidate of earthquake-related ULF magnetic change. It is important multiple analysis to study earthquake-related ULF geomagnetic phenomena.

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References

1. Hattori, K., 2004. ULF geomagnetic changes associated with large earthquakes. Terrestrial, Atmospheric and Oceanic Sciences, 15, 329–360.

2. Telesca, L., Lapenna, V., Macchiato, M., Hattori, K., 2008. Investigating non-uniform scaling behavior in Ultra Low Frequency (ULF) earthquake-related geomagnetic signals, *Earth and Planetary Science Letters*, 268 , 219-224.