ULF GEOMAGNETIC CHANGES ASSOCIATED WITH CRUSTAL ACTIVITITY

Katsumi Hattori[1], **Masashi Hayakawa**[2], **Kiyohumi Yumoto**[3],
Toshiyasu Nagao[4], **and Seiya Uyeda**[5]
1 Marine Biosystems Research Center, Chiba University, email: hattori@earth.s.chiba-u.ac.jp
2 The University of Electro-Communications, email: hayakawa@whistler.ee.uec.ac.jp
3 Kyushu University, email: yumoto@whistler.ee.uec.ac.jp
4 Tokai University, email: nagao@scc.u-tokai.ac.jp
5 Tokai University, email: suyeda@st.rim.or.jp

Abstract: Despite its extreme importance and years of effort, practical short-term earthquake prediction still remains to be achieved in future. However, earthquake- related electromagnetic phenomena are recently considered as a promising candidate for short-term earthquake prediction. There have been accumulated a lot of evidences of precursory signatures in a wide frequency range (DC-VHF). The ULF geomagnetic change is one of the most promising phenomena and it suggests that the short-term prediction is expected to realize. The methodologies to detect abnormal changes in ULF electromagnetic approach are described in this paper.

Key words: earthquake- related electromagnetic phenomena, short-term earthquake prediction, precursory signatures, ULF geomagnetic change, ULF short-term.

1. Introduction

Electromagnetic phenomena are recently considered as a promising candidate for the short-term prediction of large earthquakes (e.g. Hayakawa and Molchanov, 2002) and there have been accumulated observational reports in a very wide frequency range. Measurements of electromagnetic phenomena can be classified into three types; the passive ground-based observation for lithospheric emissions (Fraser-Smith et al., 1990, Kopytenko et al., 1993, Hayakawa et al., 1996a), the ground-based observation with the use of transmitter signals for the study of seismo-atmospheric and –ionospheric perturbations (e.g. Hayakawa et al, 1996b), and the satellite observation (e.g. Parrot, 1999). One of the most promising methods among them is a method of detecting seismogenic ULF emissions because there have been reported convincing evidences of ULF magnetic signature (Fraser-Smith et al., 1990, Kopytenko et al., 1992, Hayakawa et al., 1996a, Uyeda et al., 2002, Gotoh et al., 2002, Hattori et al., 2002). In order to verify electromagnetic phenomena preceding large earthquakes and to clarify the relationship between electromagnetic phenomena and possible physics, we intended to install sensitive geomagnetic sensors in Japan.

2. ULF geomagnetic signals associated with crustal activity

2.1 Observation system

ULF emission before and after large EQs was almost simultaneously discovered in Russia and America on the occasions of 1988 M6.9 Spitak EQ and 1989 M7.1 Loma Prieta EQ. On 8 August, 1993, a very large EQ (M8.0) occurred near Guam Island. Hayakawa et al., Geophys. Res. Lett. 23,241-244, 1996 found precursory emission of ~ 0.1 nT in 0.02-0.05 Hz band at Guam Island about r=60 km from the epicenter. They demonstrated that the use of the ratio (S_Z/S_H), called polarization, is of essential importance in discriminating the seismic emissions from space plasma waves. Here S_Z and S_H indicate the spectral intensities of vertical and horizontal components.

We embarked on ULF magnetic monitoring by installing 13 stations with 3 component induction type, torsion or fluxgate magnetometers (Fig. 1). It is important to predict earthquakes with M ≥ 6 in a highly populated region to mitigate disasters. Therefore, we decided to install a network of ULF magnetometers with high sampling rate to cover the Kanto (Tokyo) – Tokai area with inter-sensor distances of about 100km. A small L-shaped array

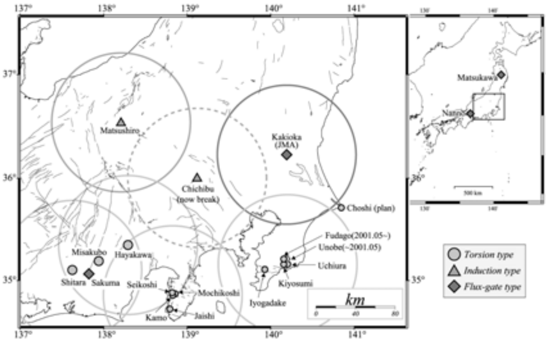

Fig. 1: ULF magnetometer network.

has been set with inter-station distance of 5 km in north-south and east-west directions in each of the western part of Izu Peninsula and the southern part of Boso Peninsula. With these arrays, a method to find the incoming direction of the ULF wave was developed (see Fig. 6).

Some case histories in tjis study are as follows. It should be emphasized here that pre-seismic anomalies are generally too weak to recognize by looking at raw data and some elaborate data processing is needed. We have found several methods, including polarization analysis, principal component analysis and direction finding technique, are quite useful for this purpose. We have found also that the frequency range of 0.01 Hz is significant for monitoring crustal activity. Hereafter typical results will be described in this paper.

2.2 Polarization analysis

In data analysis, we have confirmed the existence of ULF changes before EQs mainly through the use of the polarization (S_Z/S_H).

2.2.1 Kagoshima Earthquakes M6.5 EQ97/03/26 & M.6.3 EQ97/05/13

Two moderately large earthquakes occurred at 17h31m L.T. on March 26, 1997 (U.T. = L.T. - 9hours), and 14h38m (L.T.) on May 13, 1997, respectively. Their epicenters were (32.0 ° N, 130.3° E) and (31.9° N, 130.3° E), respectively. A fluxgate type magnetometer measuring 3 components of geomagnetic fields with l Hz sampling rate, was in operation at Tarumizu Station (31.48° N, 130.72° E), which belongs to Nagoya University. The distances between the observatory and epicenters are about 60 km. The ULF instrument is composed of three ring core type fluxgate magnetometers (H (NS), D (EW), and Z (vertical) component) and the waveform data are recorded. Details of the magnetometer system is reported by Yumoto et a1. (1992). These EQ occurred in northwestern Kagoshima Prefecture. Fig. 2 shows the time change of released seismic energy in terms of M and 10 day backward running average of polarization (S_Z/S_G in 0.01 Hz band) of night time ULF magnetic data at Nagoya University station at Tarumizu (r ~60 km). It is clearly observed that the polarization showed a remarkable pre-seismic enhancement. Similar curves for Chichijima Island in Bonin Islands 1,200 km away and Darwin, Australia (geomagnetic conjugate point to Tarumizu) do not exhibit such enhancement, supporting that the change at Tarumizu was associated with the Kagoshima EQs.

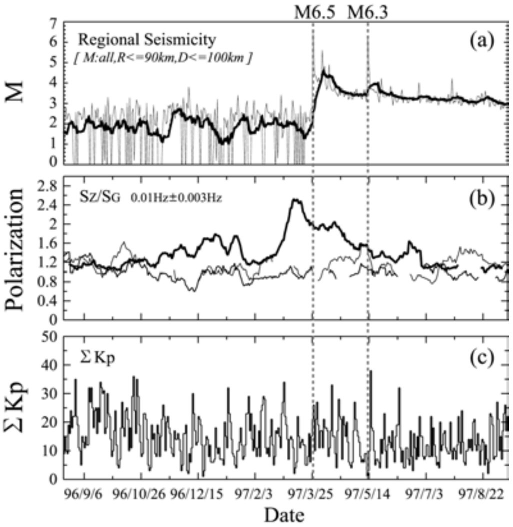

Fig. 2: The variations of polarization at 0.01Hz band. . (a) S_Z/S_G, (b) regional daily sum of seismicity in terms of magnitude and (c) Σ Kp. The variation of 10days backward running mean of daily values is plotted for polarization As for the seismicity, the thin and the thick lines show the daily variation of the regional seismicity and variation of 10 days backward running mean of the daily values.

2.2.2 Iwate Earthqyake M6.1 EQ98/09/03

In this section, we will present an example of the observed data related to Iwateken Nairiku Hokubu earthquake occurred in the vicinity of Mt. Iwate, the northern part of Honshu island (M = 6.1, Depth ~ 10 km, Sept. 3, 1998). The epicentral distance from Matsukawa station (MTK) was about 15 km. Five days running average of polarization (S_Z/S_H in 0.01 Hz band) showed an enhancement reaching three times higher than usual value about two weeks before the EQ (Fig. 3).

2. 3 Principal component analysis of the 2000 Izu Volcanic-seismic Activity in Izu Island Region

A swarm seismic activity started on June 26, 2000, simultaneously with the volcanic activity of Miyake-jima Island. It quickly spread northwestward from the Miyake-jima Island to Toshima Island via Kozu-shima and Niijima Islands. Within the three month period of activity, more than 10,000 earthquakes ($M \geq 0$), including five events with $M \geq 6$, were recorded.

Three component geomagnetic monitoring was conducted by array networks in west Izu Peninsula and south Boso Peninsula, each array consisting of three closely spaced (~5 km) stations with identical sensors. The principal component analysis (PCA) has been applied to the ULF geomagnetic data of Izu Peninsula array. The first principal component is found to be the signal originated from solar-terrestrial effects, whereas the second principal component represents the local artificial noise. It was also found that the smallest third component in the local midnight data indicated an increase in the eigenvalue a few days before the large earthquakes. Also about three months before the beginning of the swarm

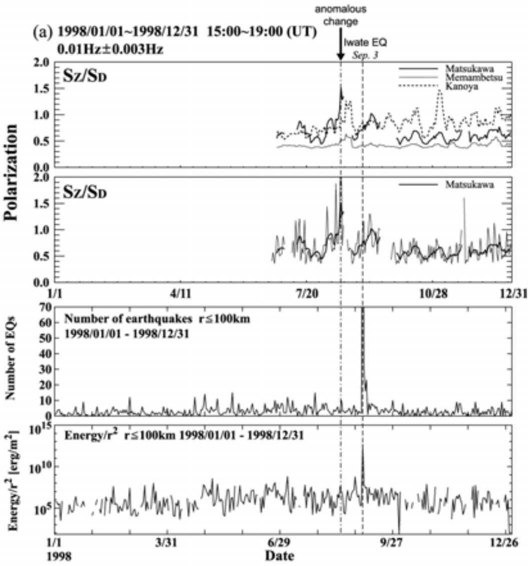

Fig. 3 : The variation of polarizations S_Z/S_D at the frequency band of 0.01Hz for five years: (a) 1998, (b) 1999, (c) 2000, (d) 2001 and (e) 2002.
The top panel shows the variation of polarizations S_Z/S_D at the frequency band of 0.01Hz. 5 days backward running mean values at Matsukawa station (thick solid line) and at two remote reference stations, Memambetsu (thin solid line) and Kanoya (broken line) are simultaneously plotted. The second panel displays the detailed variation of polarization S_Z/S_D at Matsukawa station. 5 days backward running mean (thick solid line) and daily values (thin solid line) are plotted. The third panel shows the number of earthquake near Matsukawa station (r<100 km). The bottom panel indicates the variation of daily regional seismicity E/r^2, with taking account of hypocentral distancer.

activity, the level of the third eigenvalue was slightly enhanced (Fig. 4). Correspondingly, the pattern of eigenvector direction in the signal subspace was changed simultaneously and recovered to the original position after the swarm.

2.4 Direction finding analysis of the 2000 Izu Volcanic-seismic Activity in Izu Island Region

Furthermore, from the gradient of magnetic fields among the three stations, the incoming direction of magnetic signals was estimated as shown in Fig. 5. In contrast to the usual noise coming from the northward (Izu Peninsula), the signals received in the summer of 2000 were coming from the direction of the swarm activity.

3. Comcluding remarks

Fig. 6 is the global summary of the investigation on the pre-seismic ULF magnetic changes, showing the empirical relationship between M of EQ and epicentral distance of ULF stations. White and black marks show the EQ with ULF anomalies and without ULF anomalies, respectively. The solid line indicates the threshold for appearance of ULF signals. Pre-seismic ULF emissions would be detected for M>4 EQs which roughly satisfy 0.025R<M – 4 , where R is epicentral distance. During our study period, there have been 5 EQs which are reasonably expected to show pre-seismic signatures. Out of these, 5 EQs actually showed the signatures.

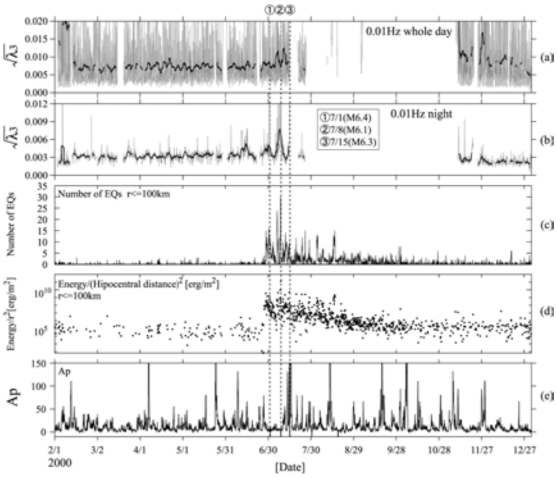

Fig. 4: The variation of third principal component $\sqrt{\lambda_3}$ in 2003. The occurrence time of a large earthquake (M>6) is described by a vertical line. (a) The variation of $\sqrt{\lambda_3}$ in a whole day, (b) the variation $\sqrt{\lambda_3}$ in midnight, (c) the variation of number of earthquakes around the Izu array stations (r < 100 km) , (d) the 30 minutes sum of the released energy (E/r^2) around the Izu array station (r < 100 km), (e) The variation of Kp index. The hypocental distance r is taken into account.

Acknowledgements

This work has been promoted by the special project of RIKEN International Frontier Research Group on Earthquake (1997-2002) and National Space Development Agency of Japan's Earthquake Remote Sensing Frontier Research (1997-2002). The authors are grateful to both institutes for their support. We thank Japan Meteorological Agency (JMA) for the use of earthquake catalog. We also thank Geomagnetic Observatory, JMA for providing us with Memembetsu and Kanoya data. This work was partially supported by the JSPS Grants-in-Aid for Scientific Research #13650477.

References

Fraser-Smith, A. C., Bernardi, A., McGill, P. R., Ladd, M. E., Helliwell, R. A., and Villard, O. G., Jr.,

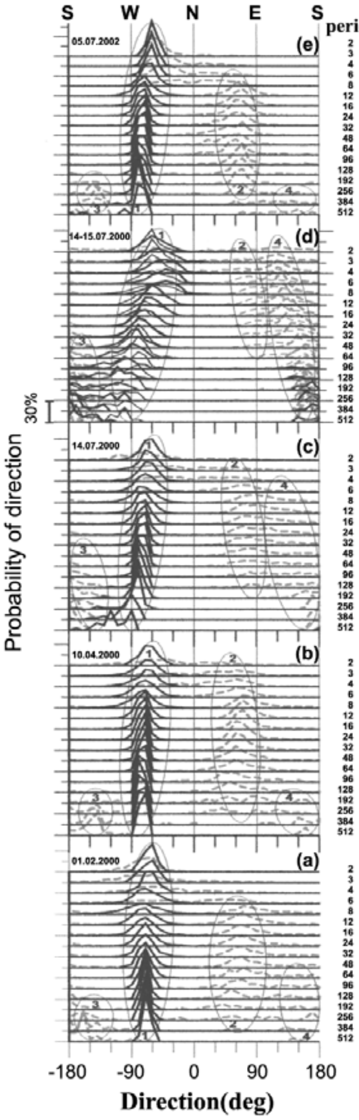

Fig. 5: Result of direction findings of Izu array station.
(a)February 1, 2000 (4 months before the swarm activity) (b) April 10, 2000 (2 months before the activity) (c) June 14, 2000 (12 days before the activity) (d) July 14-15, 2000 (active earthquake period) (e) July 5, 2002 (2 years after the activity)

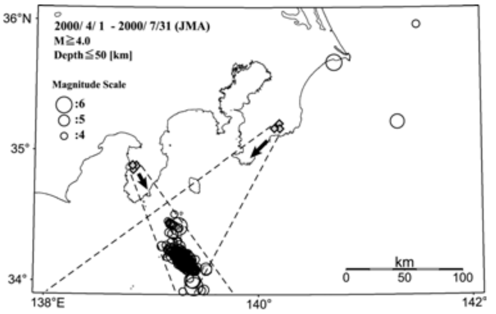

Fig. 6: Direction finding result

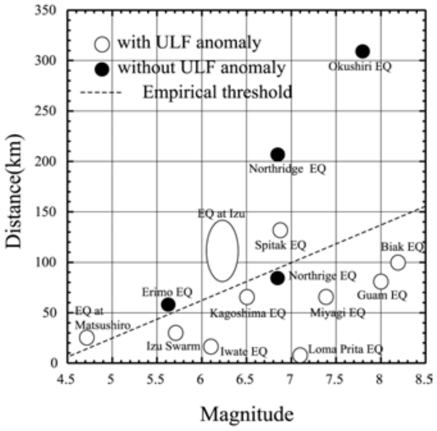

Fig. 7: Relation between magnitude and epicentral distance. ○ indicates the earthquake with the ULF anomaly, ● without the ULF anomaly

Low-frequency magnetic field measurements near the epicenter of the Ms 7.1 Loma Prieta earthquake, Geophys. Res. Lett., 17, 1465-1468, 1990.

Hattori, K., Akinaga, Y., Hayakawa, M., Yumoto, K., Nagao, T., and Uyeda, S., ULF magnetic anomaly preceding the 1997 Kagoshima Earthquakes, “Seismo Electromagnetics: Lithosphere-Atmosphere -Ionosphere coupling”, edited by M. Hayakawa and O. Molchanov, TERRAPUB, Tokyo, 19-28, 2002.

Hayakawa, M., Kawate, R., Molchanov, O. A., and Yumoto, K., Results of ultra-low-frequency magnetic field measurements during the Guam earthquake of 8 August 1993, Geophys. Res. Lett., 23, 241-244, 1996a.

Hayakawa, M., Molchanov, O. A., Ondoh, T., and Kawai, E., Anomalies in the subionospheric VLF signals for the 1995 Hyogo-ken Nanbu earthquake, J. Phys. Earth, 44, 413-418, 1996b.

Hayakawa, M., and Molchanov, O. A., Editors, “Seismo Electromagnetics Lithosphere-Atmosphere-Ionosphere Coupling”, TERRAPUB, Tokyo, pp. 477, 2002.

Kopytenko, Y. A., Matishvili, T. G., Voronov, P. M., Kopytenko, E. A., and Molchanov, O. A., Detection of ultra-low-frequency emissions connected with the Spitak earthquake and its aftershock activity, based on geomagnetic pulsations data at Dusheti and Vardzia observatories. Phys. Earth Planet. Inter., 77, 85-95, 1993.

Parrot, M., Statistical studies with satellite observation of seismogenic effects, "Atmospheric and Ionospheric Electromagnetic Phenomena Associated with Earthquakes ", Edited by M. Hayakawa, TERRAPUB, Tokyo, 685-695,1999.