Spatial Distribution of Source Locations of Earth-origin Electromagnetic Pulses Excited before Earthquakes

Minoru Tsutsui* and Takeshi Maenishi
Department of Information and Communication Sciences, Kyoto Sangyo University
Kamigamo-Motoyma, Kita-ku, Kyoto 603-8555, Japan,
E-mail: tsutsui@cc.kyoto-su.ac.jp, Phone: +81-75-705-1856, Fax: +81-75-705-1887

1. Introduction

From many detections of earth-origin electromagnetic (EM) pluses in a deep bore-hole [1], we are recently thinking that the earth-origin EM pulses were surely excited by dynamical impacts to the earth crust. For obtaining further information on the property of the earth-origin EM pulses, we developed a specific analysis method for pulsed signals [2]. By means of the analysis method, we became able to derive frequency dispersion characteristics of pulse signals, and to obtain amplitudes and phases of each frequency component contained in the earth-origin EM pulses. Then we accomplished a direction finding (DF) system which can find arrival directions of EM pulses propagating in the earth using these wave parameters [3]. This system can find propagation directions of each frequency component in the EM pulses. The obtained frequency-dependent arrival directions showed a widely spreading angle. In order to clarify the cause of the wide angle, we have analyzed the data from the various points of view. From the examinations of propagation properties and polarization loci of EM pulses detected in both regions above and under the ground, we found that the frequency-dependent direction angles represent those of waveguide-mode [3]. Among the widely spread directions, we found a way to determine the true direction which is pointing toward the source location of earth-origin EM pulses. Furthermore, we attempted to obtain the source location by the aid of theoretical estimation using a formula for waveguide-mode We applied the method to an EM pulse detected just when an earthquake occurred, and found that the source location of the EM pulse was just on the hypocenter of the earthquake [4]. The obtained result manifested that we can identify the source location of the EM pulse detected in the earth even by a single DF system only, although we need an observation network equipped by the present DF system for more accurate their identifications. Here, we applied the developed method to earth-origin EM pulses detected recently.

On September 5, 2004, we had two earthquakes under the sea of south-east of the Kii Peninsula in Kansai area of Japan. Unfortunately, we could not observe EM pulses when the earthquakes occurred, because the power line for the observation system on that day was shutdown due to the check of the power line system of Kyoto Sangyo University. Therefore, we focused on earth-origin EM pulses two days before the earthquakes in order to examine a relation of the excited EM pulses as a precursor of the earthquakes. We attempted to show a time-change and spatial distribution of source locations of earth-origin EM pulses from each dispersion curve and by the aid of theoretical estimation using a formula modified from that for tweek atmospherics detected above the ground [5].

2. True direction toward source location of earth-origin EM pulse

Figure 1 shows a typical example of frequency-dependent arrival directions of an EM pulse detected in the earth, in which a sector shape is drawn from the detection site (Kyoto Sangyo University at the cross point of the coordinate axes). The sector shape was formed by slightly different direction lines of multiple frequency components up to 6.4 kHz contained in an EM pulse. The spreading of arrival directions is caused by the different propagation directions of frequency components in the pulse in a waveguide [3]. It is interesting, as reported in the previous paper by Tsutsui [4], that some frequency components pointing toward the source location of the EM pulse can be determine by the frequency dispersion curve derived from the detected EM pulse. We already reported that the cutoff frequency of the waveguide mode of earth-origin EM pulses were usually around 200-300 Hz [1], and recently showed an evidence of frequency dispersion characteristic curve with the lower cutoff frequency at 230 Hz [3]. However, the lower frequency part of the dispersion curve was not so clear due to interference of the power line harmonic noise. On the other hand, we usually obtain clear dispersion curves in the higher frequency range with an additional cutoff frequency at few kHz. Figure 2 shows the frequency dispersion characteristic curve of magnetic component H_{EW} of the EM pulse detected in the earth, which was derived from the waveform shown at the left in Fig. 1. The dispersion curve means that the higher frequency components in the EM pulse first arrive at the receiving site, and lower ones arrive with some delays. Therefore, the true direction toward the source location is given by that of the highest frequency [4]. The dispersion curve showing such the cutoff at higher frequency are generally regarded as a result of wave propagations in a space above the ground [6, 7] where the conductive ionosphere and the ground surface make a form of a kind of wave-guide. Therefore, we thought that the detected earth-origin EM pulses would include both wave modes propagating above and under the ground. This also suggests that the part of the earth-origin EM pulse surely leaked out of the ground and propagated along the ground surface as a kind of surface wave. In the case there exists another wave modes under the dispersion curve in the higher frequency range, it is difficult to determine the clear cutoff frequency as shown in Fig.2. We need further investigation about the measured dispersion characteristics and propagation property of the earth-origin EM pulses. Based on this definition of the true direction toward the source location of EM pulses, we plotted arrival directions of the detected EM pulses for about 2 days before the earthquakes occurred on September 5, 2004.

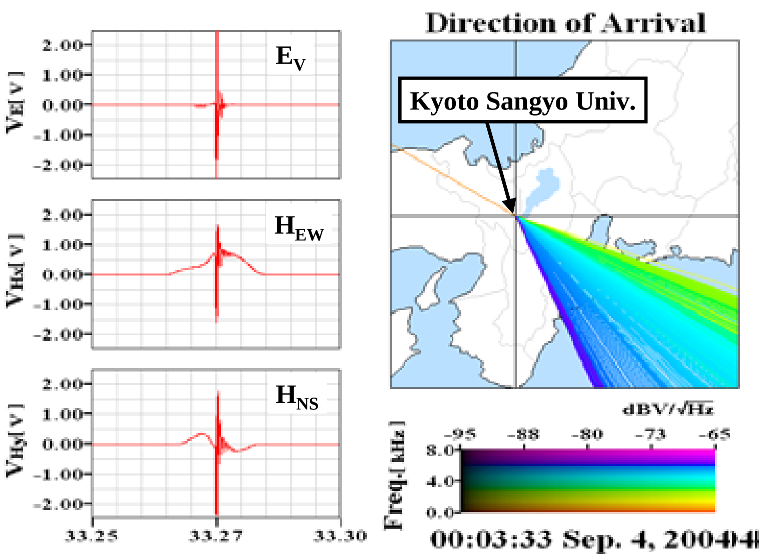

Fig. 1 Waveforms of EM electric E_V and magnetic H_{EW}, H_{NS} components (left), and frequency-dependent arrival directions (sector) drawn from the detection site (right). These pulses were detected at about 2 days before the earthquake occurred at 17:07 JST of September 5, 2004.

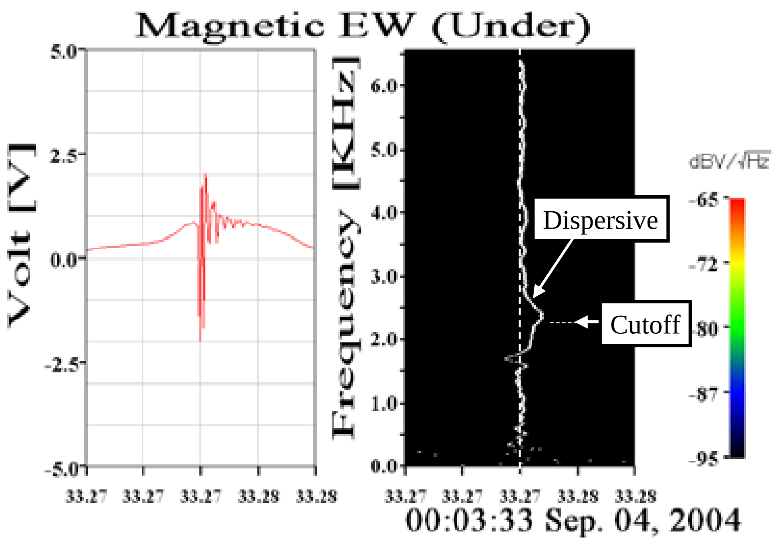

Fig. 2 Waveform of magnetic component H_{EW} shown in Fig. 1 (left), and its derived frequency dynamic-spectra showing dispersion curve and cutoff frequency which is rather lower than the peak seen in the figure (right).

3. Time-change of arrival directions of earth-origin EM pulses

Figure 3 shows a time-change of plots of arrival directions of EM pulses detected in the earth from 14:00 JST September 3, 2004 to 21:00 JST of the next day. At around 19:30 of September 3 in the figure, we clearly recognize the appearance and increasing of earth-origin

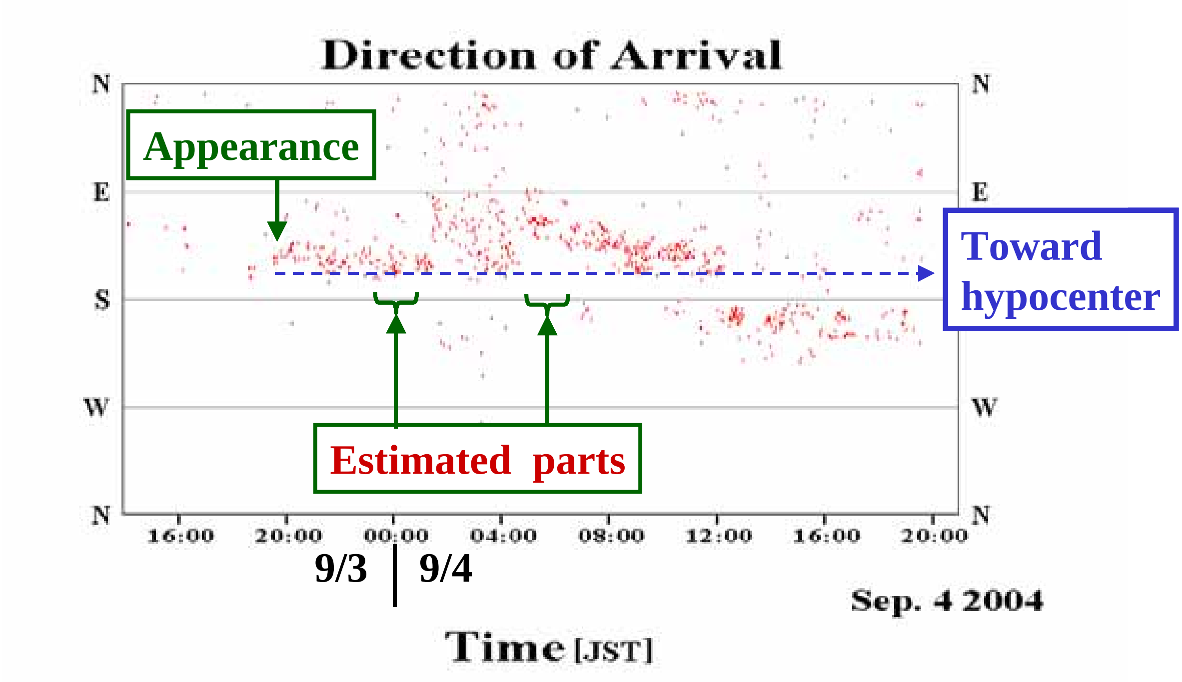

Fig. 3 Time-change of plots of arrival directions of EM pulses detected in the earth. Concentrated distributions suggest movements of EM pulse excitation areas. A horizontal broken line indicates the direction toward the hypocenter where an earthquake occurred at 19:07 JST September 5, 2004. The event shown in Fig. 1 is marked by O. The "Estimated parts" are shown in Fig. 4 as locations of EM pulse excitation areas.

EM pulses. It was about 48 hours prior to the first earthquake on September 5. Directions of these pulses were pointing toward the south-south-east, that is just the direction, as shown by the horizontal broken line, toward the hypocenter of the earthquakes measured from the detection site. These directions pointing lasted until 01:30 of September 4. During the following four hours, we can not see any concentrated directions due to probably interferences of noises. However, from 04:30 JST of September 4, directions began to appear again, and these pointing are toward the east-south-east, and their directions have been gradually shifting toward the south direction for about eight hours. Furthermore, the direction abruptly changed toward the south-south-west at 12:00, and they had lasted to 19:30 of September 4. After that time, we had to shutdown the detection system. The EM pulse detected at 00:03 JST of September 4, 2004 shown in Fig. 1 is marked by O in Fig. 3, which was very close to the direction toward the hypocenter of the earthquake occurred on September 5.

4. Source locations of EM pulses

As for the earthquake occurred at 14:50 JST of January 6, 2004, we found that the propagation distance measured from the detection site along the direction of the highest frequency component on the dispersion curve just located on the area of hypocenter [4]. Thus we here use dispersion curves in the higher frequency range to estimate propagation distances of EM pulse. Using the dielectric constant $\varepsilon' = 1$ of the air, and by fitting the measured dispersion characteristic curve to the theoretical ones, we carried out the estimation for some events detected during the period shown in Fig. 3. Fig. 4 shows a distribution of the estimated source locations of EM pulses. The ranges of estimated locations are shown by error bars along the direction of the highest frequency component. Although we had not enough time to analyze the data and to obtain the source locations of the detected EM pulses given in Fig. 3, this figure suggests that it would provide a specific distribution of EM pulse excitation area where might be closely related to the earthquakes. Now we are continuing the plotting the locations of detected EM pulses in order to make a clear spatial distribution emerged. In this figure, the estimated locations from the detection site might be thought to be shorter than the location (33.2 °N, 136.9 ° E) of the earthquake hypocenter, which might be due to deformation of dispersion characteristics by some causes and miss readings of cut off frequencies as described in Section 2. Therefore we need further investigation about the usage of the dispersion characteristic curve for reliable estimation of the propagation distances of the EM pulses. Furthermore, for obtaining these locations more accurately, measurements by an observation network are indispensable.

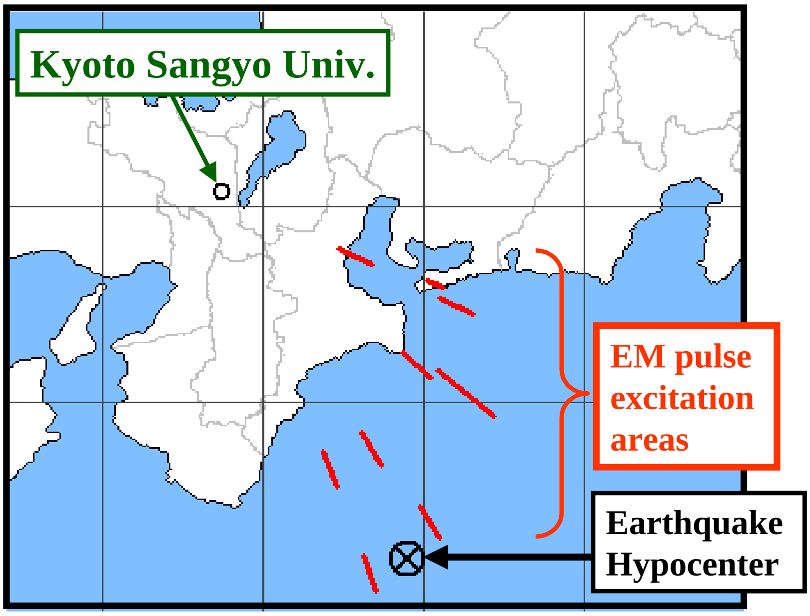

Fig. 4 Spatial distribution of the estimated source locations (bars) of EM pulses excited 2 days before the earthquake occurred at 19:07 JST of September 5, 2004.

4. Conclusions

We have been developing various techniques and analysis methods for clarifying the property of earth-origin EM pulses, and have been piling up various knowledge and information about their behaviors. Here at last, we have been able to identify their source locations, and found a method of obtaining spatial distributions of earth-origin EM pulse excitation areas where earthquake might occur in the near future.

References

[1] M. Tsutsui, Detection of earth-origin electric pulses, Geophys. Res. Letters, 29, 8, 35/1-4 (2002).

[2] M. Tsutsui, S. Konagaya, T. Kagawa, A Method of Direction Finding for Dispersive Electromagnetic Pulses, (in Japanese), submitted to IEICE (2004).

[3] M. Tsutsui, T. Kagawa, and K. Uematsu, A Study on Propagation Characteristics of Electromangetic Pulses in the Earth, submitted to Special Issue of IEICE Trans. (2004).

[4] M. Tsutsui, Identification of Earthquake Hypocenter from Measurements of Electromagnetic Pulses in the Earth, submitted to GRL, (2004).

[5] S. Yano, T. Ogawa, H. Hagino and M. Masuhiro, An analysis of slow tail atmospherics, J. Atmos. Electr., 14, 129-138 (1994).

[6] Lynn, K. J. W., and J. Chrouchley, Night time spheric propagation at frequency below 10 kHz, Aust. J. Phys., 20, 101-108 (1967).

[7] Yamashita, M., Propagation of tweek atmospherics, J. Atmos. Terr. Phys., 40, 151-156 (1978).