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Abstract 1-01

Detections and Confirmation of Co-seismic Electromagnetic Pulses in the Earth

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In order to confirm whether electromagnetic (EM) pulses could be excited or not when earthquakes occurred, we first began to measure electric noise in an electrically non-conductive borehole of 100 m in depth which was constructed in the campus of Kyoto Sangyo University in 1999. It was found, from the measurements, that many impulsive noises were detected even in the earth, and was expected that these impulsive noise would be generated in the earth because their intensity in the earth is stronger than those detected above the ground [1]. It is considered that these impulsive electric noises would be electric field component of EM pulses. In order to clarify the relation between locations of detected EM pulses and of earthquake occurrences, we next accomplished a sensor system for determining arrival directions of EM pulses, aiming to find their source locations. At 14:49:56 of January 6, 2004, the new system detected an EM pulse just when an earthquake occurred at off-shore of Kumano-nada, Mie-prefecture, and simultaneously displayed its arrival direction pointing toward the earthquake as shown in Fig. 1. From frequency dispersion characteristic curves derived from waveforms of the detected electric and magnetic field components of the EM pulse, we estimated its propagation distance, and found that the source location of the EM pulse was in the epicenter region of the earthquqake (see Fig.1). The result suggested that the EM pulse had first leaked out of the ground surface of the epicenter region of the earthquake and was propagating between the ionosphere and the ground

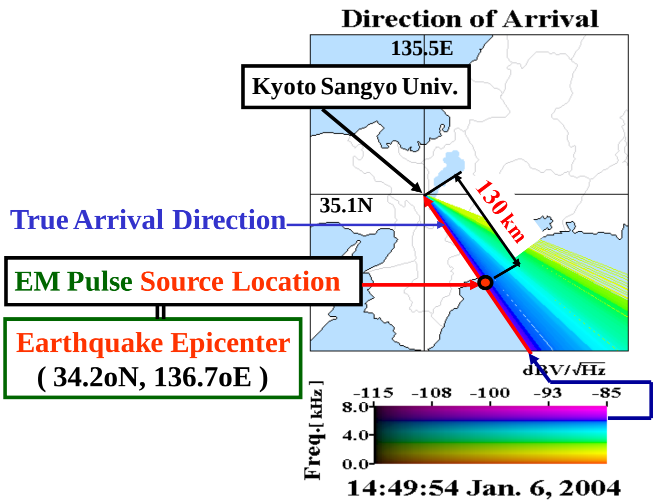

Fig. 1 Source location of earth-origin EM pulse detected at 14:49:54, Jan. 6, 2004 when the earthquake occurred. The source location was in the epicenter region.

surface and was detected in the borehole [2].

On the basis of the preciseness in determining arrival direction of EM pulses detected in the borehole, we aimed to realize real-time determination of source locations of EM pulses. For this purpose, we setup additional observation points in inland area of Kinki district of Japan, where were at Ugakei and Misugi earthquake observatories of Nagoya University in mountain sides in Mie prefecture, for distances of 80 ~ 90 km from Kyoto Sangyo University. Observation results in these places showed that almost all of detected EM pulses were not earth-origin EM pulses but radiated from electronic power lines, because many power lines are widely spread above the mountain ranges. Thus we gave up the observations in inland area, and have been searching for another place more suitable for the observation without interferences by power line radiations. We found an electro-magnetically quiet place in the campus of the Seto Marine Biological Laboratory, Field Science Education and Research Center, Kyoto University, where is on a narrow peninsula (about 300 m in width) at Shirahama-town, Wakayama prefecture. We constructed the second observation borehole of 100 m in depth there in 2008. We have been measuring arrival directions of EM pulses detected at both levels, at 95 m-depth in the borehole and on the ground. Examining EM pulses detected during the period 115 days from May to August in 2009, we found that their detections were counted to 7300 in maximum per day as shown by the upper graph in Fig.2. Since arrival directions of the detected EM pulses were almost omni-directional, and daily variations of their detected counts became maximum at night, we concluded that they were almost "tweek" atmospherics caused by lightning discharges generated on all over the globe [3]. Almost all of their waveforms showed oscillations of four or five cycles in the frequency range of few kHz range. Arrival directions of many EM pulses determined by sensor system which can make it possible to determine three dimensional arrival directions showed upward directions at the depth of 90 m in the borehole. Furthermore, the observation system showed elliptical polarizations in magnetic

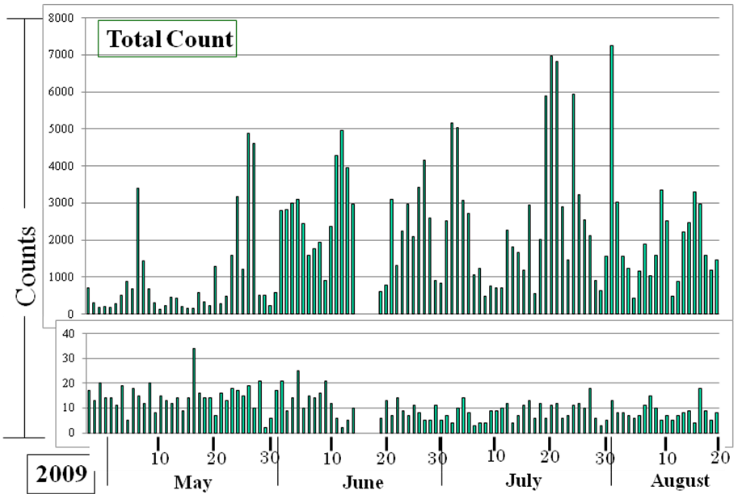

Fig. 2 Counts detected EM pulse in the borehole of Shirahama observation site during from April 27 to August 20, 2009. Upper graph indicates daily total count of their detections. Lower graph indicates counts of EM pulses radiated from electric power lines.

field components of detected EM pulses. Since the elliptical polarizations were formed by their reflections at boundary layers of earth media, it was expected that lightning EM pulses penetrated into the ground were reflected from deeper layers below the sensor depth. We found another type of EM pulses (10 ~ 20 counts per day as shown by the lower graph in Fig.2) showing two-cycle waveform with a period shorter than the lightning EM pulses. From a quantitative analysis of their detections, we found that their detections were concentrated in some time ranges closely related to the human daily activity, in the morning and in the evening. Therefore, we concluded that they were radiated from local electric power lines.

Judging from the measured results in these observations, we concluded that it was very difficult to find out earthquake related EM pulses in the frequency range around few kHz from the following two reasons. One is the difficulty in distinguishing and extracting earth-origin EM pulses among a large amount of lightning EM pulses with large amplitude. Another is the undetectable weakness of field amplitude of earth-origin EM pulses in few kHz components, because they have been decayed during their propagations by large electric conductivity σ of the earth medium. The skin depth δ is defined as a propagation distance during which the wave amplitude decays to 1/e, which is given by $\delta = \sqrt{\frac{1}{\omega\mu\sigma}}$, where $\omega\,(=2\pi f\,)$ is angular frequency of the EM pulse, and μ are the magnetic permeability. From this formulae, we can easily understand that the skin depth becomes longer for waves of lower frequency, which means that low frequency waves can propagate for a long distance than those of higher frequency ones. Therefore we began to watch waves in very low frequency range below the frequency of power line (below 60 Hz) since December 2011.

We had several earthquakes with magnitude M >2 occurred near the observation points from December, 2011 to July, 2012. Our system detected magnetic pulses as co-seismic ones and displayed them in extremely low frequency range of frequency dynamic spectra (*f*-*t* diagram). A typical example is shown in Fig. 3, in which (a) is the map showing positions of epicenter of the earthquake occurred at 00:20 on May 10, 2012 and of the observation point. The distance between their positions is about 15 km, and (b) shows frequency dynamic spectra (*f*-*t* diagram) of east-west component of magnetic field in the frequency range below 25 Hz. In the *f*-*t* diagram, we can see clear pulsed spectrum at 00:20. We also confirmed other magnetic pulses related to several earthquakes showing one to one relation between the earthquakes and EM pulse as shown in Fig. 3.

(a) **(b)**

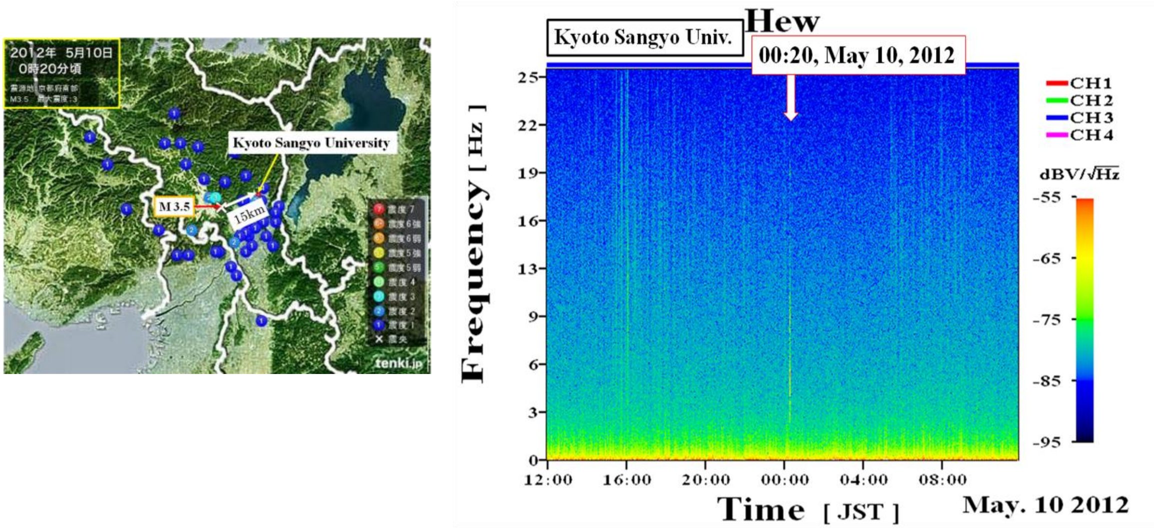

Fig. 3 (a) positions of epicenter of earthquake occurred at 00:20 on May 10, 2012 and of EM observation. (b) frequency dynamic spectra (*f-t* diagram) of east-west component of magnetic field. A magnetic pulse can be seen at 00:20.

Such the pulsed frequency spectrum shows strong evidence that the electromagnetic pulses were surely excited by the earthquake and they were propagating in the earth. Therefore, we can conclude that the EM pulse detected at 14:49:56 of January 6, 2004 was the result of propagation above the ground after leaking out of the ground surface of the epicenter region, and that the EM pulses in the extremely low frequency range detected since December, 2011 were co-seismic EM pulses having been propagating in the earth medium.

References

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