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Geomagnetic pulsations caused by the Sumatra earthquake on December 26, 2004

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[1] A long period Pc5 pulsation was observed at Phimai in Thailand, shortly after the origin time of the Sumatra earthquake on December 26, 2004. The localized nature and the period of oscillations suggest that the long period magnetic pulsation was generated by dynamo action in the lower ionosphere, set up by an atmospheric pressure pulse which propagated vertically as an acoustic wave when the ocean floor suddenly moved vertically. It is speculated that a Pc3 type pulsation observed at Tong Hai in China, 10 degrees north of Phimai in latitude, was the result of magnetic field line resonance with a magnetosonic wave generated from the electric and magnetic fields of the dynamo current caused by the Earthquake. **Citation:** Iyemori, T., et al. (2005), Geomagnetic pulsations caused by the Sumatra earthquake on December 26, 2004, *Geophys. Res. Lett.*, *32*, L20807, doi:10.1029/2005GL024083.

1. Introduction

[2] Geomagnetic pulsations are classified by their wave form and period [e.g., *Saito*, 1978]. Although there are a few reports which suggest possible excitation of geomagnetic pulsations by earthquakes [e.g., *Golikov et al.*, 1985; *Pokhotelov et al.*, 1995], most of them are known to be generated in space plasmas and with an energy source in the solar wind or in the magnetosphere. A geomagnetic pulsation with a period of approximately 3.6 minutes was observed at Phimai, 12 minutes after the origin time of Sumatra earthquake on December 26, 2004. At Tong Hai in China, 10 degrees north of Phimai in latitude, only a short period (about 30 seconds) magnetic oscillation was observed. At higher latitudes, no magnetic pulsation with these periods was observed. It is clear that the pulsation is not the effect of sensor tremor, because of the timing relation between the origin time of the earthquake and the onset time of the magnetic pulsation, and also because of the amplitude relation amongst the magnetic components.

[3] Although there existed a continuous weak geomagnetic disturbance from the previous day, the localized nature of the long period pulsation and its timing of onset which will be shown in the following sections strongly suggest that the source of the pulsation is the earthquake. In this paper, we show the observational facts and possible mechanism which may explain the origin of the pulsations.

2. Observations

[4] In the following, 'ALat.' means magnetic Apex latitude defined by *VanZandt et al.* [1972] which is suitable for analyzing ionospheric phenomena near geomagnetic equator; N and E are geographic latitude (North) and east longitude, respectively. Fluxgate magnetometers at Phimai (15.2N, 102.6E, 7.0ALat.) in Thailand, Tong Hai (24.0N, 102.7E, 16.6ALat.) in China and Aso (32.9N, 131.0E, 25.5ALat.) in Japan were in operation with a sampling rate of 1 second at the time of the Sumatra earthquake. The earthquake origin time was 00:58:53UT (Universal Time) when the three observatories were in the sunlit hemisphere where the ionosphere is conductive.

[5] Figure 1 shows the geomagnetic measurements from Phimai and Aso for the period from 00:30UT to 02:30UT on December 26, 2004. H, D and Z indicate magnetic north, east and downward components in nanotesla (nT), respectively. The vertical dotted line indicates the origin time and the vertical solid line indicates the onset time of a long period (about 3.6 minutes) pulsation at Phimai. At Aso, no similar pulsation is seen. Although it is not shown here, there was also no pulsation with similar frequency at other Chinese stations such as Urumqi (43.8N, 87.7E, 38.3ALat.) or Lanzhou (36.1N, 103.8E, 29.7ALat.).

[6] Figure 2 shows the data from Tong Hai for the period from 01:08UT to 01:20UT. Although the longitudes at Phimai and Tong Hai are almost the same and the difference in latitude is only 10 degrees (i.e., about 1000 km), the oscillation with a period of 3.6 minutes is not appreciable there. However, we see a Pc3 type oscillation with a period of about 30 seconds. We have checked the data from other stations such as Phimai, Lanzhou, Urumqi and Aso, however none of them showed Pc3 activity at the time.

[7] For removal of long period variations we applied a band-pass filter of Gaussian type with a period range between 30 seconds and 12 minutes to Phimai and Aso measurements. Because the wave form of the short period fluctuations, caused by the disturbance before the earthquake, are very similar for both magnetic north-south (H) and magnetic east-west (D) components between the mea-

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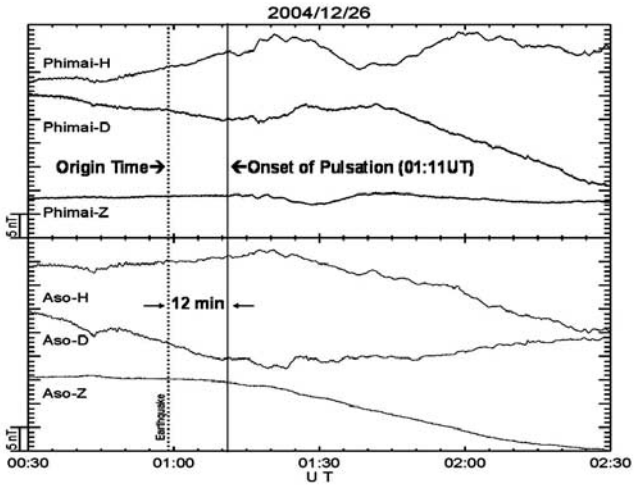

Figure 1. Geomagnetic variation (top) at Phimai and (bottom) at Aso from 00:30UT to 02:30UT.

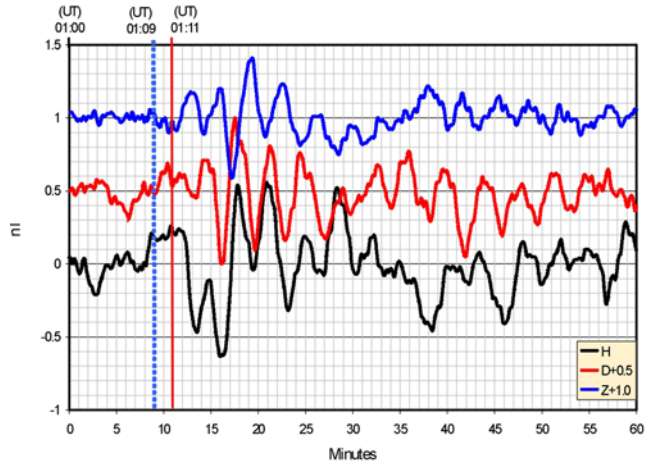

Figure 3. Filtered data at Phimai (PHI) for December 26, 2004 from 01:00UT to 02:00UT. See text for the filtering technique.

surements from Phimai and Aso, we subtracted the fluctuation at Aso from Phimai normalizing the amplitude with the amplitude ratio between them before the earthquake, i.e., we multiplied the fluctuation at Aso by 0.667 and subtracted it from the data at Phimai for H and D. For the vertical component (Z), we did not subtract the fluctuation observed at Aso because it depends largely upon the conductivity structure of the Earth at the observation site. Figure 3 shows the H, D and Z variations at Phimai processed as described above and Figure 4 shows their spectra calculated with MEM (Maximum Entropy Method). These figures indicate that there was a localized long period pulsation with a period about 3.6 minutes at Phimai.

3. Discussion

[8] Geomagnetic oscillations with a period of 3.6 minutes are normally categorized to Pc5 or Pi3 [e.g., *Saito*, 1978]. However, in middle or low latitudes, these pulsations are normally observed in much wider area both in latitude and longitude, or on a global scale. If it is a normal Pc5 pulsation generated by external sources, the amplitude is, in general, larger at higher latitudes. However, there was no Pc5 with the period of 3.6 minutes at Aso or Tong Hai or at other Chinese stations. There was some Pc5 activity, mainly in the D component, both at Phimai and Aso with periods other than 3.6 minutes and the amplitude was larger at Aso than that at Phimai suggesting an external source. By subtracting the fluctuations in the Aso data, normalized with the amplitude ratio (i.e., 0.667) as explained in previous section, the 3.6 minutes oscillation appears clearly in Figure 3 and the spectral peaks at the frequency become sharp. Perhaps this is a Pi2 type pulsation with a longer period which is generated at magnetospheric substorm onset. However, it is known that the amplitude in the H component is almost the same in low and middle latitudes for Pi2 pulsations [e.g., *Osaki et al.*, 1996]. On the other hand, if the oscillation comes from sensor tremor caused by the passage of seismic wave, it should appear mainly in the Z component because the magnetic inclination at Phimai is

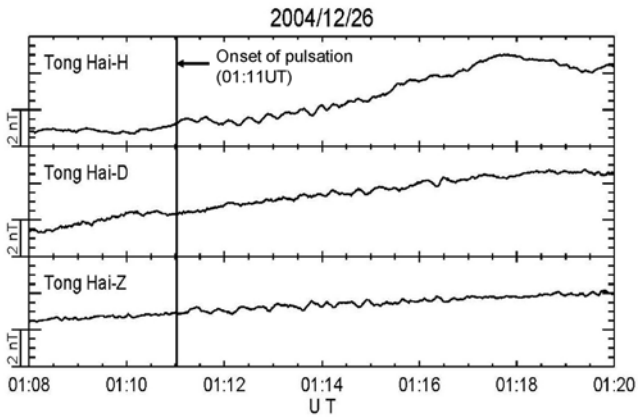

Figure 2. Geomagnetic variation at Tong Hai from 01:08UT to 01:20UT.

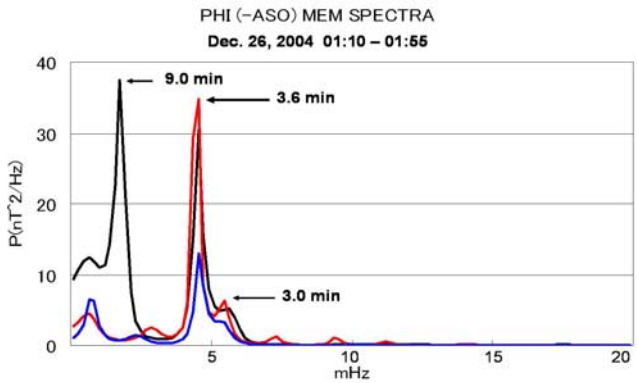

Figure 4. Power spectral density of the data shown in Figure 3. A common sharp peak appears at a period of 3.6 minutes.

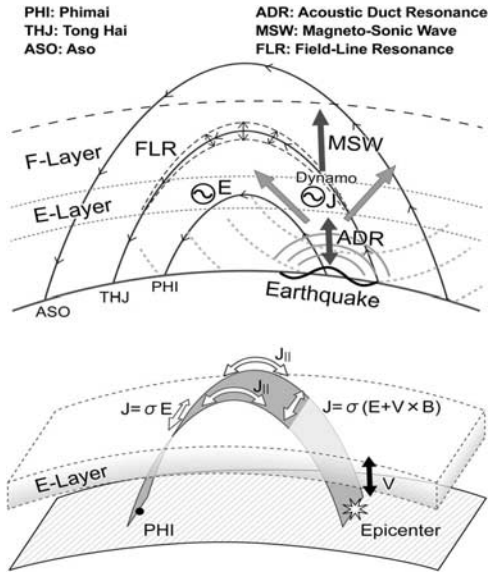

Figure 5. A schematic drawing of the possible generation mechanism of pulsations caused by the earthquake. An electric field oscillation generated by the dynamo is mapped to the ionosphere over Phimai (PHI) along geomagnetic field lines and causes current to flow. The dynamo current (J) and electric field (E) launch a magneto-sonic wave which may cause the Pc3 type short period oscillation at Tong Hai (THJ).

small (i.e., about 15 degrees) and it should start much earlier with a delay about 6 or 7 minutes from the earthquake origin time because the distance from the epicenter to Phimai is less than 1500 km. From these facts, it is difficult to explain the 3.6 minutes oscillation as a geomagnetic pulsation caused by an external source or as a sensor tremor.

[9] Many papers predict oscillations, with approximately 4 minute periods, of atmospheric pressure caused by a duct resonance of acoustic waves between the ground and lower thermosphere at altitudes of about 100 km [e.g., *Harkrider*, 1964; *Francis*, 1973; *Tahira*, 1995, and references therein]. The global seismic wave (Rayleigh wave) event observed during the Pinatubo eruption in 1991 was explained as a forcing of a ground oscillation by the resonance wave of the atmosphere [*Kanamori and Mori*, 1992].

[10] As for the 3.6 minute oscillation, we propose an ionospheric dynamo mechanism in ionospheric E-region at 100–120 km altitudes over the epicenter (3.3N, 95.9E, −6.3ALat) generated by a vertical wind oscillation caused by the atmospheric duct resonance set up by the Earthquake. That is, at the commencement of the earthquake, a wide area at the epicenter suddenly lifted up or depressed and an atmospheric pressure variation propagated upward as an acoustic wave, and part of the acoustic wave was reflected back to the lower thermosphere forming a duct resonance. The result is a vertical wind having a resonance frequency of 3.6 minutes in the ionospheric E region which generated the dynamo current there. The time lag of 12 minutes is consistent with the time necessary for an acoustic wave to travel from ground to the ionosphere (about 6 minutes) and reflect back to form a duct resonance. Because the geomagnetic latitudes at the epicenter and at Phimai are almost the same, that is, they are about 7 degrees south and north from the geomagnetic equator, respectively, regardless of the 5 degrees longitude difference, a polarized electric field generated by the dynamo current in an east-west direction over the epicenter was mapped along geomagnetic field lines to the ionosphere above Phimai. The electric field then generated the ionospheric currents in both east-west and north-south direction by Pedersen and Hall ionospheric electric conductivities, respectively, over Phimai, and they are observed as the north-south (H) and east-west (D) geomagnetic oscillation on the ground. Since the currents form a 3-dimensional circuit which consists of ionospheric Pedersen currents and field-aligned currents on both east and west sides, it also generates a vertical component (Z) as schematically shown in Figure 5 (bottom).

[11] In Figure 3, a second wave packet appears at around 01:35UT with smaller amplitude. According to recent simulations with realistic atmospheric parameters, oscillations of 3–5 minutes appear in the thermosphere as a result of energy input at lower atmosphere and it lasts for a rather long period. For example, for *Walterscheid et al.* [2003, Figure 5], the wave lasts more than 30 minutes without forcing. It is interesting to see that the second wave packet appears also in their simulation without a second source. On another clear spectral peak having a period of 9 minutes in Figure 4, we have no explanation and need more analysis including the ionospheric electron content (TEC) estimated from GPS signal.

[12] If a dynamo current flows in the ionosphere and produces an electric field, MHD waves are also generated [e.g., *Pokhotelov et al.*, 1995, and references therein] and propagate in the upper ionosphere to the magnetosphere as a magneto-sonic wave that could cause field-line resonance (FLR) if resonance conditions are met. The Pc3 type pulsation observed at Tong Hai could be explained as the result of FLR. The resonance frequency could be longer (i.e., about 30 second) even in low latitudes because most part of field line is in the lower ionosphere where heavy ions such as oxygen are dominant.

[13] In Figure 5, the relationship amongst the phenomena observed and expected is shown as a schematic drawing. To confirm the reality of this speculation, we need to compare the results presented here with other data and a realistic computer simulation of the effect of the earthquake on the atmosphere. More detailed and quantitative analysis and discussion will be presented as a separate article after this initial report.

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