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Anomalous ultra low frequency signals possibly linked with seismic activities in Sumatra, Indonesia

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ABSTRACT

Anomalous Ultra Low Frequency signals observed by ground-based magnetometers that linked with seismic events are commonly accepted. These anomalous signals can be promising phenomena for constructing early Earthquake-warning systems. The present study analyzes high-resolution (1-s) geomagnetic data recorded at the Kototabang (KTB) station, Indonesia, and other remote reference stations to detect the occurrence of any anomalous ULF signals that may associated with a number of seismic events occurred in Sumatra, Indonesia. The amplitude of the ULF emissions in the Pc3 range (10–45 s) was examined during three big seismic events that occurred in Sumatra between 2004 and 2007. Results of data processing and analysis indicate the presence of anomalous enhancement in the Pc3 amplitude ratio (ZPc3/HPc3) at KTB station in association with the studied seismic events. On the other hand, there are no noticeable changes at other distant reference stations during the examined periods. In addition, there are no remarkable external geomagnetic disturbances during the studied seismic events as it reveals from the Disturbance storm time (Dst) index. So, we can conclude that the observed anomalous changes might be a possible signature related to the above-mentioned seismic events in Sumatra, Indonesia.

1. Introduction

Earthquakes are natural phenomena result from an abrupt release of energy in the crustal layer; which sometimes cause great damages. Thus, finding a way to predict Earthquakes or construct an Earthquake warning system can be useful for reducing the Earthquake damages. Since, there is no reliable way to predict Earthquakes, it is important to look for some precursory phenomena in a relationship to the physical properties of the Earth's crust; that can show some anomalous behavior in association with Earthquakes.

Geomagnetic field measured on the Earth's surface is not constant and many sources can make variations in that field. These variations are classified as external and internal variations with respect to surface of the Earth. The solar wind, magnetosphere and ionosphere are considered as the major causes of the external geomagnetic changes, while the internal geomagnetic variations are linked with the tectonic processes and generally related to the magnetization of the crustal rocks (Merrill et al., 1996; Mandea and Purucker, 2005). The response of magnetic minerals to the variation in the external field and also their reaction to the crustal stress field can cause local crustal geomagnetic anomalies which vary on all spatial scales. This portion of the geomagnetic field is generally known as the crustal field. Previous studies about the characteristics of Earthquake precursors show that the amplitude of the observed anomalous variations could be correlated with the magnitude of seismic event, in other words, large precursory signals can be recorded in association with big seismic events (Cicerone et al., 2009).

However, the occurrence of major Earthquakes can be preceded by anomalous variations in several geophysical parameters such as anomalous changes in the geomagnetic field (Vere-Jones, 1995), many discussions and arguments are still arising about the signature and influence of Earthquakes on the geomagnetic field measurements. Moreover, researchers are not able to identify the exact physical mechanisms causing these anomalous variations and how to predict them until this moment.

2. Ultra low frequency emissions and earthquake occurrence

Geomagnetic pulsations, ULF waves, are natural magneto-hydrodynamic waves in the magnetosphere which can be classified as either

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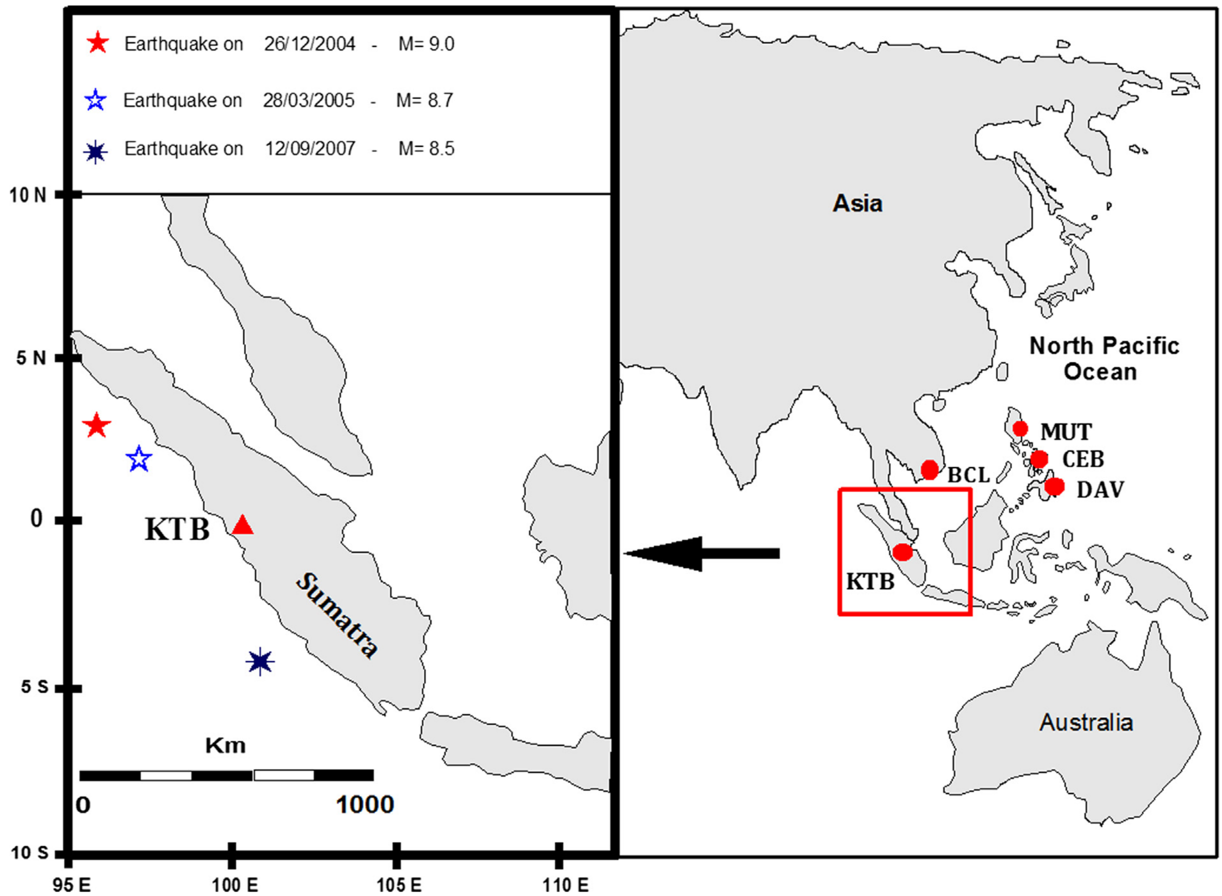

Fig. 1. location map shows the geomagnetic stations and location of the studied Earthquakes.

continuous (Pc) or irregular (Pi) pulsations. Each category is subdivided into period bands that roughly separate a specific type of pulsation. The Pc 3 pulsations are comparatively small amplitude variations in the Earth's geomagnetic field with the range of 10–45 s. The amplitude of the Pc3 varies from part of a nano Tesla (nT) to a several nT (Saito, 1969; Yumoto, 1986; McPherron, 2005).

The ULF waves are considered as a capable tool to monitor the crustal activity in seismically active areas compared with higher frequency waves due to their larger skin depth. Moreover, the attenuation of the ULF emissions is small in comparison with that of higher frequency emissions (Park et al., 1993; Hayakawa et al., 2007). ULF measurement that carried out to observe any abnormal ULF emissions connected with the Loma Prieta Earthquake in 1989, is the early observations in that field of study. The observed anomalous ULF emission linked with the Loma Prieta Earthquake was considered as a precursory signal (Fraser-Smith et al., 1990; Bernardi et al., 1991). Recently, several research works have reported the presence of abnormal ULF emissions in various frequency bands in association with Earthquakes (Hayakawa and Fujinawa, 1994; Pilipenko et al., 1999; Hattori et al., 2002; Hayakawa et al., 2007; Bleier et al., 2009; Yumoto et al., 2009; Takla et al., 2011a,b, 2012).

Using data from different geomagnetic stations inside and outside the epicentral region is a useful technique for extracting local geomagnetic anomalies related to seismic activities.

3. Geomagnetic data

The data used in the current study were mainly obtained from the Circum-pan Pacific Magnetometer Network (CPMN) and the MAGnetic Data Acquisition System (MAGDAS) Project [PI: Prof. A. Yoshikawa]. The CPMN network was constructed by Kyushu University in cooperation with many international associations along the 210° Magnetic Meridian chain. Generally, the CPMN covers high-, mid- and low-latitudes areas (Yumoto and 210°MM group, 1995, 1996; Yumoto, 2004).

Currently, the MAGDAS Network is considered as biggest network of magnetometers all over the world. MAGDAS system consists of two main units. The first unit includes the magnetometer sets for measuring the recording the geomagnetic data, while the second unit receives and analyzes the recorded from each station. The second MAGDAS unit is installed at the International Center for Space Weather Science and Education [ICSWSE], Kyushu University, Japan (Yumoto and the MAGDAS Group, 2006 and 2007).

Both MAGDAS and CPMN instruments are ring core-type fluxgate magnetometers which are able to measure very small geomagnetic variations. Each magnetometer has 3 sensors installed along three perpendicular directions to measures the components of the Earth's magnetic field. These components are the North-South component (H), East-West component (D), and the Vertical component (Z). MAGDAS and CPMN magnetometers provide high resolutions data (one second data) with a noise level of about 0.02 nT (Yumoto and the MAGDAS Group, 2006 and 2007).

4. Results of data analysis and discussion

The availability and accuracy of magnetic data are essential elements for studying the abnormal magnetic changes linked with seismic activities. In addition, a network of ground-base geomagnetic stations is important for observing and extracting the precursory phenomena or anomalous geomagnetic changes associate with seismic activities. In the current study, the availability of geomagnetic data helps us to examine the occurrence of any geomagnetic changes that maybe associated with the Sumatra Earthquakes. The comparison between the geomagnetic data in the vicinity of the epicenter with those recorded at distant stations (away from the epicenteral region) is considered as a valuable method to observe any geomagnetic changes of a crustal origin (Takla et al., 2011a,b, 2012).

In the current study, we report a number of observations of ULF signals (10–45 s) that maybe connected with some seismic events occurred at Sumatra, Indonesia. Our technique to identify any signature of the Earthquakes on the geomagnetic field measurements is based on a direct examination of the amplitude of ULF emissions in the vicinity of the seismic activities as shown in Fig. 1. According to Hayakawa et al. (2007), natural ULF emissions can be emitted from the center of seismic activities due to several effects such the piezo-magnetic, the electro-kinetic and the micro-fracturing effects during their preparation stage. Moreover, the changes of underground conductivity can cause an enhancement of the observed ULF signals (Mogi, 1985). Therefore, to identify any anomalous ULF signal in the time interval proceeding, during or after the studied events, the components of the geomagnetic field at KTB [0.3S, 100.3E] station (the nearest geomagnetic observing station from the epicenter of examined Earthquakes) were band-pass filtered in the Pc 3 range (10–45 s). Fig. 2 shows the Pc3 band-pass filtered data of the three geomagnetic components at the KTB for one hour (1530 UT-1630 UT). We should emphasize here that pre- or co-seismic anomalous geomagnetic variations are very weak to be detected by just visual examination of the raw-data. Therefore, some data processing techniques should be used to detect these kinds of anomalous variations. Toward this goal, the Pc3 amplitude ratio technique has been applied to detect any anomalous variations in the Pc3 amplitude (Takla et al., 2011b, 2012). The Pc 3 amplitudes were calculated hourly during three months for each seismic event (the month where the seismic event occurred and one month before and after each Earthquake). The Pc3 amplitude ratio (ZPc3 / HPc3) was calculated during the three months for KTB data and also for other two reference stations. The first Earthquake occurred on 26 December 2004 with magnitude 9 [3.31N, 95.85E] as shown in Fig. 1. The Pc3 amplitude ratio at KTB station was calculated from 1 November 2004 to 31 January 2005 (three months) and was compared with those from Bac Lieu (BCL) [9.32N, 105.71E] and Cebu (CEB) [10.36N, 123.91E] stations as remote reference points as shown in Fig. 3. It is clear in Fig. 3 that there is an enhancement in the Pc 3 amplitude ratio during December 2004 at KTB station compared with other reference stations. The Pc3 amplitude ratio started to increase about two weeks before the seismic activity and lasted for about one week after the 26 December 2004 Earthquake. A significant enhancement in the Pc3 amplitude was detected during the Earthquake occurrence. The upper panel in Fig. 3 shows the Dst index during the studied time interval to examine the occurrence of any external field variations during the Earthquake occurrence. The Dst is an index to measure the geomagnetic activity and the severity of the geomagnetic storms in nanoteslas. It is calculated from the hourly averaged values of the horizontal geomagnetic component that recorded at four near-equatorial geomagnetic observatories. The Dst Index does not show any clear or remarkable external field variations during the Earthquake. The second seismic event occurred on 28 March 2005 with magnitude 8.7 [2.09N, 97.15E] as shown in Fig. 1. Fig. 4 shows the Pc3 amplitude ratio during the period from first of February 2005 until end of April 2005 at the KTB, BCL and CEB stations. The Pc3 amplitude ratio at KTB station shows clear abnormal fluctuations during the Earthquake. These anomalous fluctuations and enhancement started also about two weeks prior to the Earthquake and recovered after a few days from the occurrence of the Earthquake. In addition, no anomalous changes were detected during the seismic event at the other two reference stations and also in the Dst index. The Pc3 amplitude ratio was also examined during another seismic event occurred during 12 September 2007 with magnitude 8.5 [4.5S, 101.4E] at shown in Fig. 5. Similar to the previous two cases, there was anomalous enhancement in the Pc3 amplitude ratio at KTB station during the seismic events. For the examination of the Pc3 amplitude during the last seismic event, we used data from two other reference stations Davao (DAV) [7.0N, 125.4E] and Muntinlupa (MUT) [14.37N, 121.02E] due do the lack of geomagnetic data at BCL and CEB during the studied period, see Fig. 1.

The Pc 3 amplitude ratio provides a clear picture about the relationship between the ULF emissions and the Earthquakes. The maximum enhancement in the Pc3 amplitude ratio mainly occurs during the

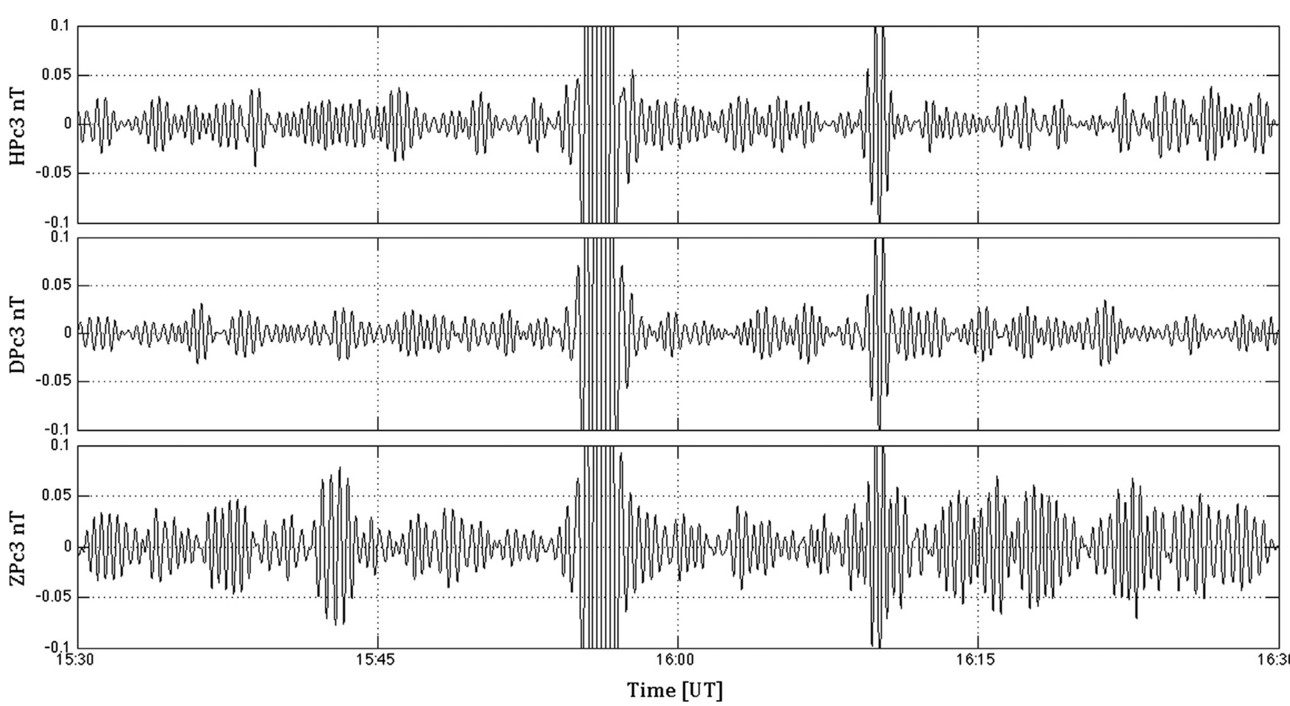

Fig. 2. The band-pass filter in the Pc3 range (10–45 s) of the KTB data for one hour (1530 UT-1630 UT) for the three geomagnetic components (H-, D-, and Z-components).

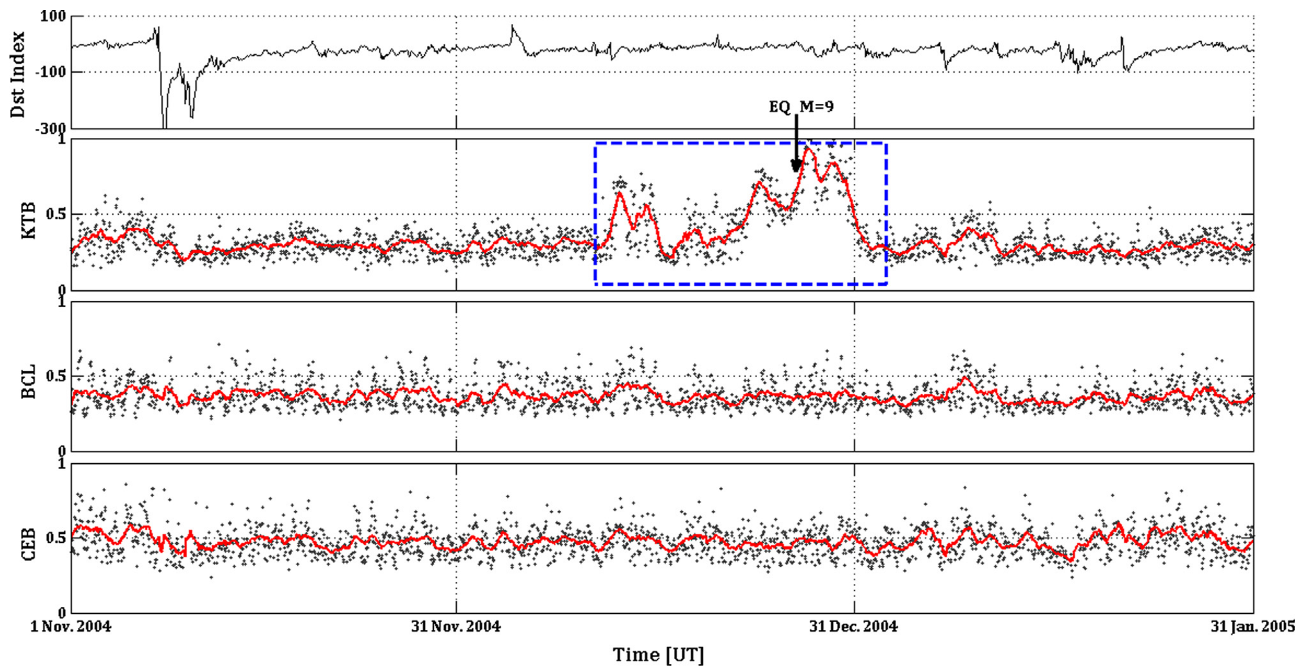

Fig. 3. The Pc 3 amplitude ratio (ZPc3/HPc3) observed at KTB, BCL and CEB stations from 1 November 2004 to 31 January 2005. The red line represents 24 points running average. The dashed rectangle indicates the anomalous changes in the Pc3 amplitude ration at KTB station.

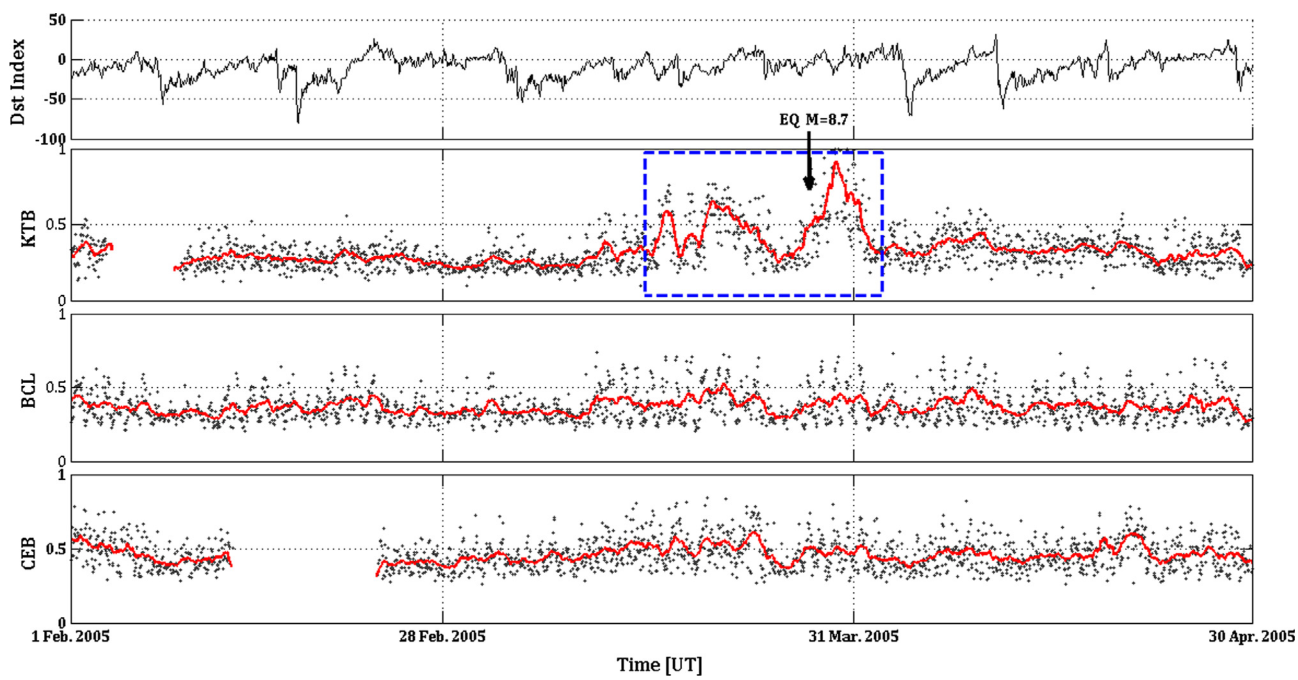

Fig. 4. The Pc 3 amplitude ratio (ZPc3/HPc3) observed at KTB, BCL and CEB stations from 1 February to 30 April 2005. The red line represents 24 points running average. The dashed rectangle indicates the anomalous changes in the Pc3 amplitude ration at KTB station.

seismic events.

Several mechanisms were provided to explain and clarify the generation of the ULF signals in relationship with seismic activities. The piezo-magnetic effect (Sasai, 1991), the electro-kinetic effect (Fitterman, 1979) and the micro-fracturing effect (Molchanov and Hayakawa, 1995) have been proposed as causes for generating ULF emissions prior or during seismic activities. The inhomogeneous enhancement of the underground conductivity resulting from stress accumulation and/or underground fluid motion maybe play an important role for amplifying the ULF emissions of external origin. According to Chi et al. (1996), the amplitude of the electromagnetic emissions recorded on the ground depends on the underground conductivity structure and can be calculated by the equation:

$$A = B[f(t)]\sigma$$

where, A is the approximate wave amplitude recorded on the Earth's surface, B is the magnitude of the wave, f (t) is the local time dependence and σ is amplification factor which depends on the underground conductivity structure. In this case, the change in the underground conductivity can have an effective impact on the Pc 3 amplitude; which can lead to precursory anomalous ULF signal especially before large Earthquakes. This may explain why the Pc 3 amplitude ratio at the KTB

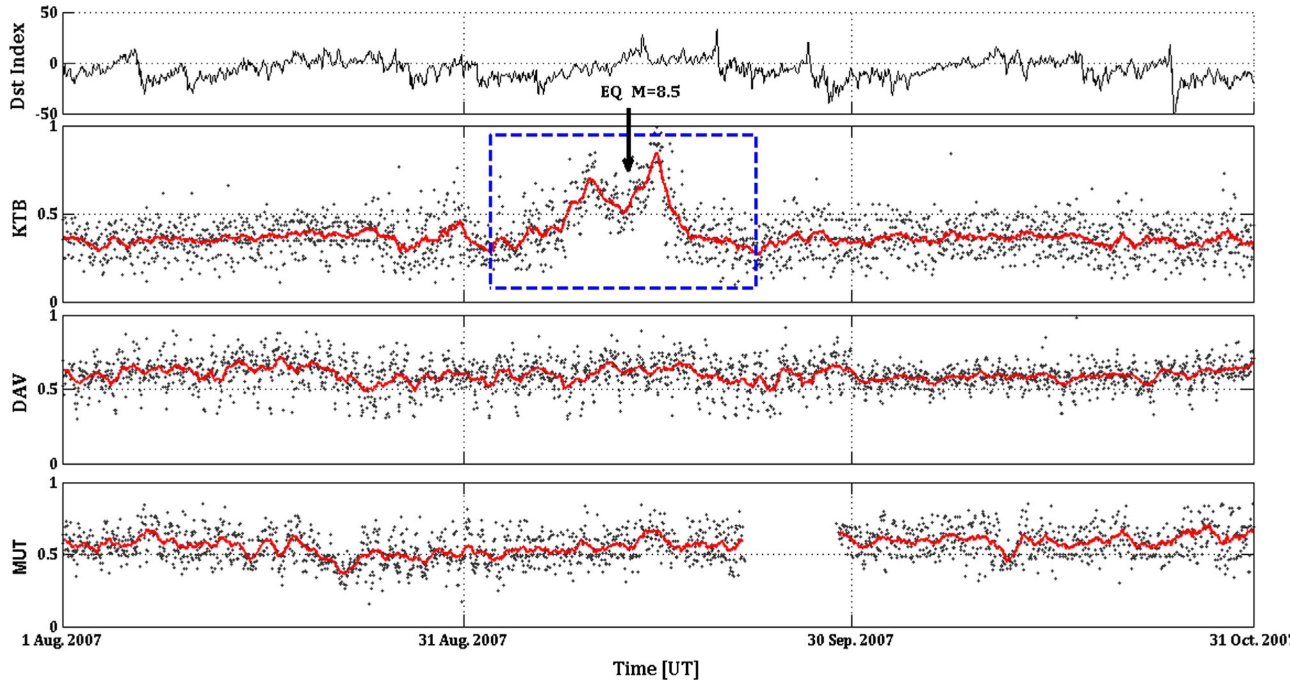

Fig. 5. The Pc 3 amplitude ratio (ZPc3/HPc3) observed at KTB, DAV and MUT station from 1 August to 31 October 2007. The red line represents 24 points running average. The dashed rectangle indicates the anomalous changes in the Pc3 amplitude ration at KTB station.

station showed a remarkable enhancement in association with the seismic activities. The exact source of detected anomalous ULF signals is still unidentified. The amplitude ratio technique is a simple process but at the same time it requires multiple-station analysis (reference stations). It remains the topic of future study to clarify the physical mechanism responsible for producing the observed anomalous variations.

5. Summary and conclusion

In the present study, we have observed abnormal geomagnetic variations at the KTB station, Sumatra, Indonesia in the vicinity of the epicenter of some seismic events. The result obtained from data analysis indicates the occurrence of anomalous enhancement in the Pc3 amplitude ratio (Z/H) at the KTB station during the studied seismic events in Sumatra, Indonesia. The Dst index and the analysis of the geomagnetic data from other reference stations indicate no anomalous variations compared with those obtained at the KTB station. Thus, the obtained result suggests that the observed anomalous variations at the KTB station have a local tectonic origin.

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References

Bernardi, A., Fraser-Smith, A.C., McGill, P.R., Villard Jr., O.G., 1991. ULF magnetic field measurements near the epicenter of the Ms 7.1 Loma Prieta earthquake. Phys. Earth Planet. Inter. 68, 45–63.
Bleier, T., Dunson, C., Maniscalco, M., Bryant, N., Bambery, R., Freund, F., 2009. Investigation of ULF magnetic pulsations, air conductivity changes, and infra red signatures associated with the 30 October Alum Rock M5.4 earthquake. Nat. Hazards Earth Syst. Sci. 9, 585–603.
Chi, P.J., Russell, C.T., Le, G., Hughes, W.J., Singer, H.J., 1996. A synoptic study of Pc 3, 4 waves using the AFGL magnetometer array. J. Geophys. Res. 101, 13215–13224.
Cicerone, R.D., Ebel, J.E., Britton, J., 2009. A systematic compilation of earthquake precursors. Tectonophysics 476, 371–396.
Fitterman, D.V., 1979. Theory of electrokinetic-magnetic anomalies in a faulted half-space. J. Geophys. Res. 84, 6031–6040.
Fraser-Smith, A.C., Bernardi, A., McGill, P.R., Ladd, M.E., Helliwell, R.A., Villard Jr., O.G., 1990. Low-frequency magnetic field measurements near the epicenter of the Ms 7.1 Loma Prieta earthquake. Geophys. Res. Lett. 17, 1465–1468.
Hattori, K., Akinaga, Y., Hayakawa, M., Yumoto, K., Nagao, T., Uyeda, S., 2002. ULF magnetic anomaly preceding the 1997 Kagoshima earthquakes. In: Hayakawa, M., Molchanov, O., (Eds.). Seismo- Electromagnetics (Lithosphere-Atmosphere-Ionosphere Coupling). TERRUPUB, pp. 19–28.
Hayakawa, M., Fujinawa, Y., 1994. Electromagnetic Phenomena Related to Earthquake Prediction. Terra Sci. Pub. Co., Tokyo, Japan.
Hayakawa, M., Hattori, K., Ohta, K., 2007. Monitoring of ULF (ultralow - frequency) geomagnetic variations associated with earthquakes. Sensors 7, 1108–1122.
Mandea, M., Purucker, M., 2005. Observing: modeling, and interpreting magnetic fields of the solid earth. Surv. Geophys. 26, 415–459.
McPherron, R.L., 2005. Magnetic pulsations: their sources and relation to solar wind and geomagnetic activity. Surv. Geophys. 26, 545–592. http://dx.doi.org/10.1007/s10712-005-1758-7.
Merrill, R.T., McElhinny, M.W., McFadden, P.L., 1996. The Magnetic Field of the Earth. Academic Press, San Diego, pp. 531.
Mogi, K., 1985. Earthquake Prediction. Academic Press, Tokyo, pp. 382.
Molchanov, O.A., Hayakawa, M., 1995. Generation of ULF electromagnetic emissions by microfracturing. Geophys. Res. Lett. 22, 3091–3094.
Park, S.K., Johnston, M.J.S., Madden, T.R., Morgan, F.D., Morrison, H.F., 1993. Electromagnetic precursors to earthquakes in the ULF band: A review of observations and mechanisms. Rev. Geophys. 32, 117–132.
Pilipenko, V.A., Fedorov, E.N., Yagova, N.V., Yumoto, K., 1999. Attempt to detect ULF electro-magnetic activity preceding earthquake. In: Hayakawa, M. (Ed.), Atmospheric and Ionospheric Electromagnetic Phenomena Associated with Earthquakes. Terra Scientific Publishing Company (TERRAPUB), Tokyo, pp. 203–214.
Saito, T., 1969. Geomagnetic pulsations. Space Sci. Rev. 10, 319.
Sasai, Y., 1991. Tectonomagnetic modeling on the basis of the linear piezomagnetic effect. Bull. Earthq. Res. Inst. Univ. Tokyo 66, 585–722.
Takla, E.M., Yumoto, K., Sutcliffe, P.R., Nikiforov, V.M., Marshalle, R., 2011. Possible association between anomalous geomagnetic variations and the Molise Earthquakes at Central Italy during 2002. Phys. Earth Planet. In. 185, 29–35. http://dx.doi.org/10.1016/j.pepi.2010.12.003.
Takla, E.M., Yumoto, K., Liu, J.Y., Kakinami, Y., Uozumi, T., Abe, S., Ikeda, A., 2011. Anomalous geomagnetic variations possibly linked with the Taiwan earthquake (Mw = 6.4) on 19 December 2009. Int. J. Geophys. 2011http://dx.doi.org/10.1155/2011/848467. Article ID 848467.
Takla, E.M., Yumoto, K., Ishitsuka, J., Rosales, D., Dutra, S., Uozumi, T., Abe, S., 2012. Geomagnetic variations possibly associated with the Pisco earthquake on 15 August 2007, Peru. Tectonophysics 524–525, 29–36.
Vere-Jones, D., 1995. Forecasting earthquakes and earthquake risk (invited review

paper). Int. J. Forecasting 11, 503–538.
Yumoto, K., 1986. Generation and propagation mechanisms of low-latitude magnetic pulsations: A review. J. Geophys. 60, 79–105.
Yumoto, K., and the 210o MM Magnetic Observation Group, 1995. The 210o MM magnetometer network. IUGG_XXI_General_Assembly, held at Boulder, Colorado, on July 2-14.
Yumoto, K., The CPMN Group, 2001. Characteristics of Pi 2 magnetic pulsations observed at the CPMN stations: A review of the STEP results. Earth Planets Space 53, 981–992.
Yumoto, K., 2004. Transport of HM energy through the magnetosphere-ionosphere coupling system-Results from the ground-based network observations. Advances in Solar-Terrestrial Physics, edited by H. Oya, TERRAPUB, Tokyo, pp. 175–211.
Yumoto, K., the MAGDAS Group, 2006. MAGDAS project and its application for space weather, Solar Influence on the Heliosphere and Earth's Environment: Recent Progress and Prospects, Edited by N. Gopalswamy and A. Bhattacharyya, ISBN-81-87099-40-2, pp. 399–405.
Yumoto K., the MAGDAS Group, 2007. Space weather activities at SERC for IHY: MAGDAS. Bull. Astr. Soc., India 35, 511–522.
Yumoto, K., Ikemoto, S., Cardinal, M.G., Hayakawa, M., Hattori, K., Liu, J.Y., Saroso, S., Ruhimat, M., Husni, M., Widarto, D., Ramos, E., McNamara, D., Otadoy, R.E., Yumul, G., Ebora, R., Servando, N., 2009. A new ULF wave analysis for seismo-electromagnetics using CPMN/MAGDAS data. Phys. Chem. Earth 34, 360–366.