Data Processing Method to classify Pc5 ULF Pulsations due to Solar Wind Perturbations at Equatorial region

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Abstract: - Space weather study has increasingly attracts the attention of many scientists to explore the interaction between solar activity and geomagnetic activity. Observation on Pc5 geomagnetic pulsations with periods ranging from 150-600 seconds due to solar wind perturbations at the equatorial region currently not widely explored. In this paper, we will briefly discuss the data processing methods involve in order to analyze the geomagnetic data observed by magnetometer from geomagnetic observation stations; Tirunelveli (TIR), India, Langkawi (LKW), Malaysia and Yap Island (YAP), Federated States of Micronesia which are located at equatorial region. The explanation of the processing methods is based on the 24-hour data with 1 second sampling interval extracted during quiet and disturbed days. The result indicates that the higher amplitude of H geomagnetic field is recorded during daytime and maintain during nighttime at all analyzed stations. In addition, Pc5 ULF pulsations are corresponding well with the solar wind perturbations.

Key-Words: - Magnetometer, geomagnetic data, magnetic pulsation, solar wind perturbations and data processing method

1 Introduction

Magnetic pulsations or called ultra-low frequency (ULF) pulsations is electromagnetic waves generated in the magnetosphere. Its frequency range is between 1 mHz and 1Hz. The generation of magnetic field is dependent on solar and processes in the magnetosphere. Earth's magnetic field observations play important role in the understanding of the Earth's electromagnetic environment. Many experiments has been done by previous researchers found that the variations in magnetic fields are caused by the dynamo action in the upper atmosphere. Daily variation (24 hours period) of geomagnetic field components was first observed by G. Graham in London [1]. The variations are then observed as magnetic pulsations on the ground and recorded in the range of Ultra Low Frequency (ULF) with periods of 0.2 - 600 sec [2]. The classification of ULF wave has been established since 1964 as shown in Table 1.

There are evidences that the previous researchers investigated the correlation of Pc3-Pc4 with the solar wind at equatorial region [3]-[6]. Other than that, the observations on the Pc5 ULF waves are widely observed at high and mid-latitudes. This is done by [7]-[10]. Studies on the Pc5 ULF pulsations with periods ranging from 150-600 seconds due to solar wind perturbations at the equatorial region have received less attention.

Table 1 IAGA classification of ULF waves in 1964

ULF pulsations		**Period (sec)**	**Frequency (mHz)**
Continuous	Pc1	0.2-5	200-500
	Pc2	5-10	100-200
	Pc3	10-45	22-100
	Pc4	45-150	6.7-22
	Pc5	150-600	1.7-6.7
Irregular	Pi1	1-40	25-200
	Pi2	40-150	6.7-25

1.1 Solar Wind Perturbations

The Sun producing solar activities which can be classified into sunspots, coronal mass ejections (CME), coronal holes and solar flares [11]. These activities will cause higher variation on solar wind speed and solar wind dynamic pressure which later will influence the amount of solar wind input energy that penetrating into the Earth's ionosphere. The input energy transferred from the solar wind into the magnetosphere depends on the orientation of the interplanetary magnetic field (IMF) [12]. Solar wind input energy can be calculated using Akasofu epsilon, ε [13] as equation (1):

$$\varepsilon = V_{sw} B^2 F(\theta) I_o{}^2 \quad \text{(Watt or ergs)} \quad (1)$$

Where Vsw is solar wind speed [km/s], B is total magnetic field [nT], Io is Earth's radius [km] and F (θ) is a function of the angle, θ (By/Bz).

1.2 Geomagnetic

Geomagnetic data which extracted from magnetometer is used in this study to monitor ambient magnetic activities. The data was extracted from a real-time Magnetic Data Acquisition System of Circum-pan Pacific Magnetometer Network, i.e. MAGDAS/CPMN magnetometer. It is a ring core-type fluxgate magnetometer that measures three components of the geomagnetic field; Horizontal component (H), Declination component (D), and the Vertical component (Z).

The 1-sec resolution data from horizontal component were extracted to examine the geomagnetic pulsation as mention before as shown in Table 1. The raw data from MAGDAS/CPMN stations was first bandpass-filtered before applying dynamic power spectra density using Fast Fourier Transform (FFT) to identify the occurrences of geomagnetic pulsations. Another method to identify the occurrences of ULF pulsations is by using wavelet transform. The similar basic functions between FFT and wavelet transform are the methods localized in the frequency domain [14] and the information from magnetic field is extracted in a noisy environment [15].

2 Methodology

2.1 Instrumentation

MAGDAS/CPMN magnetometer has been developed by International Center for Space Weather Science and Education, ICSWSE, Kyushu University, Japan for space weather study and application. The extracted data from this system can be used to conduct real-time monitoring and modeling of (1) global 3-dimensional current system, (2) plasma mass density, and (3) penetrating process of polar electric fields into the equatorial ionosphere, in order to understand the Sun-Earth coupling system and the electromagnetic and plasma environment changes [17]. To date, MAGDAS/CPMN consists of three (3) unique chains of magnetic observatories; the most magnetometers were densely installed at 210° magnetic meridian, on African longitude-sector and the other one is on the sector along the magnetic equator (with total of 72 stations worldwide), as shown in Figure 1.

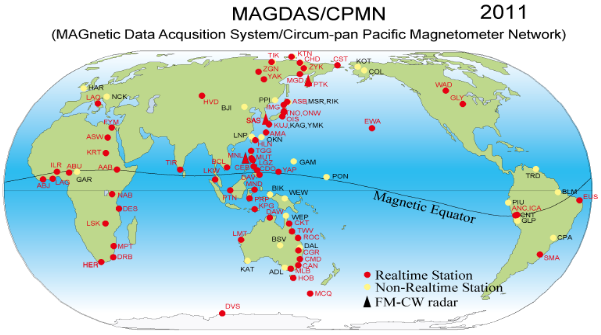


Figure 1: Map of magnetometers installed under MAGDAS/CPMN

2.2 Data Analysis

In this work, we have analyzed horizontal component of geomagnetic data at three (3) stations; Langkawi (LKW), Malaysia, Tirunelveli (TIR), India and Yap Island (YAP), Federated States of Micronesia which are located at equatorial region. The map and coordinates of these stations are shown in Figure 2 and Table 2. At equatorial region, the horizontal component is the major part of the total field and the vertical component is significantly affected by the geological and geographic surroundings of the station [16].

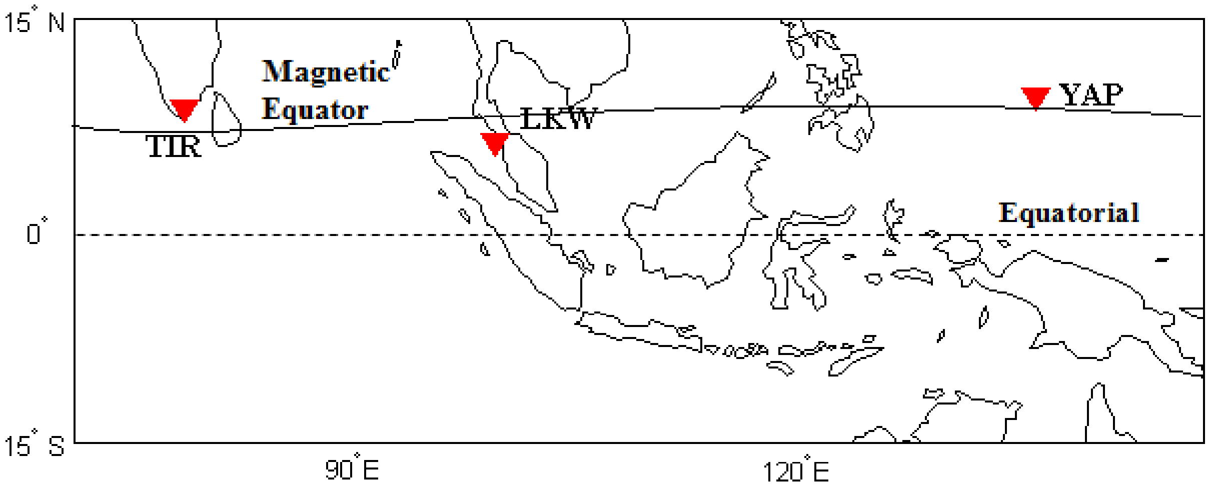


Figure 2: Map of LKW, TIR and YAP stations.

Table 2: List of observatories

		Geographic		Geomagnetic			
Station name	Code	GG lat.	GG lon.	GM lat.	GM lon.	L	Dip lat.
Langkawi	LKW	6.30	99.78	1.49	209.06	1	1.70
Tirunelveli	TIR	8.70	77.80	0.21	149.30	1	0.6
Yap Island	YAP	9.5	138.08	1.49	209.06	1	1.70

Therefore at present only the horizontal component of the geomagnetic field is analyzed. The aim of this study is to present the variability of the earth's horizontal magnetic field component, H at different equatorial stations and to discuss the correlation of Pc5 ULF pulsations extracted from geomagnetic data with solar wind parameters (solar wind speed and solar wind input energy).

The data were divided into 2 categories; quiet and disturbed period, available at Data Analysis Center for Geomagnetism and Space Magnetism, Kyoto University, Japan (WDC). The selection of the quietest days (Q-days) are derived from the magnetic activity indices by index ranges through 0 to 9 with 0 is being quietest or most disturbed days and 9 being least of both. Furthermore, the selection of the most disturbed days (D-days) are derived from the magnetic activity indices by index ranges through 1 to 5 with 1 is being quietest or most disturbed days and 5 being least.

To further compare with solar wind events, solar wind speed and solar wind input energy has been plotted. Solar wind speed events and other parameters (proton density [cm-3], magnetic field in x, y and z-direction [nT]) on March 2010 were obtained from the Space Physics Data Facility (SPDF) based at NASA's Goddard Space Flight Center.

The occurring of ULF pulsations can be determined by referring to the solar wind parameters (solar wind speed and solar wind input energy). Figure 3 shows a solar wind speed and solar wind input energy from 11-16 March 2010. Solar wind speed and solar wind input energy reached a higher peak level on disturbed days (12 March 2010) as compared to the quiet day which occurred 3 days later on 15 March 2010.

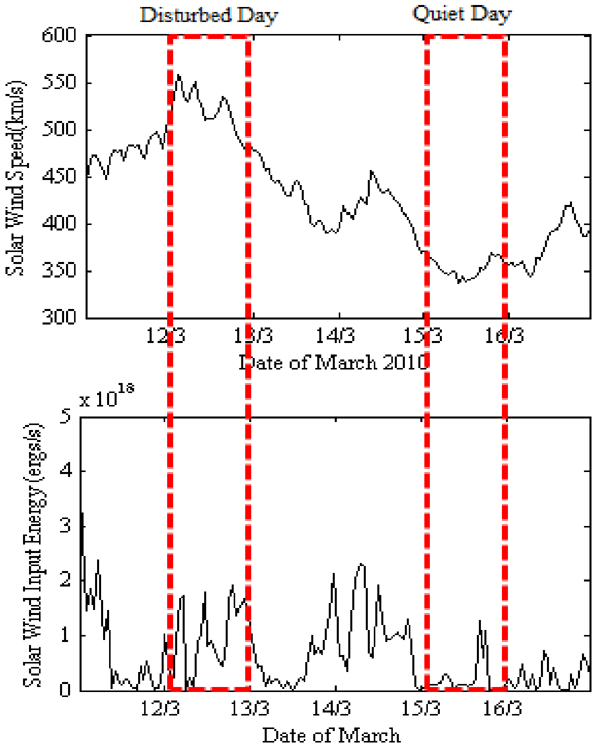


Figure 3: Solar Wind Speed (top) and Solar Wind Input Energy (bottom) from 11-16 March 2010.

2.3 Data Processing

The flow of the data processing is shown in Figure 4. The observed geomagnetic which stored in data cards should be processed to be convenient for end user of data in research work. The data processing method needs to be implemented to ensure the quality of data and the processed data is useful for scientific research. As current procedures, Matlab programming language is used to process the raw data covering the processes for data availability screening, ambient noise check-up, plotting, band-pass filtering, power spectra density and Fast Fourier Transform (FFT) analysis.

1-sec resolution of MAGDAS magnetometer data is processed to extract raw data of the geomagnetic field components (H, D and Z). Raw data were analyzed based on the Q-day and D-day. Next, the band-pass filtered method is applied to determine the geomagnetic pulsations either irregular pulsations (Pi) or continuous pulsations (Pc) according IAGA classification. To further confirm the occurrences of geomagnetic pulsations, Power Spectra Density (PSD) method has been applied and the results were plotted based on color spectrum which corresponds to the algorithm of the power in nT2/Hz. The calculation was implemented based on Hanning window through the data and Fast Fourier Transform (FFT) on the subset of the signal within the window. This method also was applied by [18] to detect a noise computed by integrating the Fourier and Wavelet methods.

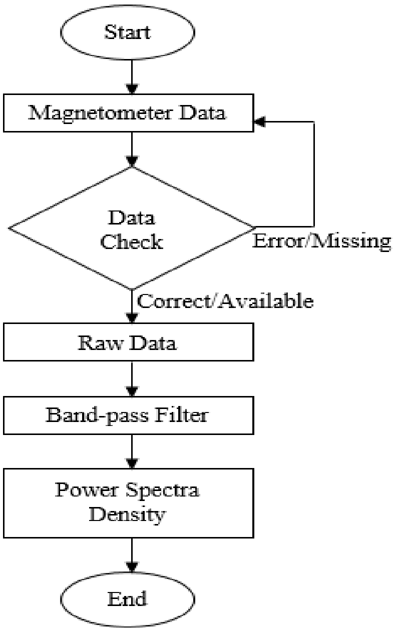
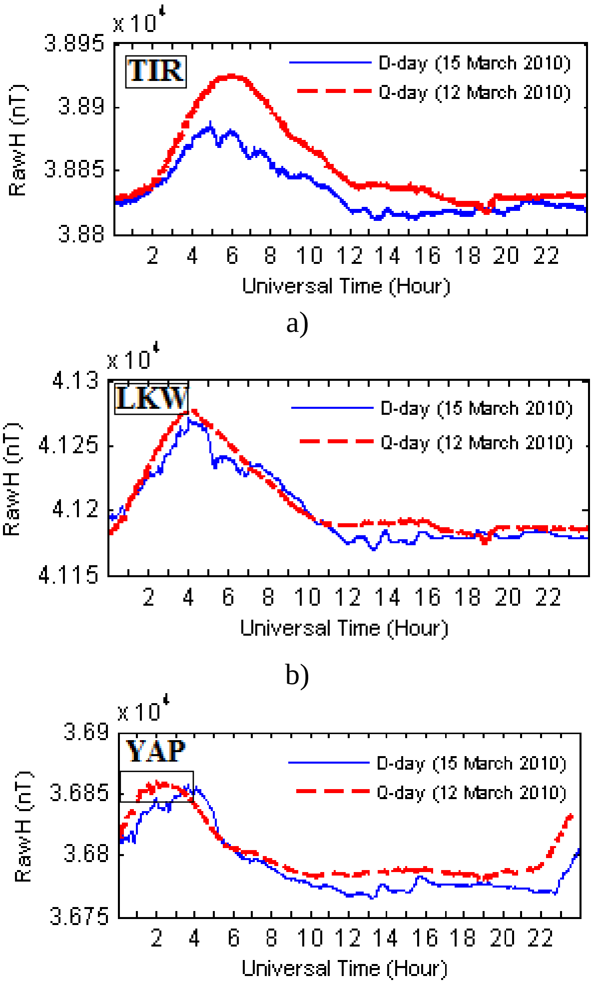


Figure 4: Flowchart of process MAGDAS data

3 Result and Analysis

3.1 Raw Data

Figure 5 shows raw data of the horizontal magnetic field components observed at equatorial region on quiet (Q-day), 15 March 2010 and disturbed days (D-day), 12 March 2010. Both variations on quiet and disturbed days at LKW and TIR stations show that H component recorded higher amplitude at time 0000 to 1000 UT (Universal Time). While for YAP station, the amplitude of H component is higher start from 0000 UT to 0600UT. The local H component afterwards maintained during night time from 1000 till 2300 UT. One can see clearly the H component recorded on disturbed days (12 March 2010) is distracted and drop as compared to H variation recorded on quiet day (15 March 2010). The average of H is higher at LKW station followed by average of H at TIR and YAP station on quiet and disturbed days.



a)

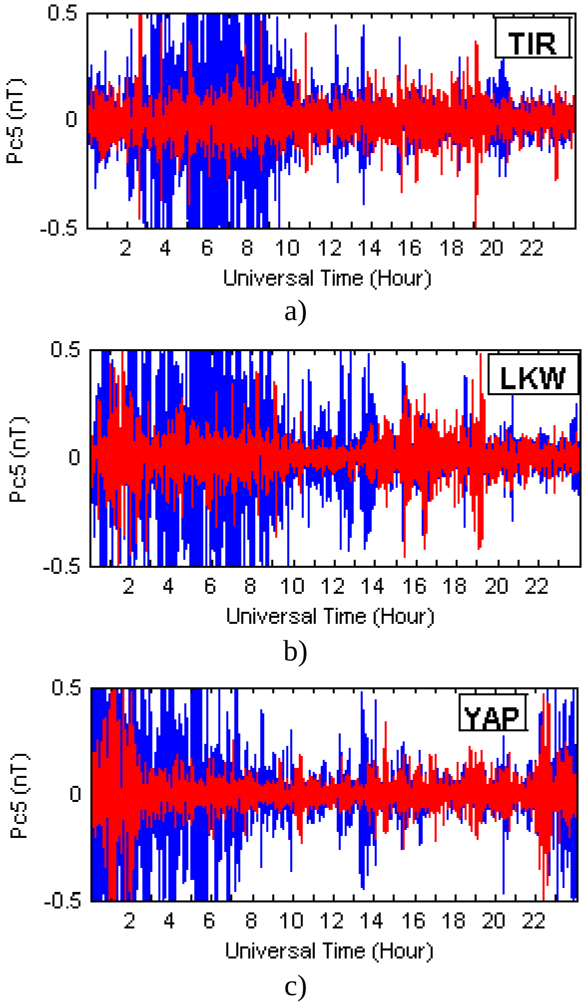
b)

c)

Figure 5: Raw data of H (nT) magnetic components on disturbed days (15 March 2010) and quiet day (12 March 2010) at a) TIR, b) LKW and c) YAP stations.

3.2 Band-pass Filter

Figure 6 shows the Pc5 ULF pulsations on disturbed days (blue) and quiet day (red) at a) LKW, b) TIR and c) YAP stations. The Pc5 ULF pulsations observed during disturbed days show higher fluctuation as compared to the Pc5 during quiet day. The fluctuation on disturbed days is higher at time 0000 to 1000 UT (Universal Time).



a)

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Figure 6: Pc5 ULF pulsations on disturbed days (blue) and quiet day (red) at a) TIR, b) LKW and c) YAP stations.

3.3 Power Spectral Density

Figure 7 shows PSD plot for quiet day at equatorial region. PSD plot for quiet day Pc5 ULF pulsation is observed and occurred at range between 1.7-3.7 mHz. Figure 8 shows PSD plot for disturbed days at LKW, TIR and YAP stations. Pc5 more occurred and reached almost 6.7 mHz during disturbed days as compared to the quiet day at these three stations. This Pc5 event is occurred at time around 0000 to 0900 UT.

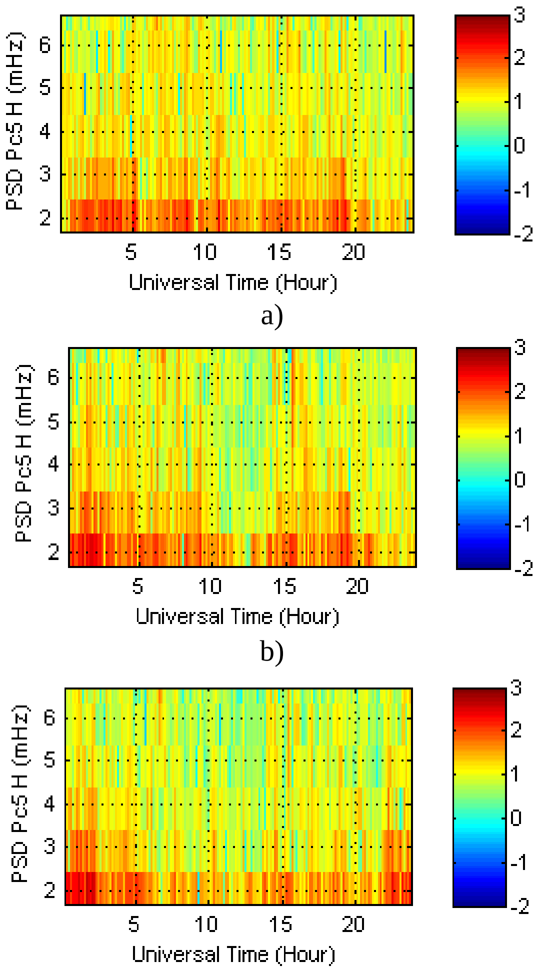

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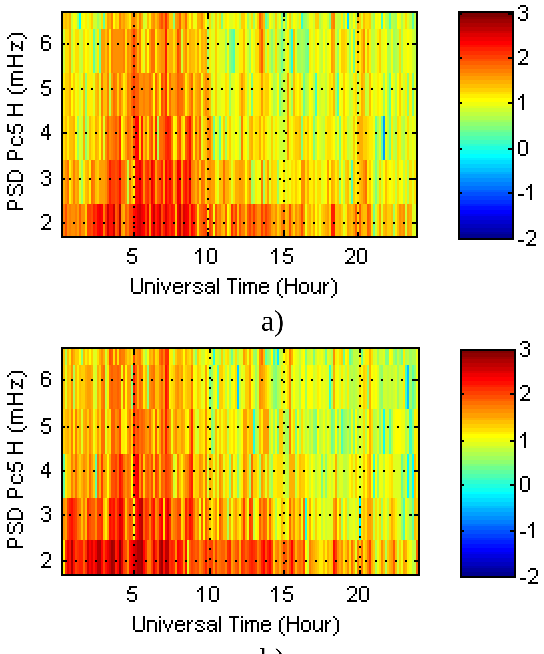
Figure 7: Power Spectra Density on quiet day (15 March 2010) at a) TIR, b) LKW and c) YAP stations.



a)

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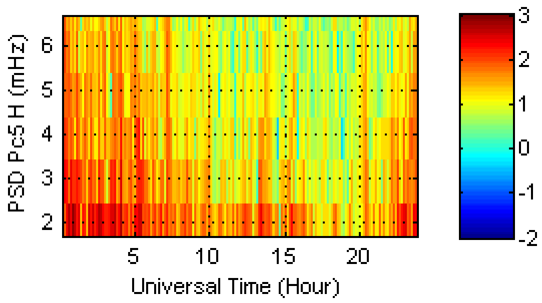

c)

Figure 8: Power Spectra Density on disturbed days (12 March 2010) at a) TIR, b) LKW and c) YAP stations.

4 Discussion

In this paper, we examined the variability of the earth's horizontal magnetic field, H different equatorial stations and present the relationship geomagnetic activity, Pc5 pulsations with solar wind parameters. The following features are worth noting.

First, the variation of H geomagnetic field at equatorial region shows clear pattern with reached a higher peak during daytime and maintained during nighttime. This observation agrees with the result of previous study e.g. [1], [16] and [19]. The variation on H is referred to the classical dynamic theory. It is indicated that the night amplitudes are seen to remain relatively constant since there are no solar radiations during night. These diurnal variations of H on quiet days are related with currents flowing in the E-region of the ionosphere [16]. The decrease on variation of H during the nighttime than the daytime is due to the eccentric ring current [19].

Second, the fluctuation of Pc5 is higher during daytime compared to the nighttime. This is due to the fact Pc5 is more dominated by solar wind-magnetopause interaction via Kelvin-Helmholtz instability in daytime and by earth-toward magneto-tail plasma particle stream in nighttime [20]. The higher fluctuation in Pc5 is rare especially during nighttime which related with the complicated dynamics of upper atmosphere.

Lastly, the results suggest that Pc5 is a good index for solar wind parameters (solar wind speed and solar wind input energy). This is confirms the studies by previous researchers [21] and [22]. They found that the strong correlation between solar wind speed and Pc5 band PSD is independent of local time. The generation mechanism of Pc5 pulsations is mainly due to the solar wind perturbations which related with Kelvin-Helmholtz instability.

5 Conclusion

The data processing method of geomagnetic data recorded by magnetometer from equatorial stations has been discussed based on the 24-hour data extracted during quiet and disturbed days. The occurrence of Pc5 ULF pulsations is influenced by the solar wind parameters (solar wind speed and solar wind input energy). The ability of the MAGDAS/CPMN magnetometer to measure ULF pulsations is important to understand the space weather using geomagnetic field data. By applying the aforementioned data processing methods, it is possible to extract and investigate the possible relationship of space weather and the activities on the lithosphere. However, further analysis and evaluation involving extension of observational data with advanced statistical analysis method are needed to ensure the relationship of space weather and geomagnetic activity can be comprehensively explained.

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