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Pc5 MAGNETIC PULSATIONS DURING THE OUTER ELECTRON RADIATION BELT

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ABSTRACT

Since the discovery of the radiation belt decades ago, there still remain some fundamental questions as to which one is the mechanism responsible for the acceleration of electrons. Ground-based Pc5 magnetic pulsation during the process of increasing of 2-MeV electron fluxes has been analyzed. First, a filter bandpass in the period range of 150-600 seconds has been used to localize the Pc5 waves. Second, we then applied a wavelet transform procedure, whereby the Morlet function as a mother wavelet was selected to analyze Pc5 wave packets. First, we show that dynamic pressure of solar wind controls the power of Pc5 magnetic pulsations. Second, by performing a cross-spectrum analysis of Pc5 wavelet during electron radiation belts we show that the wavelet power of Pc5 magnetic pulsations which is associated with a maximum wavelet cross spectrum show a similar change of Pc5 pulsations occurs during radiation belt events. Increasing of electron fluxes which is initiated by the presence of large power of Pc5 magnetic pulsations has been observed. This indicates that Pc5 magnetic pulsations could play a role in the acceleration and transport mechanism of the electron radiation belt. Also, 4-5 days from the beginning of increasing of electron fluxes we observed globally, a depression in the power of Pc5 magnetic pulsations as well as a monotonically decreasing of the solar wind dynamic pressure. On the other hand, during the end period of the electron belt, we also observed a sudden increasing of Pc5 power. We suggest that during the expansion periode of the outer electron radiation belt outward to interplanetary electron belt pressure that will reduce the solar wind dynamic pressure and consequently a decrease occurs in the power of Pc5 magnetic pulsation. And, in the end period of the electron radiation belt the electron fluxes back to its normal level and consequently a sudden increase of the Pc5 solar wind dynamic pressure occurs and that sudden increase also drives the sudden increasing power of Pc5 magnetic pulsations.

Keywords: Electron fluxes; Magnetic field; Pc5 magnetic pulsations; Radiation belt

1. INTRODUCTION

Electron radiation belts consist of trapped energetic electrons in the geomagnetic field. There are three kinds of essential periodic motions of the charged particles in the geomagnetic field: gyro-motion, bounce-motion and drift-motion.

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Gyro-motion of charged particles occurs around the local field line with a kHz frequency and the drift-motion with a mHz order of frequency (Elkington, 2006). On the other hand, disturbances in the geomagnetic field cover a broad range of frequency ranges. ULF waves in the period range of 150–600 seconds or in the range of a mHz frequency has been observed in space- and ground-based magnetometer data and the quasi-continue ULF waves in that the period range has been classified into Pc5 magnetic pulsation (Jacobs, 1970).

The study of relations between enhancement relativistic electron fluxes with Pc5 magnetic pulsations has been studied by many scientists (Baker, 1994; Mathie, 2000; Ukhroskiy, 2006). The interaction of Pc5 pulsation and relativistic electron of radiation belt via a resonant drift mechanism has been attention of many researchers as a possible mechanism for acceleration and transport of the outer electron radiation belt (Elkington, 1999). In this paper we analyzed the Pc5 magnetic pulsations during periods of enhancement of relativistic electron fluxes.

2. METHODOLOGY

In this study we analyzed the ground Pc5 magnetic pulsations of MAGDAS chain magnetometers during 2007–2008. The magnetic data from off equator-dip (ANC and DAV); low-latitude (PRP); mid-latitude (MGD) and high-latitude (DVS) have been analyzed. If data from stations located at low- and mid-latitude, as mentioned above, are not available in a certain time range, then we used data from the following stations: KUJ (low-latitude) and HOB (mid-latitude). The locations of the magnetometer are given in Table 1 and the map of stations is shown in Figure 1. On the other hand, the radiation belt electron events are selected using GOES satellite data. The radiation belt events are identified when data are continuously increasing in relation to 2-MeV electron fluxes where electron fluxes are observed as being more than 103, extended over a period of several days. We analyzed the relationship between Pc5 power and the enhancement of relativistic electron fluxes for outer radiation belt events that are listed in the Table 2.

Table 1 Location of magnetometers site

Stat Code	Location	Geographic		Geomagnetic	
		Long.	Lat.	Long.	Lat.
ANC	Ancon, Peru	-77.15	-11.77	354.33	0.77
DAV	Davao. Philippines	125.40	7.00	196.54	-1.02
PRP	Pare-Pare, Indonesia	119.40	-3.60	190.75	-12.38
MND	Manado, Indonesia	128.84	1.44	196.06	-6.91
KUJ	Kuju, Japan	131.23	33.06	202.96	26.13
MGD	Magadan, Russia	150.86	59.97	219.10	53.62
HOB	Hobart, Australia	147.32	-42.94	226.53	-54.19
DVS	Davis, Antarctica	99.62	-74.49	100.25	-76.60

The magnetometers record 3-components of magnetic field with 1-second time sampling. However, in this study we only analyzed the north-south component of the magnetic field. In the first step, we performed 3-second interval averaging in order to reduce the noise level in the magnetic data. Furthermore, a bandpass filter in the range of 150 to 600 sec (1.67–6.67 mHz) for each 1-hour data intervals was performed in order to localize the Pc5 waves. Then, we applied a wavelet transform procedure to the filtered signals in the scale range from 40.5 to 162.5 with selected scale steps of 0.5 intervals.

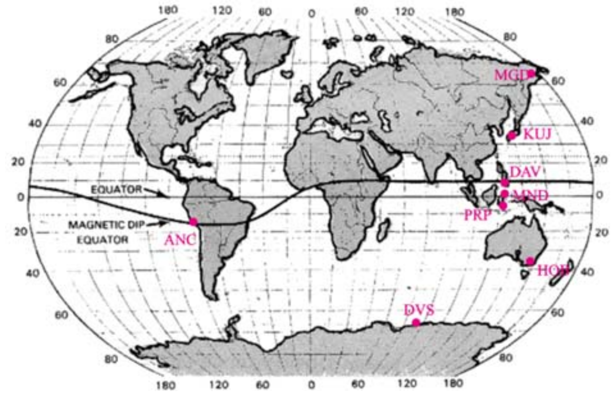

Figure 1 Map showing magnetometers sites

Table 2 List of date range of electron belt events

Start Date			End Date		
Year	Month	Day	Year	Month	Day
2007	4	27	2007	5	8
2007	5	23	2007	6	10
2007	7	14	2007	7	21
2007	7	30	2007	8	17
2007	8	27	2007	9	1
2007	9	2	2007	9	16
2007	9	22	2007	9	28
2007	9	29	2007	10	14
2007	10	20	2007	10	25
2007	10	26	2007	11	6
2007	11	21	2007	12	5
2007	12	17	2008	1	1
2008	1	6	2008	1	13
2008	1	13	2008	2	1
2008	2	2	2008	2	10
2008	2	11	2008	2	28
2008	2	29	2008	3	8
2008	3	10	2008	3	24
2008	3	27	2008	4	16
2008	4	23	2008	5	16
2008	5	22	2008	5	28
2008	6	15	2008	6	25
2008	7	13	2008	7	28
2008	8	10	2008	8	17
2008	8	18	2008	8	29
2008	9	4	2008	9	19
2008	10	2	2008	10	21
2008	10	29	2008	11	17
2008	12	5	2008	12	17

The continuous wavelet transform of a signal $x(t)$ is defined by (Traub, 2010)

$$W(b,a) = a^{-1/2} \int_{-\infty}^{+\infty} \psi^{*}\left(\frac{t-b}{a}\right) x(t)\,dt \qquad (1)$$

where b, a and ψ^* denote translation, scale, and complex conjugate of the mother wavelet, ψ is defined on the open time and real scale (b,a) half-plane, respectively, and the Morlet function has been used as the mother wavelet, ψ_0 which is given by

$$\psi_0(t) = \pi^{-1/4}\exp(i\omega_0)\exp(-t^2/2) \tag{2}$$

where t describes time and ω_0 is the frequency that represents the number of oscillations within the wavelet itself (Torrence and Compo, 1998).

Wavelet transform decomposes a wave into its component parts based on the frequency which is specified by wavelet scales. Wavelet power is determined from the wavelet coefficients. This means that the average of wavelet power spectrum for each scale of each hourly segment data describe the power of Pc5 magnetic pulsation in that hourly segment. In this case, the maximum power of Pc5 magnetic pulsations in an hourly segment could be represented by the maximum of the total power spectrum for all wavelet scales. In this paper, the term ‘averaged power spectrum’ has been used to describe the maximum of average of the wavelet power spectrum in hourly Pc5 wave intervals. Meanwhile, the maximum power spectrum describes the Pc5 power that is related to the maximum power spectrum of a specific wavelet packet in an hourly data segment.

3. RESULTS AND DISCUSSION

The Pc5 magnetic pulsations that are observed in the Earth’s magnetosphere mainly are driven by the changes of solar wind dynamic pressure which is implying the energy transfer from solar wind to the magnetosphere (Takahashi, 2007; Kessel, 2008). Usually, the study on the relationship of solar wind and Pc5 magnetic pulsations were conducted by using the Fourier analysis. To confirm our results where our analysis was performed based on the wavelet transform we examined the effect of solar wind dynamic pressure on the power of Pc5 magnetic pulsations during outer electron belt events.

Examples of dependence on Pc5 power are shown in Figure 2 during periods from 1 April–12 April 2007 and 23 May–10 June 2007 in Figure 3. Panels in both figures from above represent solar wind dynamic pressure and averaged Pc5 power at Stations ANC, DAV, PRP, MGD and DVS, respectively. Both figures generally show that solar wind dynamic pressure controls the power of global Pc5 magnetic pulsation from the equator-dip to the high-latitudes. During periods of increasing solar wind dynamic pressures, the power of Pc5 magnetic pulsations globally increased and also similarly during periods of decreasing solar wind dynamic pressures, the Pc5 power globally decreased. Kelvin-Helmholtz instability at the magnetosphere flank can be excited by solar wind flow.

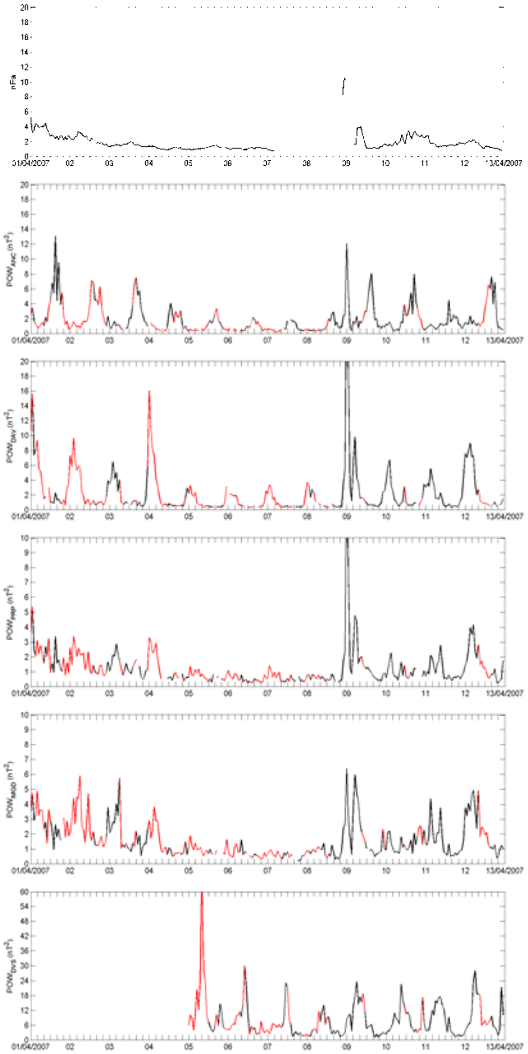

Figure 2 Comparison solar wind dynamic pressure and power of Pc5 magnetic pulsations during electron radiation belt events on 1-12 April 2007

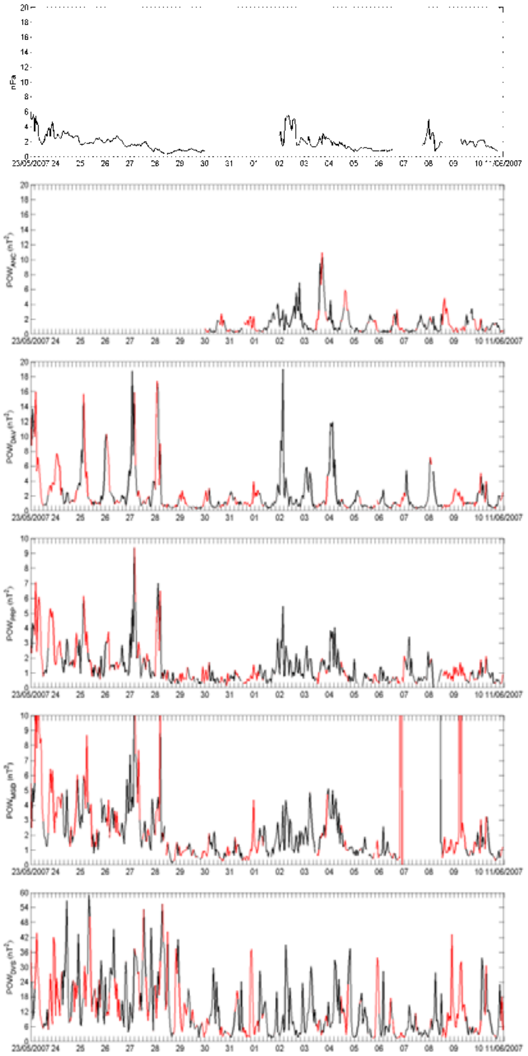

Figure 3 Comparison of solar wind dynamic pressure and power of Pc5 magnetic pulsations during electron radiation belt events on 23 May-10 June 2007

*) *The red-line in all panels indicates a time period when the Bz-component of interplanetary magnetic field is negative*

The Kelvin-Helmholtz instability generates surface waves at the magnetopause and resonant field lines inside magnetosphere that have been considered as a source of Pc5 magnetic pulsations as observed both in the magnetosphere and on the ground (Dungey & Southwood, 1970; Samson et al., 1971; Singer et al., 1977; Singer et al., 1979). The results are also consistently observed for the other outer electron belt events that are listed above. This observation confirmed that our results were comparable with the previous results. The second and third panels in Figures 2 and 3 represent the Pc5 power at Stations ANC and DAV, respectively. Both stations are around the equator-dip region where the equatorial electrojet maybe contributed to the enhancement of Pc5 power. As shown in the figures there are daily of Pc5 power for both stations as well as clearly being observed in the bottom panel in Figure 2. They may be connected with the effect of the equatorial electrojet that flows around the equatorial region. This issue will be discussed in more detail in a separate paper. Even so, the peaks of the Pc5 power at both stations follow the decreasing tendency of solar wind dynamic pressure.

To investigate the relation between the enhancement of relativistic electron fluxes and the ground-based power of Pc5 magnetic pulsations, we believe that the Pc5 magnetic pulsation that is related with the outer electron belt should be observed globally. To do that we performed a cross wavelet spectrum analysis for two adjacent latitude stations in order to examine the similarity of their wavelet packets. The maximum cross-spectrum represents the strongest correlation of Pc5 spectrum criteria for these the stations. The normalized power wavelet power data that are related to the maximum cross-wavelet spectrums are shown in Figures 4 and 5. The upper panels in Figures 4 and 5 represent 2-MeV electron fluxes during the same period as in Figures 2 and 3. The second to fifth panels in Figures 4 and 5 respectively represent the normalized wavelet power associated with the cross wavelet spectrum of DAV (black) and PRP (red), DAV (black) and MGD (red), PRP (black) and MGD (red), MGD (black) and DVS (red). The normalized Pc5 wavelet power in all panels in Figures 4 and 5 shows similar change during electron radiation belt events.

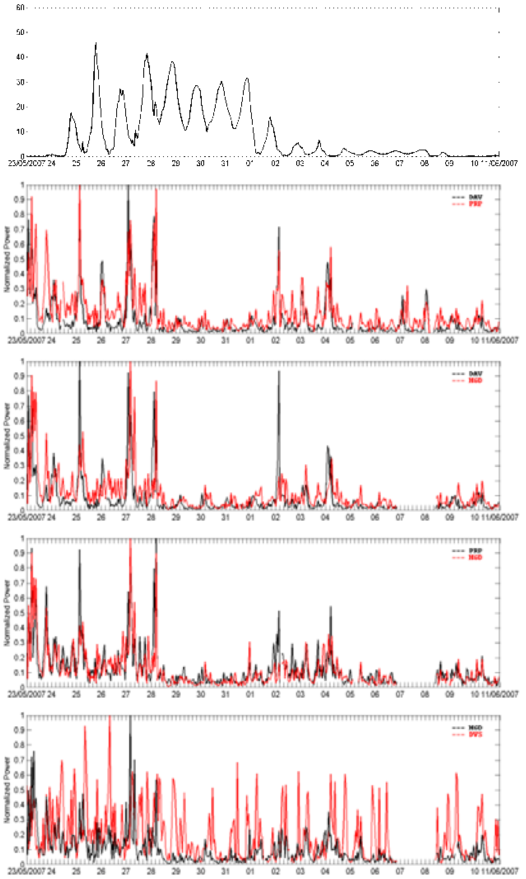

Figure 4 Electron radiation belt event on 23 May-10 June 2007. The first panel shows >2MeV electron fluxes and the red and black line in Panels 2-4 mean that the normalized power of Pc5 pulsation is associated with the maximum cross-wavelet spectrum

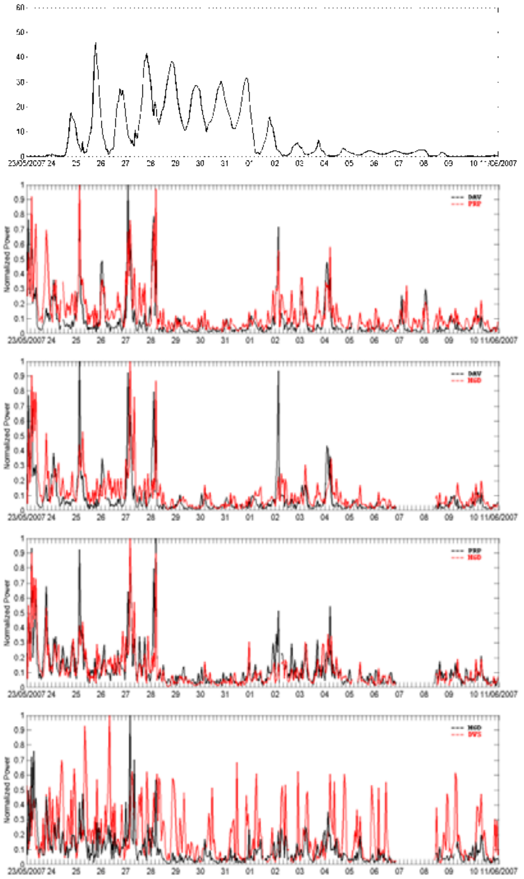

Figure 5 Electron radiation belt event on 23 May-10 June, 2007. The first panel describes >2MeV electron fluxes and the red and black lines in Panels 2-4 mean that the normalized power of Pc5 pulsation is associated with the maximum cross-wavelet spectrum

The increasing frequency of global data related to Pc5 power data preceding relativistic electron fluxes enhancement was observed as shown in Figures 4 and 5. These results also are consistent for other electron belt events. It could be interpreted that Pc5 magnetic pulsation can play a role in the processes of electron belt acceleration. The global increase of Pc5 power is driven by solar wind dynamic pressure and then it may be observed that the Pc5 wave acts to accelerate the electrons in the outer radiation belt. The Pc5 magnetic pulsations interact with the relativistic electron belt and these also can be considered responsible in the electron transport via the resonant drift mechanism (Ukhroskiy, 2006).

The other facts are as follows: during electron radiation belt events, several days prior to the beginning of electron fluxes enhancement, we observed a gradual decrease in the frequency of solar wind dynamic pressure as well as the decreasing of Pc5 power, and at the end of the electron radiation belt events, an enhancement of solar wind dynamic pressure as well as enhancement of Pc5 powers occurred. We suggest that during the expansion phase of the outer electron radiation belt outward to the interplanetary space, electron belt pressure reduce the solar wind dynamic pressure and consequently a decrease in the power of Pc5 magnetic pulsation occur. Furthermore, in the end period of the electron radiation belt event the electron fluxes back to its normal level and consequently a sudden increase of the Pc5 solar wind dynamic pressure occurs and this sudden increase also drives the sudden increasing power of Pc5 magnetic pulsations.

4. CONCLUSION

The ground-based Pc5 magnetic pulsations from the equator-dip to high latitudes have been analyzed for 29 events of enhancement in terms of relativistic electron fluxes. The strong power of Pc5 magnetic pulsations occurs during enhancement of the electron fluxes, but after 4-5 days, a global depression of the Pc5 magnetic pulsation as well as decreasing solar wind dynamic pressure has been observed. On the other hand, an increase of Pc5 power as well as solar wind dynamic pressure occurs during the end period of the electron radiation belt events. We suggest that if Pc5 magnetic pulsations play a role in the acceleration and outward transport mechanism, then outward expansion of the electron belt event would reduce the effect of solar wind dynamic pressure that will in turn affect the power of Pc5 magnetic pulsation. And then, when the electron fluxes recovery to its original level of a pre-expanding electron belt, this will release the solar wind dynamic pressure and cause a sudden enhancement of Pc5 power.

5. REFERENCES

Baker, D.N., et al., 1994. Relativistic Electron Acceleration and Decay Time Scales in the Inner and Outer Radiation Belts: SAMPEX. *Geophys. Res. Lett.*, Volume 21, pp. 409

Dungey, J.W., Southwood, D.J., 1970. Theory of ULF Waves in the Magnetosphere. *Space Sci. Rev.*, Volume 10, pp. 672

Elkington, S.R., Hudson, M.K., Chan, A.A., 1999. Acceleration of Relativistic Electrons via Drift-resonance Interaction with Toroidal Mode Pc5 ULF Oscillations. *Geophys Res. Lett.*, Volume 26, pp. 3273

Elkington, S.R., 2006. *A Review of ULF Interactions with Radiation Belt Electrons, in Magnetospheric ULF Waves: Synthesis and New Directions*. K. Takahashi, Peter J. Chi, Richard E. Denton, Robert L. Lysak, Geophysical Monograph Series, AGU, pp. 177–193

Jacobs, J.A., 1970. *Geomagnetic Micropulsations*, Springer-Verlag

Kessel, R.L., 2008. Solar Wind Excitation of Pc5 Fluctuations in the Magnetosphere and on the Ground. *J. Geophys. Res.*, Volume 113, A04202

Mathie, R.A., Mann, I.R., 2000. A Correlation between Extended Intervals of ULF Wave Power and Storm-time Geosynchronous Relativistic Electron Flux Enhancements. *Geophys. Res. Lett.*, Volume 27, pp. 3261

Samson, J.C., Jacobs, J.A., Rostoker, G., 1971. Latitude-dependent Characteristics of Long-period Micropulsations. *J. Geophys. Res.*, Volume 76, pp. 3675

Singer, H.J., Russell, C.T., Kivelson, M.G., Greenstadt, E.W., Olson, J.V., 1977. Evidence for the Control of Pc3, 4 Magnetic Pulsations by the Solar Wind Velocity. *Geophys. Res. Lett.*, Volume 4, pp. 337

Singer, H.J., Russell, C.T., Kivelson, M.G., Fritz, T.A., Lennartson, W., 1979. Satellite Observations of Spatial Extent and Structure of Pc 3, 4, 5 Pulsations Near the Magnetic Equator. *Geophys. Res. Lett.*, Volume 6, pp. 889

Takahashi, K., Ukhorskiy, A.Y., 2007. Solar Wind Control of Pc5 Pulsation Power at Geosynchronous Orbit. *J. Geophys. Res.*, Volume 112, A11205

Torrence, C., Compo, G.P., 1998. A Practical Guide to Wavelet Analysis. *Bulletin of the American Meteorological Society*, Volume 79, pp. 61–78

Trauth, M.H., 2010. *Matlab Recipes for Earth Sciences*. 3rd edition, Springer-Verlag

Ukhroskiy, A.Y., Anderson, B.J., Takahashi, K., Tsyganenko, N.A., 2006. Impact of ULF Oscillations in the Solar Wind Dynamic Pressure on the Outer Belt Electrons. *Geophys. Res. Lett.*, Volume 33, L06111