Pc4Magnetic Micropulsations with Kp indices and its Variation on Solar wind Velocity

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Abstract

Magnetic Pulsations recorded on the ground on the Earth are produced by processes in the magnetosphere and solar wind. These processes produce a wide variety of ULF hydromagnetic wave types that are classified on the ground as either Pi or Pc pulsations (irregular or continuous). Different regions of the magnetosphere originate different frequencies of waves. Digital Dynamic Spectra (DDS) for the north-south (X), east-west (Y) and vertical (Z) components of the recorded data were constructed for each day for one year (January 1 to December 31, 2005). Pc4 geomagnetic pulsations are quasi-sinusoidal variations in the earth's magnetic field in the period range 45-150 seconds. The magnitude of these pulsations ranges from fraction of a nano Tesla (nT) to several nT.

The present study is undertaken for describing the Pc4 ULF with Kp indices at low latitude in India and its Variation on Solar wind Velocity (VSW). The monthly variation of Pc4 occurrence has a Kp dependence range of 0 to 9-. The magnitudes of durations of Pc4 occurrence decreased in the station order PON, HAN and NAG respectively. It is also worth noting that Pc4 in winter was observed during intense magnetic activity when 5+ <Kp< 8+. Analysis of the data for the whole year 2005 provided similar patterns of Pc4 occurrence for VSW at all the three stations. Although Pc4 occurrence was reported for VSW ranging from 250 to 1000 Km/s, yet the major Pc4 events occurred for a VSW range of 300-700 Km/sec. The results suggest that the solar wind controls Pc4 occurrence through a mechanism in which Pc4 wave energy is convected through the magnetosheath and coupled to the standing oscillations of the magnetospheric field lines.

Keyword— Pc4 Magnetic pulsations, MHD waves and instabilities, Solar wind-control of Pc4 pulsation

Introduction

Ultra low frequency (ULF) waves incident in the Earth's environment are produced by processes in the magnetosphere and solar wind. These processes produce a wide variety of ULF hydromagnetic waves. Different frequencies of waves and polarizations originate in different regions of the magnetosphere. Ultra low frequency waves (magnetic pulsations) are caused by hydromagnetic waves that may be generated as a result of different types of plasma instabilities in the magnetosphere or on its boundary in a very complicated manner. In this paper, the generation of hydromagnetic waves, their sources within and external to the magnetosphere and their propagation and modification within the magnetosphere and ionosphere are briefly discussed. A very good summary of these topics, with references to the most important publications dealing with ULF waves, has elegantly been reported by McPherron [1], Southwood and Hughes [3] and also presented in the books "Introduction to Space Physics", edited by Kivelson, M.G. and Russell, C.T. [2] and "Geomagnetic Micropulsations" by Jacobs [4]. The information given in this paper is mainly cited from these publications and references contained therein. The study will be very effective in investigation of magnetic field variation of earth**. The earth's atmosphere has good number of charge particles and specially two layers of electrons at different heights. The energetic charge particles entering during pressure pulses of solar wind can interfere in their normal condition and in worst case may lead to complete blackout in some area of earth by changing the worldwide current system which can disturb the electric power supply network. The advanced research focused on magnetic micropulsations conditions may help to prevent these worst situations to be happening.**

Magnetic Indices Kp

The intensity of magnetic disturbances, recorded on the magnetograms of a magnetic observatory is measured by a figure 'K' between '0' and '9' for an interval of 3 Greenwich hrs. 0-3, 3-6 etc (Table1).

Table 1 Relation between Kp and a_p magnetic indices[4]

Kp	0_0	0_+	1-	1_0	1_+	2-	2_0	2_+	3-	3_0	3_+	4-	4_0	4_+
a_p	0	2	3	4	5	6	7	9	12	15	18	22	27	32
Kp	5-	5_0	5_+	6-	6_0	6_+	7-	7_0	7_+	8-	8_0	8_+	9-	9_0
a_p	39	48	56	67	80	94	111	132	154	179	207	236	300	400

At a standard station in about 50^0 geomagnetic latitude, a_p may be thought of as range of the most disturbed of the three field components expressed in the unit 2γ, i.e. the range in 3hr interval with K=4+ is 2 X 32, i.e. 64 γ. The average of the eight $a_p$values for a day is called A_p.

The intensity of magnetic disturbances increases from low to high latitudes up to latitude of the auroral zones, i. e., about magnetic latitude 65^o. In the high latitudes, magnetograms are seldom completely undisturbed. Intense magnetic storms usually commence suddenly at almost the same instant all over the Earth. In addition to large-scale magnetic storms there are disturbances of much shorter duration, such as polar magnetic sub-storms and bays. Abrupt impulsive change (sudden impulses) may also occur and are often observed simultaneously all over the world and have also been detected in the magnetosphere. Variations with periods roughly from 0.1s to 10min. are grouped together and called geomagnetic micropulsations[2], [4],[13].

The diurnal variation of occurrence and frequency of Pc3-4 waves recorded at ground station and their dependence on latitude and geomagnetic indices Kp and also vital identification their source and propagation modes. The present study describes the statistical characteristic of Pc4 magnetic pulsations with Kp indices and their dependence with solar wind velocity atlow latitude in India.

Data Analysis and Results

The investigation of this paper is based on digitized one-second sampling geomagnetic data on the latitudinal array of three Indian stations. Geomagnetic data of X (north-south), Y (east-west) and Z (vertical) components of earth's magnetic field for the duration of the study (01 Jan. 2005 to 31 Dec. 2005) were recorded using three axis flux gate magnetometer array [5] at the stations Hanle, Nagpur and Pondicherry with one second sampling interval. The stations were situated at very low latitudes in India. The magnetometer array was established and operated by Indian Institute of Geomagnetism, Navi Mumbai. The coordinate details of these stations are shown in Table2. Time is always represented in UT such that IST= UT + 5:30 hr [24].

Table 2: Coordinate details of recording stations

Recording stations	Geographic co-ordinates		Geomagnetic co-ordinates	
	Long. °E	Lat. °N	Long. °E	Lat. °N
Pondicherry(PON)	79.92	11.92	151.97	02.50
Nagpur (NAG)	79.00	21.10	151.93	11.72
Hanle (HAN)	78.97	32.78	151.89	23.38

The data of all the stations were sampled at 1 second time interval. Digital dynamic spectra (DDS) for the north-south (X), east-west (Y) and vertical (Z) components of the recorded data were constructed for each day for one-year duration. The X- and Y-components of these DDS were investigated for undertaking the above diurnal and seasonal statistical study [[6]]. The digital dynamic spectra (DDS) of the time series for 24 hours were constructed for the whole year 2005 for all the three stations [24]. These DDS enabled us to identify the pulsation events. We found the micropulsation events at all the stations on different dates. Mostly the pulsation events were lying in the 10 to 30 mHz frequencies ranges. The data of solar wind velocity Vsw for the year 2005 obtained from websiteof NASA.

The statistical characteristics of very low latitude Pc4 geomagnetic pulsation were investigated for both north-south (X) and east-west (Y) components of these waves in the present study. The studies of the dependence of Pc4 occurrence on Kp valuesand Vsw magnitude were undertaken for all the individual months of the year. All these results are not shown for carrying out brief reporting. Only one of the representative results for the individual month of January, 2005 is presented in Fig.1

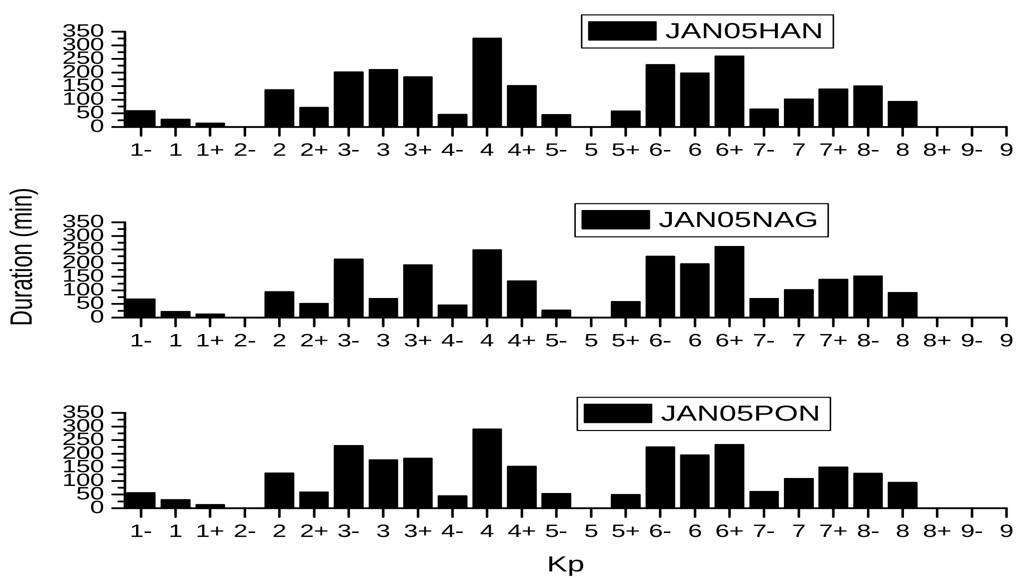

Fig.1 Diurnal variation in Pc4 occurrence at all three stations Hanle (HAN), Nagpur (NAG), and Pondicherry (POND) in January 2005.

The variation of Pc4 occurrence on Kp values for January, 2005 is depicted in Fig. 1. Similar variation of Pc4 occurrence with Kp are observed at all the three stations. However prominent peaks in Pc4 occurrence are situated at Kp = 3-,4 and 6+. The plots for the individual months of February to December, 2005 are not depicted. However, these show variable pattern for each month with prominent Pc4 maxima occurring at Kp = 0+, 2-, 3+, 4- and 4+ (for February,2005); Kp = 2-, 3-, 3, 3+ and 4- (for March, 2005); Kp = 0+, 1-, 1+, 3-, 3+ and 4+ (for April, 2005); Kp = 2, 3, 5, 6- and 8+ (for May, 2005); Kp = 1-, 1+, 2-, 2, 4-, 4+, 6- and 7 (for June, 2005); Kp = 1-, 1+, 22-, 2+, 3+, 4- and 4+ (for July, 2005); Kp = 3, 3- (for August, 2005); Kp = 1, 6-, 7 and 8- 9for September, 2005); Kp = 0+, 1-, 1+, 2 and 3+ (for October, 2005); Kp = 1-, 1, 1+, 2-, 3, 3+ and 4+ (for November,2005); and Kp = 2-, 2, 3-, 3, 3+ and 4- (for December, 2005) [6] .

All these results are not shown for carrying out brief reporting. Only one of the representative results for the individual session of Spring, 2005 represented in fig.2. Fig.2 Depicts the Kp dependence of the occurrence of Pc4 waves for the Spring season of 2005. Prominent peaks in Pc4 occurrence are located at Kp = 1, 1+, 2, 3-, 3, 3+, 4- with an additional peak at Kp = 8+ at all the three stations. However, these show variable pattern for each session with prominent Pc4 maxima occurring at Kp = 1+, 2-, 2, 2+, 3, 3+, 4-, 4 and 4+ at all the three stations and additional peaks are observed at Kp = 6+ and 9- at Nagpur and Pondicherry (For Summer session, 2005); Kp = 1-, 1, 1+, 2-, 2, 3 and 4+ at all the three stations and additional peaks are observed at Kp = 6-, 7 and 8- at Nagpur and Pondicherry (For Autumn season of 2005); Kp = 0+, 1-, 2-, 2, 2+, 3-, 3, 3+, 4, 6-, 6, 7+ and 8- at all the three station (For Winter season of 2005).

The Kp dependence of Pc4 occurrence for the whole year 2005 is shown in Fig.3. Although major prominent peaks are situated at Kp = 3, 3- and 3+, there are minor prominent peaks present at Kp = 0+, 1-, 1, 1+, 2, 4, 4+, 6-, 6+, 7 and 8-.

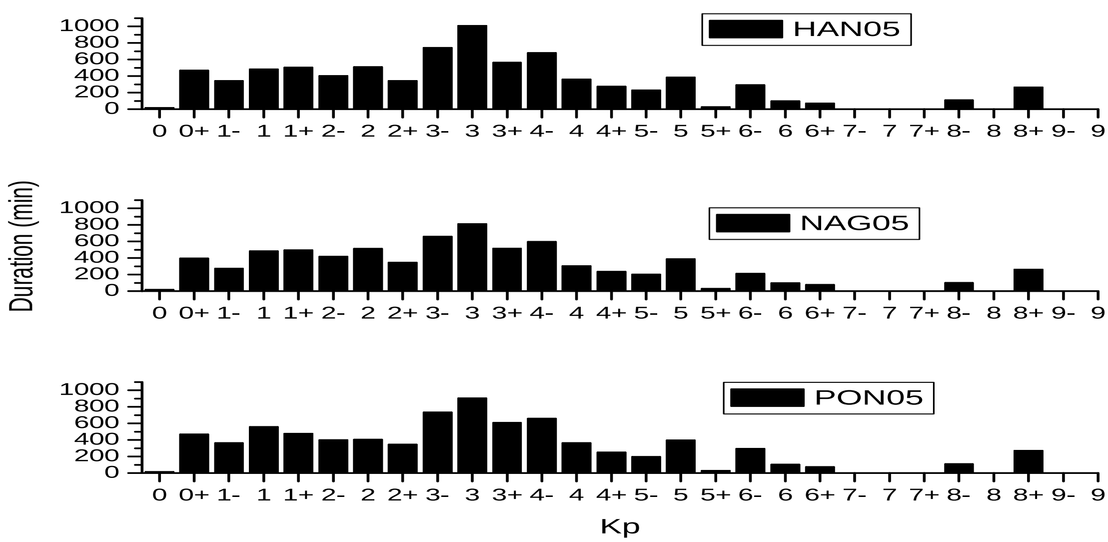

Fig. 2: Variation of Pc4 Occurrence (in minutes) with Kp for the Spring season of 2005.

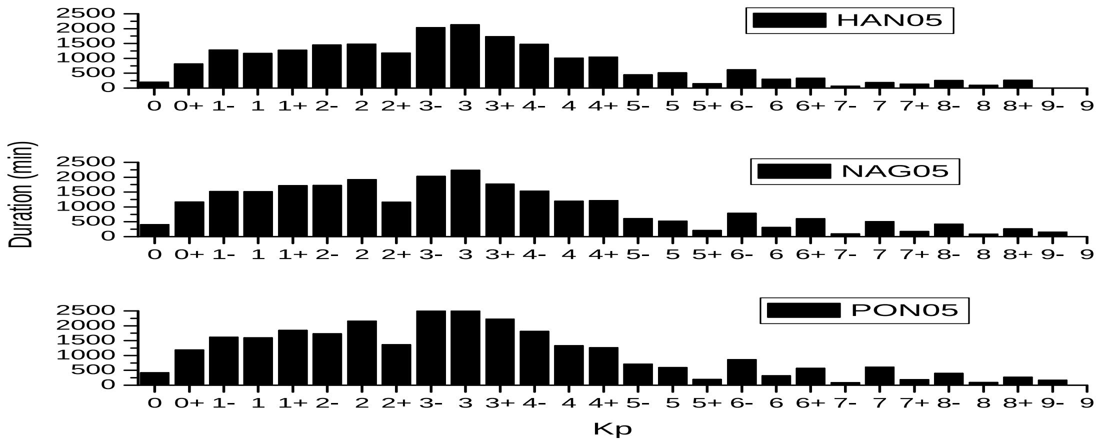

Fig.3: Variation of Pc4 Occurrence (in minutes) with Kp for the whole year 2005.

The studies of the dependence of Pc4 occurrence on Vsw was also undertaken for all the individual months of the year. All these results are not shown for carrying out brief reporting. Only one of the representative results for the individual month of January, 2005 is presented in Figure 4. The solar wind velocity is expressed in km/s on the X-axis and total duration of events for the corresponding value of solar wind velocity for the whole month is given in minutes (min) on the Y-axis. It is clear from the graph that at all the stations, nearly similar pattern of dependence of Pc4 occurrence on Vsw is found. The value of Vsw ranged from 300 km/s to 700 km/s. However, Pc4 events were observed for al-most all values of Vsw in this range.

The maximum value of duration of events at Nagpur was found to be 489 min corresponding to Vsw values of 400 - 450 km/s. At Hanle, the main peak of duration was of 472 min. Similar pattern was also observed at Pondicherry with the maximum occurrence peak having duration of 490 min corresponding to VSW values of 400 - 450 km/s. The statistical results on the dependence of Pc4 occurrence on Kp and Vsw for the entire year 2005 provided quite interesting information. The dependence of Occurrence of Pc4 pulsations on Vsw for the whole year 2005 observed at all the three stations is depicted in Fig. 5. It is evident from the figure that similar patterns of Pc4 occurrence with Vsw were observed all the three stations. Pc4 occurrence was reported for Vsw ranging from 250 to 1000 km/s. However major Pc4 events occurred for a Vsw range of 300 - 700 km/s [22].

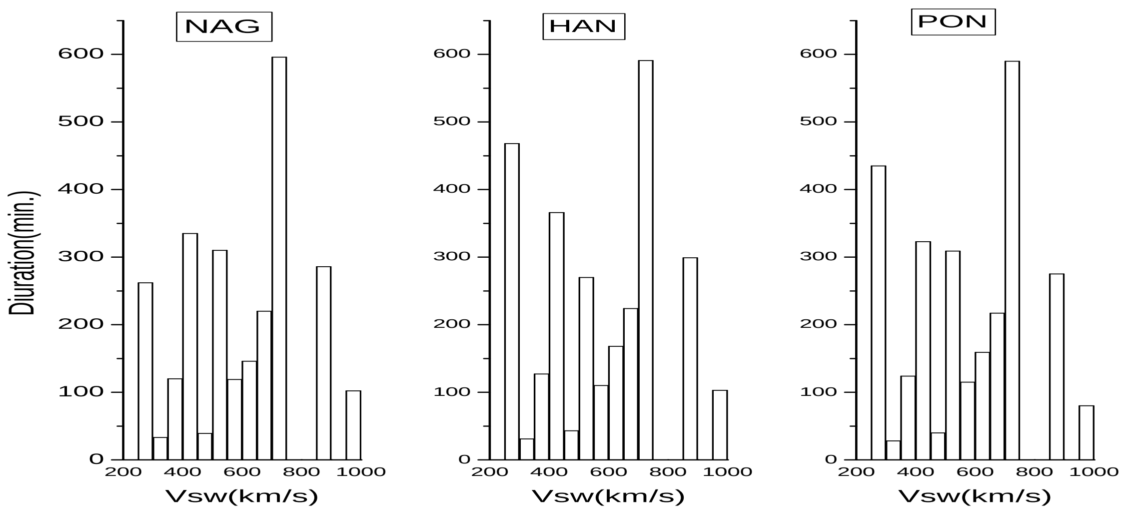

Fig. 4. Dependence of events duration on Vsw for all three stations Nagpur, Hanle and Pondicherry in month January 2005.

Discussion and conclusion

Pc4 Magnetic Pulsation observed on ground may either be internal or external to the magnetosphere. This mechanism was found to be most plausible for shorter wavelengths and great localization in longitude. Such localized waves have been observed in space at geostationary orbit [7], [8] but are screened from the ground by the magnetosphere. Till date is no comprehensive theory of internal excitation of Pc4 waves that could explain the external control which is compatible with observations and generally models for the external excitation of these waves are favored [9]. There are two possible locations for the external origin of pulsations, at the magnetopause, and upstream from the magnetopause. Surface waves generated by Kelvin-Helmholtz instability are important at the magnetopause [12], [10], [11]. Upstream from the magnetopause, large amplitude waves in the quasi-parallel bow shock are swept back into the magnetosheath and then penetrate the magnetosphere [13].

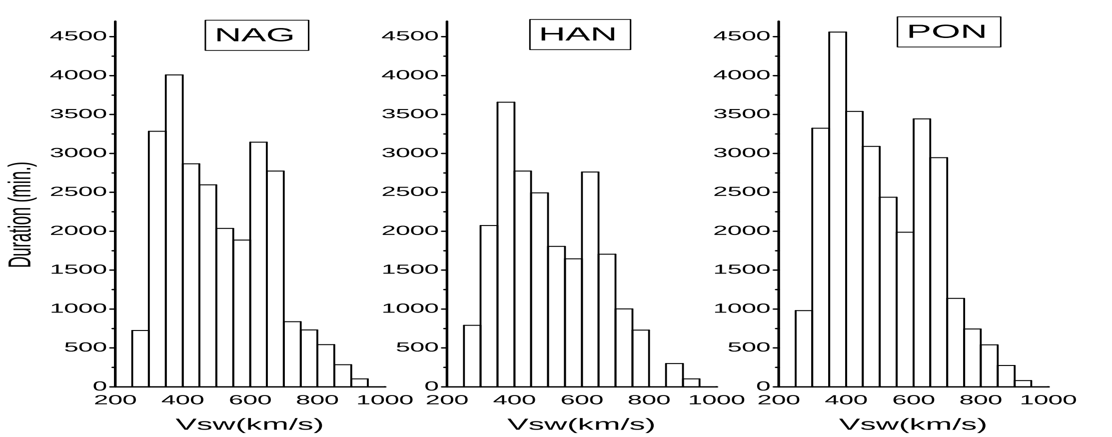

Fig. 5 Dependence of events duration on Vsw for all three stations Nagpur, Hanle and Pondicherry in total year 2005.

The first direct evidence for the propagation of external Pc3-4 wave power into the magnetosphere has been presented by Greenstadt et al [14]. Using a few individual events from the ISEE 1-2 spacecrafts, they have verified that the same frequencies in the 10 – 100 mHz band were observed in the magnetosheath and also in the magnetosphere but lower power was observed there. Similar results were reported by Tomomura et al [16] from six months of ISEE data in the 3 – 30 mHz band. These authors further demonstrated that the compressional oscillations dominated in the magnetosheath around local noon while transverse Alfven waves were observed within the magnetosphere.

The transmission of upstream wave energy into the magnetosphere probably occurs predominantly near the subsolar region. This is a requirement for these waves to gain access to low latitudes. The index of refraction of the magnetospheric plasma decreases with decreasing radial distance except at the plasmapause [18]. This decrease should refract waves away from radial propagation reducing the wave energy that can penetrate to low latitudes, allowing access only to those waves that are nearly radially propagating. This is supported by the results of Tomomura et al [18] who have shown that the wave spectral power is generated in the magnetosheath around noon. If it is assumed that significant Pc3-4 wave energy can penetrate to low latitudes, then there are a number of possible excitation mechanisms available for wave generation. These are collective transverse surface wave eigen oscillations at the plasmapause (L_{pp}); fundamental toroidal mode standing oscillations at L = 1.1 and L = 1.76 – 2.6 and higher order harmonics at L = 2.0 – L_{pp} ; and trapped oscillations in the equatorial plane between the two peaks of the Alfven velocity at L = 1.7 – L_{pp} [10].

In the light of the above discussed excitation mechanisms and the observed results of the diurnal and seasonal variation of low latitude Pc4 pulsations, it is suggested that the upstream waves are a major source of Pc4 pulsations detected on the nightside which were originated on the dayside and most likely by an extended region of ULF waves. It is further suggested that the plasmaspheric cavity mode resonance may have played a role in filtering the broadband input to the magnetosphere. The results of the present study are also in agreement with the observed characteristics of ULF upstream waves by Heilig et al [15].

The monthly variation of Pc4 occurrence has a Kp dependence range of 0 to 9-. However the yearly Pc4 occurrence was found to be evenly distributed with magnetic activity over the Kp = 2- to 4 range at all the three stations with the peak occurrence recorded at Kp = 3-. The magnitudes of durations of Pc4 occurrence decreased in the station order PON, HAN and NAG respectively. The prominent peaks in the seasonal Pc4 occurrence were observed at Kp = 3-, 3 for all the seasons. However additional peaks were observed at Kp = 1-, 1 and 1+ for the autumn season. It is also worth noting that Pc4 in winter was observed during intense magnetic activity when 5+ <Kp< 8+.

In the present study, the results are in agreement with suggestions of Takahashi et al [20] who reported that the pulsations detected on the nightside originated on the dayside and most likely by an extended region of ULF waves in front of the bow shock and not from processes occurring in the nightside magnetosphere as there was absence of substorm onsets or intensification. Similar results were also reported by Villante et al [19]. The main peaks in Pc4 occurrence at local winter and local autumn found at the same time at all the three stations agree with the previous studies of Ansari and Fraser [17] and Kuwashima et al [21] where the main occurrence peaks in winter and equinox did not change with time. As the stations array was spread over a latitudinal range of 21° only, it was not sufficient for identification of latitude dependence of Pc4 pulsation occurrence since the data from large-scale latitudinal separation was required for this purpose.

In conclusion it has been demonstrated that the occurrence of Pc4 pulsations depends on solar wind velocity with a threshold at about 250 km/s and ranging up to 950 km/s. It is likely that an instability originating from the direct interaction between the solar wind and the magnetosphere is exciting Pc4 pulsations through bow-shock associated waves.

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