ISSN 2229-5518

# Pc4 Magnetic Pulsations at Low latitudes in India and its Dependence on Solar Wind Velocity and Interplanetry Magnetic Filed

I. A. Ansari, K. A. Nafees

**Abstract**— Magnetic Pulsations recorded on the ground are the signatures of the integrated signals from the earth's magnetosphere. 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. Although these pulsations can be observed in a number of ways, yet the application of ground-based magnetometer arrays has proven to be the most successful methods of studying the spatial structure of hydromagnetic waves in the earth's magnetosphere. The solar wind provides the energy for the earth's magnetospheric processes. The source of Pc4 magnetic pulsations can either be internal to the magnetosphere (endogenic) or external to it, transmitted through the magnetopause (exogenic). Most of the Pc4 studies undertaken in the past have been confined to middle and high latitudes.

The spatial and temporal variations observed in the Pc4 occurrence are of vital importance because these provide evidence that can be directly related to both endogenic and exogenic wave generation mechanisms. At low latitudes ( L< 2), the wave energy predominates in the Pc4 band. However the spatial characteristics of these pulsations have received little attention in the past. The present study is undertaken for describing the dependence of low latitude Pc4 occurrence on the Solar Wind Velocity ($V_{SW}$) and the Interplanetary Magnetic Field (IMF) over the period range 01 January to 31 December, 2005 employing an array of three low latitude recording stations at Hanley, Nagpur and Pondicherry.

Analysis of the data for the whole year 2005 provided similar patterns of Pc4 occurrence for $V_{SW}$ at all the three stations. Although Pc4 occurrence was reported for $V_{SW}$ ranging from 250 to 1000 Km/s, yet the major Pc4 events occurred for a $V_{SW}$ range of 300-700 Km/sec. The IMF dependence of Pc4 occurrence for the year 2005 has shown that even though at all the three stations, it spread for IMF magnitude of up to 22 nT, yet the majority of Pc4 events occurred for a narrower range of 2-10 nT. However it is important to note that at all the three stations, the peak in the occurrence of Pc4 events was observed for IMF range of 3 to 5 nT. 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.

**Index Terms**— Pc4 Magnetic pulsations, MHD waves and instabilities, Solar wind-IMF control of Pc4 pulsations..

## 1 Introduction

EXAMPLES of exogenic sources of Pc4 are surface waves produced at the magnetopause by Kelvin-Helmholtz instability, and waves produced at the bow shock or in the magnetosheath, all of which eventually propagate into the magnetosphere. The internal generation occurs by means of plasma instabilities within the magnetosphere. Free energy internal sources include pressure gradients, velocity shears and rapid changes in the magnetospheric geometry associated with substorms. Greenstadt et al [1] have presented the first direct evidence for the propagation of external Pc3-4 wave energy into the magnetosphere. Using a few individual events from ISEE 1-2 spacecrafts, they have verified that the same frequencies in the 10 – 100 mHz band were observed in the magneto-sheath and also in the magnetosphere but lower power was seen there. Tomomura et al [2] have also observed similar results from six months of ISEE data in the 3-30 mHz band. These researchers further demonstrated that the compressional oscillations dominated in the magneto-sheath around local noon while transverse Alfven waves were observed within the magnetosphere.

There is ample evidence that the solar wind velocity controls some of the properties of Pc3-4 pulsations [3],[4]. In addition the magnitude and direction of IMF also play an important role in controlling these pulsations [5], [6], [7]. Studies of the joint effect of $V_{SW}$ and the angle of the interplanetary field from the sun-earth line ($\Theta_{XB}$) have shown that the amplitude (occurrence) and energy of Pc3-4 pulsations are positively and negatively correlated with $V_{SW}$ and $\Theta_{XB}$ respectively [8], [9]. Using the data from four-spacecraft Cluster mission, Eastwood [10] have reported the results of a statistical investigation into the nature of oblique wave propagation in the foreshock. Their observations have revealed that the foreshock ULF waves tend to propagate obliquely to the background magnetic field.

Luhr [11] have studied 41 Sudden Commencement (SC) events using simultaneous magnetic field data from the CHAMP satellite and ground stations of the year 2000 – 2007. CHAMP sometimes recorded small-scale magnetic variations different from the ground, which was explained by local ionospheric currents. They have also studied the relationship between the SC amplitude seen by CHAMP and the corresponding abrupt solar wind dynamic pressure change. It was found that the induction effect in the Earth at low latitudes is quite small.

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## 2 Data Analysis and Results

An array of three very low latitude stations, viz Pondicherry (PON) (geomagnetic latitude 2.5° N, geomagnetic longitude 151.97° E), Nagpur (NAG) (geomagnetic latitude 11.72° N, geomagnetic longitude 151.93° E), Hanley (HAN) (geomagnetic latitude 23.28° N, geomagnetic longitude 151.89° E) using three axis fluxgate magnetometers, established and operated by the Indian Institute of Geomagnetism (IIG), Navi Mumbai, was employed for carrying out the study of the effect of $V_{SW}$ and IMF magnitude on these pulsations. 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 [12]. The $V_{SW}$ and IMF data for the year 2005 were obtained from NASA's website.

The studies of the dependence of Pc4 occurrence on $V_{SW}$ and IMF 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 November, 2005 is presented in Figure 1. The solar wind velocity is expressed in km/s on the 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 almost 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 $V_{SW}$ values of 400 - 450 km/s.

The study of the dependence of Pc4 occurrence with IMF were also carried out for all individual months of the year. However, due to brevity, the results for all the three stations for the month of January, 2005 only are shown in Figure 2. The magnitude of IMF is expressed in nT on the X-axis while the corresponding durations of occurrence are depicted in min on the Y-axis. It is clear from the graph that although the occurrence of Pc4 events was observed for IMF magnitude of up to 22 nT , yet the majority of events were observed for the IMF magnitude range of 2 - 10 nT. The maximum peak of Pc4 occurrence was observed for IMF range of 4 – 6 nT. Nearly similar behavior was observed at all the three stations. The duration of maximum occurrence was found to be 576 min at Nagpur for the IMF value in the range of 5 - 6 nT. At Hanle the duration of maximum occurrence was detected to be 612 min, while at Pondicherry it was observed to be 570 min for the IMF range of 5 - 6 nT.

The statistical results on the dependence of Pc4 occurrence on $V_{SW}$ and IMF for the entire year 2005 provided quite interesting information. The dependence of Occurrence of Pc4 pulsations on $V_{sw}$ for the whole year 2005 observed at all the three stations is depicted in Fig. 3. It is evident from the figure that similar patterns of Pc4 occurrence with $V_{sw}$ were observed at all the three stations. Pc4 occurrence was reported for $V_{sw}$ ranging from 250 to 1000 km/s. However major Pc4 events occurred for a $V_{sw}$ range of 300 - 700 km/s.

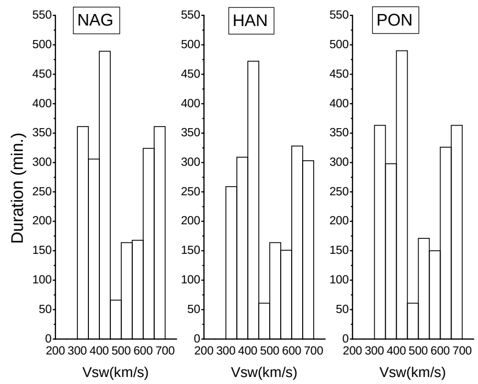


Fig. 1 Dependence of Pc4 events duration on Vsw at all the three stations Nagpur, Hanle and Pondicherry for the month of November 2005.

At Hanley the main peak of Pc4 occurrence with 3658 min of duration was observed for $V_{sw}$ range of 350 - 400 km/s. A secondary maximum peak of Pc4 occurrence of duration 2762 min was observed for $V_{sw}$ range of 600 - 650 km/s.

It is interesting to note that the maximum peak of occurrence with duration of 4009 min was also observed at Nagpur for the same $V_{sw}$ range of 350 - 400 km/s. However a secondary maximum peak of duration longer than 3000 min was also observed for Pc4 occurrence during $V_{sw}$ range of 600 - 650 km/s.

At Pondicherry the main peak of Pc4 occurrence ( 4559 min) was observed for $V_{sw}$ range of 350 to 400 km/s A secondary maximum peak of Pc4 occurrence of approximate duration 3400 min for $V_{sw}$ range of 600-650 km/s was also observed.

The IMF dependence of Pc4 pulsations occurrence for the entire year 2005 at all the three stations is shown in Figure 4. It is evident from the figure that even though the Pc4 events at all the three stations occurred for IMF magnitude of up to 22 nT, the majority of events were observed for a narrower range of IMF magnitude 2 - 10 nT. However it is important to note that at all the three stations, the maximum occurrence of Pc4 events was observed for IMF magnitude range of 3 to 5 nT.

## 3 Discussion and Conclusion

The bounce resonance mechanism [13] is not a likely source of Pc3-4 waves. 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 [14], [15] but are screened from the ground by the magnetosphere. Till date is no comprehensive theory of internal excitation of Pc3-4 waves that could explain the external control which is compatible with observations and generally models for the external excitation of these waves are favored [16].

ISSN 2229-5518

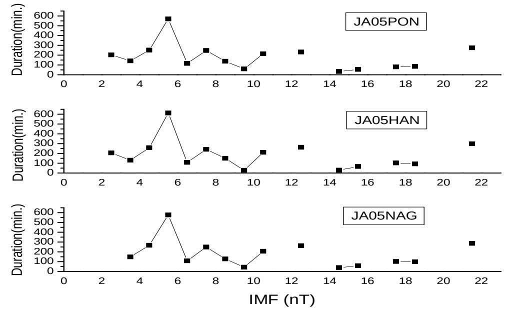


Fig 2. Dependence of Pc4 events duration on IMF magnitude for all the three staions Nagpur, Hanle and Pondicherry during the month of January 2005.

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 [17], [18], [19]. Upstream from the magnetopause, large amplitude waves in the quasi-parallel bow shock are swept back into the magnetosheath and then penetrate the magnetosphere and couple to the standing oscillations of the magnetospheric field lines [20]. This coupling may occur at all latitudes [21].

The characteristics of the waves excited by the K-H instability are dependent on the length of the field lines and the plasma density at the magnetopause [22]. It is also difficult to see how the externally excited evanescent surface waves with large damping rates can propagate deep into the magnetosphere and through the plasmapause to couple with the field line resonance at low latitudes. In addition the threshold velocity for the K-H instability involves the angle between the magnetic fields across the magnetopause. Hence on a statistical basis it is likely that the magnetopause is more unstable for higher solar wind velocity, which is consistent with the present results.

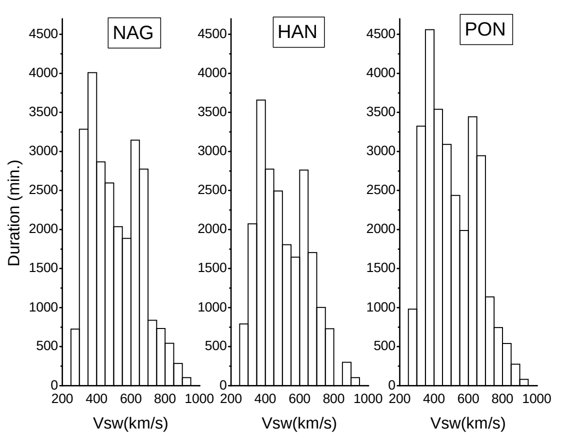


Fig. 3 Dependence of Pc4 occurrence duration on Vsw for all the three stations Nagpur, Hanle and Pondicherry for the year 2005.

The quasi-parallel shock transition has been found to be highly turbulent [23]. Furthermore the amplitude of bow-shock-associated waves seems to be dependent on the magnetosonic Mach Number [24] and therefore on the solar wind velocity. The association of higher Pc4 occurrence at low latitudes with higher solar wind velocity is therefore more likely to be a consequence of bow-shock associated waves. The results of Yumoto et al [6] support this mode of Pc4 wave generation and resonance. Chugunova [25], using the data of search coil magnetometers from two Antarctic stations (sub-auroral Pc3-4), have found that the suggested idea about the possibility of two channels of the penetration of primary upstream turbulence, i.e., via the cusp and via the lobe flanks is statistically feasible. It is however obvious that further studies are needed to uniquely determine the external and internal contributions to the generation of Pc4 waves observed at low latitudes.

The Pc4 occurrence at low latitudes in India at the three stations Hanley (L=1.178), Nagpur (L=0.974) and Pondicherry (L=0.910) have been found to have two main streams. The primary stream of maximum occurrence of Pc4 events corresponds to $V_{sw}$ range of 350-400 km/sec. The secondary stream consists of less prominent Pc4 occurrence related to $V_{sw}$ range of 600-650 km/sec. In the present study, the IMF magnitude dependence for Pc4 occurrence extended up to 22 nT. However major Pc4 occurrence was reported for IMF magnitude 3-5 nT.

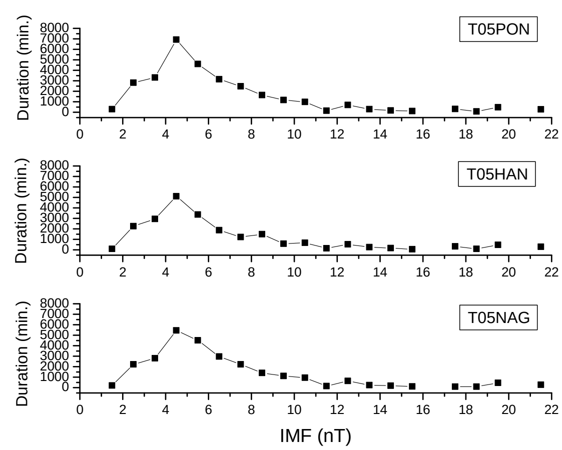


Fig 4. Dependence of Pc4 occurrence on IMF magnitude for all the three stations Nagpur, Hanle and Pondicherry for the year 2005

The results of the present study are in agreement with the internationally reported study of Ansari [16] who found a correspondence between the occurrence of Pc3 waves at low latitudes in south-east Australia and solar wind velocities between 350 to 700 km/sec. In the present study, the appearance of Pc4 waves at such small radial distances (L= 0.910 to 1.178) placed additional constraints on generation mechanisms. Evanescent surface waves on the magnetopause (one possible source of Pc4 waves) may find it difficult to penetrate to these low L-values. Waves generated at the bowshock, swept into the magnetosheath and subsequently coupling into the field line resonance are better candidates.

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.

## Acknowledgment

The authors are thankful to the Director, Indian Institute of Geomagnetism (IIG) Navi Mumbai, India for kindly providing Pc4 pulsations data.

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