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E: ISSN NO.: 2455-0817 *Remarking An Analisation*

Statistical Characteristic of Pc4 Magnetic Micropulsation at Low Latitude in India

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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 present study is undertaken for describing the dependence of low latitude Pc4 occurrence on the Kp values 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 Kp at all the three stations. Although Pc4 occurrence was reported for Kp values, yet the major Pc4 events occurred for rage 5+ Kp 8. 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.

Keywords: Pc4 Magnetic Pulsations, MHD Waves and Instabilities, Solar Wind-IMF Control of Pc4 Pulsations.

Introduction

Examples of exogenic sources of Pc4 are surface waves produced at the magnetopause by Kelvin Helmholtz in-stability, 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 sub-storms. 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. The study will be very effective in investigation of magnetic field variation of earth. This will ultimately provide an insight to future atmosphere.

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. Thus they incorporate also any local effects such as the systematic diurnal variations in geomagnetic activity. To overcome this problem, a new index 'Kp' is used to measure planetary variations in magnetic activity. This index is based on 'standardized' indices, which have been freed as for as possible from local features.

The quiet conditions as well as the day-to-day changes in the intensity of any disturbance are usually widespread and follow a similar pattern over a wide area. Except in periods of very violent activity, it is found that the disturbance D, which remains present in most of the days, is superposed on a regular daily variation-called the solar daily variation S. Each magnetic element is affected in a characteristic way by each of the variations S and D. The type and range of variations also vary throughout the year, showing a seasonal change and the range and indices of D also vary from year to year.

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 [R. L. McPherron (1995), Jacobs (1970)].

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 diurnal and seasonal dependence on Pc4 wave occurrence on Kp at very low latitude in India [Ansari et.al. (2012)].

Data Analysis

The investigation of this thesis 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 (Pathan et al. 1999) 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 and the schematic representation of their locations are shown in Table2 and Fig.1 respectively. Time is always represented in UT such that IST= UT + 5:30 hr [(Ansari et al., 2009)].

The data of all the stations were sampled at 1 second time interval. The dynamic spectra of the time series for 24 hours were constructed for the whole year 2005 for all the three stations [Ansari et al., 2009]. These dynamic spectra 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.

Results

The statistical characteristics of very low latitude geomagnetic pulsations in Pc4 pulsations were investigated for both the north-south (X) and the east-west (Y) components of these waves in the current study. While considering the statistical characteristics of diurnal and seasonal variations of these pulsations, it is the total duration of events that is more important than the total number of events in a particular hourly bin. Therefore the total duration of events in minutes has been taken into consideration. The variation of the total hourly occurrence of Pc4 events for all the three stations for the whole year 2005 is plotted in Fig.4. It is evident that the occurrence was prevalent during all the hours of the day with the major events being observed between 15 hr to 22 hr UT at all the three stations. The occurrence pattern was nearly same for all the stations and the maximum occurrence was observed at 17-18 hr UT with a succeeding secondary peak at 18-19 hr UT. The total duration of the maxima in the Pc4 occurrence were found to decrease in the station order Pondicherry, Nagpur and Hanle. Variations in the Y component occurrence were observed to be nearly similar but had relatively less power. At Hanle, the duration in Pc4 occurrence was detected to be less dominant in comparison to the other stations. The main reason was the unavailability of data during many days in August, September and October 2005 for this station. The major occurrence of Pc4 events observed in the current study between 14 hr UT to 20 hr UT have also been reported in several previous studies both at low and high latitudes [Takahashi et al (2005), Obana et al (2005), Ziesolleck et al (1997), Zanandrea et al (2004)].

Diurnal variation in frequency of Pc4 for total year 2005 at all three stations is plotted in Fig. 5. Nearly similar pattern of frequency variation was found at all the three stations. The range of the higher and the average frequency of occurrence found at Nagpur were slightly less in comparison to other stations in between 03-12 hr UT interval. There were coincident peaks found in the frequencies occurring simultaneously at all the stations between 04-05 hr UT and 18-19 hr UT interval. The lower latitude stations Pondicherry and Nagpur also showed a peak in frequency, occurring between 21-22 hr UT but it was absent at the comparatively higher latitude station Hanle. The range of higher frequency at Nagpur was observed from 17.81 mHz to 20.27 mHz and the average frequency range was 12.72 to 14.17 mHz giving a mean of about 13.45 mHz. At Hanle the range of higher frequency was found from 17.78 mHz to 20.58 mHz while the average frequency range was 12.89 to 14.58 mHz giving a mean of about 13.74 mHz. At Pondicherry, the average frequency range was 12 to 15 mHz giving a mean of about 13.5 mHz. It can be seen from Fig. 5 that the frequency variation at all the stations showed 'U-type' pattern between 00-10 hr UT and 'inverted U-type' pattern in between 12-24 hr UT. Ansari and Fraser (1985) have also reported this type of behavior in frequency variation in south-east Australia corresponding to Australian Eastern Standard Time (AEST).

The variation of Pc4 occurrence on Kp values for January, 2005 is depicted in Fig. 6. 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).

Fig. 7 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. The Kp dependence of occurrence of Pc4 waves for the summer season of 2005 is shown in Fig. 8. Prominent peaks in the Pc4 occurrence are observed at Kp = 1+, 2-, 2, 2+, 3, 3+, 4-, 4 and 4+ at all the three stations. However additional peaks are observed at Kp = 6+ and 9- at Nagpur and Pondicherry. The variation in Pc4 occurrence with Kp for the Autumn season of 2005 is demonstrated in Fig. 9. There are prominent peaks in the Pc4 occurrence located at Kp = 1-, 1, 1+, 2-, 2, 3 and 4+ at all the three stations. However additional peaks are observed at Kp = 6-, 7 and 8- at Nagpur and Pondicherry. The Pc4 occurrence dependence on Kp for the Winter season of 2005 (depicted in Fig. 10) show prominent peaks located at Kp = 0+, 1-, 2-, 2, 2+, 3-, 3, 3+, 4, 6-, 6, 7+ and 8- at all the three stations.

The Kp dependence of Pc4 occurrence for the whole year 2005 is shown in Fig. 11. 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-.

Discussion

The energy source for Pc3-4 waves observed on the ground may either be external or internal to the magnetosphere. Internal sources of energy include instabilities associated with the cyclotron, bounce and drift motion of particles whose distribution functions are anisotropic. Free energy internal sources include pressure gradients, velocity shears and rapid changes in the magnetospheric geometry associated with substorms. It should also be noted that the bounce resonance mechanism [Southwood et al (1969)] 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 [Cummings et al (1969, 1978)] but are screened from the ground by the magnetosphere. To date there is no comprehensive theory of internal excitation of Pc3-4 waves that could explain the external control which is compatible with observations [Ansari (2008)] and generally models for the external excitation of these waves are favored. 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 [Southwood (1968), Yumoto (1984) , Kivelson and Pu (1984) and Wu (1986)]. Upstream from the magnetopause, large amplitude waves in the quasi-parallel bow shock are swept back into the magnetosheath and then penetrate the magnetosphere [Greenstadt (1972)].

The first direct evidence for the propagation of external Pc3-4 wave power into the magnetosphere has been presented by Greenstadt et al (1983). 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 (1983) 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.

Yumoto et al (1985) have identified compressional waves in GOES-2 magnetometer data in association with Pc3-4 ground pulsations at low latitudes. However this wave energy does not necessarily have to be monochromatic. A broadband source could couple to a field line resonance at middle or low latitudes to provide the monochromatic waves seen at ground stations.

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 [Burton et al (1970)]. 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 (1983) 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} [Yumoto et al (1985)].

The toroidal field line resonance theory of Southwood (1974) and Chen and Hasegawa (1974) provides the mechanism by which waves are seen on the ground. In this mechanism the wave polarization characteristics depend on the azimuthal wave propagation direction and the latitude of the recording station with respect to that of the field line resonance.

Zanandrea et al (2004) have analyzed simultaneous Pc3-4 geomagnetic data at very low and equatorial latitudes (L = 1.0 to 1.2). The characteristics of the observed Pc4 events have been attributed to the increase of the ionospheric conductivity and the intensification of the equatorial electrojet during daytime that regulated the propagation of compressional waves generated in the foreshock region and transmitted to the magnetosphere and the ionosphere at low latitudes. They have suggested that the source mechanism of the observed Pc3-4 modes may be the compressional global mode or the trapped fast mode in the plasmasphere during the field line oscillations at very low and equatorial latitudes.

In their attempt for locating source of Pc4 pulsations observed on the nightside, Takahashi et al (2005) have pointed to a common upstream wave energy source. They have observed strong low latitude Pc4 pulsations on the dayside by IMP-8 during the period of the nightside Pc4 pulsations. However, the spectrum of the upstream magnetic field oscillations at IMP-8 was characterized by broadband power below 20 mHz instead of a strong peak at the frequency of the observed ground Pc4 pulsations.

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 (2007).

Conclusion

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+.

Determining the hourly occurrence of ULF waves and their seasonal variation is important for quantifying their propagation and generation mechanism properties. With this aim the results of the analysis of diurnal variation in the occurrence of Pc4 geomagnetic pulsations for the whole year 2005 recorded at three stations situated at low latitudes in India have been reported in the present study. The seasonal variation in the hourly occurrence of these pulsations were also studied and reported. The majority of occurrence of Pc4 events observed in our study between 14hr UT to 20 hr UT (local nighttime) has also been reported in many previous studies. Several other Pc4 events in local daytime were also found in the course of the present study. The results are in agreement with suggestions of Takahashi et al (2005) 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 (1999). 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 (1985) and Kuwashima et al (1979) 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.

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Table 1: Coordinate Details of Recording Stations

Recording stations	**Geographic co-ordinates** **Long. °E**	 **Lat. °N**	**Geomagnetic co-ordinates** **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

Fig. 1: Schematic Map Showing Locations of The Three Recording Stations

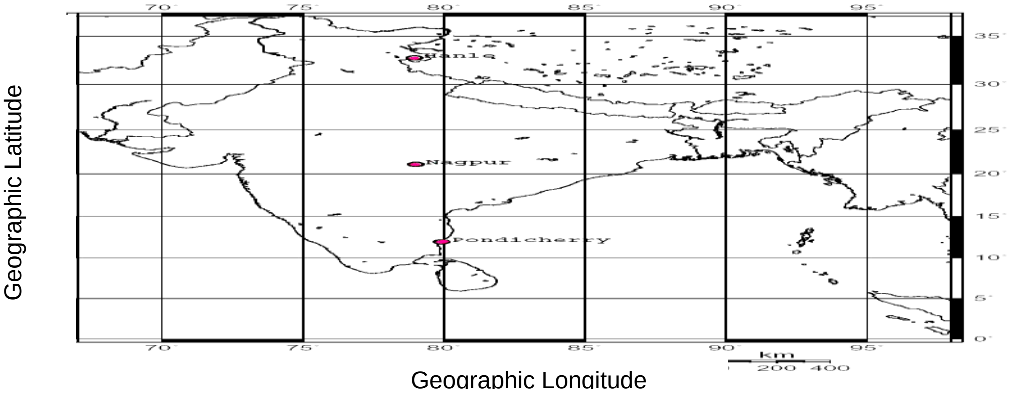

Fig. 2: Dynamic spectra of full day on 28th January, 2005 at Hanle. Time (UT) is expressed in seconds and frequency in Hz. Relative intensities are indicated by various colors.

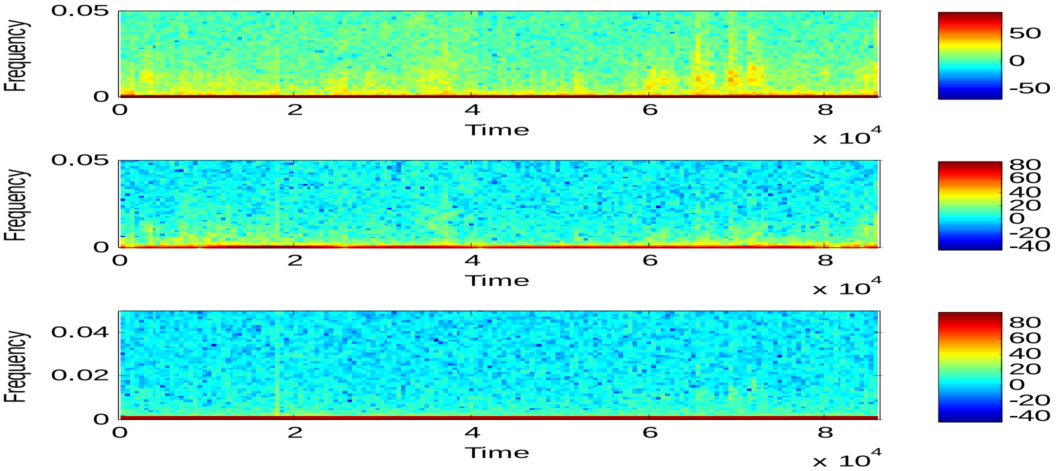

Fig.3: Filtered Pulsations (in the Interval 5-40 Mhz) at Hanle on 28th January, 2005

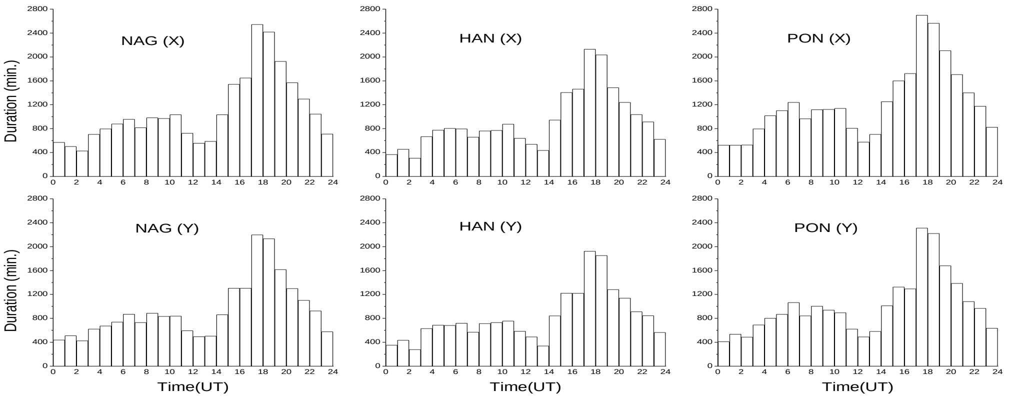

Fig.4 Diurnal Variation in Pc4 Occurrence at All Three Stations for the Total Year 2005

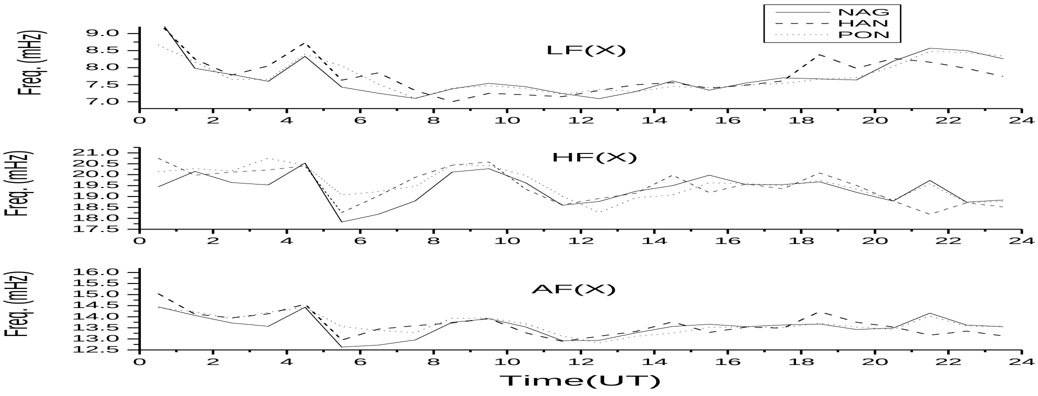

Fig. 5: Diurnal Variation in Frequency of Pc4 for Total Year 2005 at All The Three Stations Nagpur, Hanle and Pondicherry

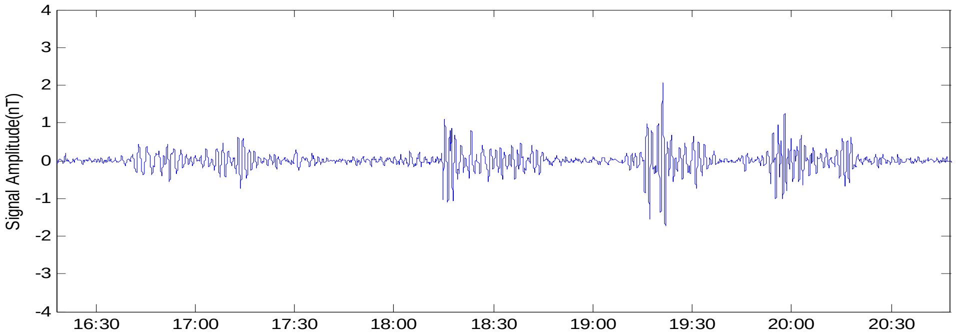

Fig. 6: Variation of Pc4 Occurrence (in Minutes) with Kp for January, 2005

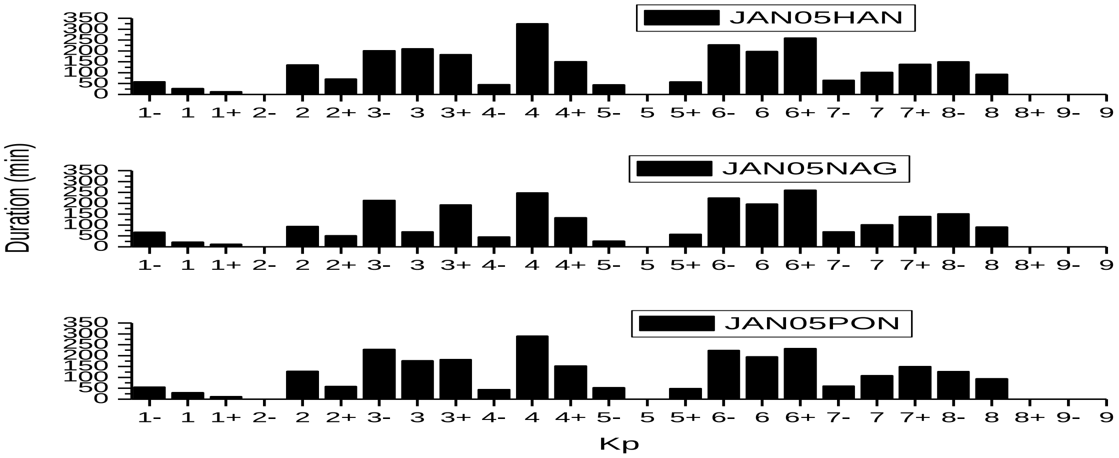

Fig. 7: Variation of Pc4 Occurrence (In Minutes) with Kp for the Spring Season of 2005

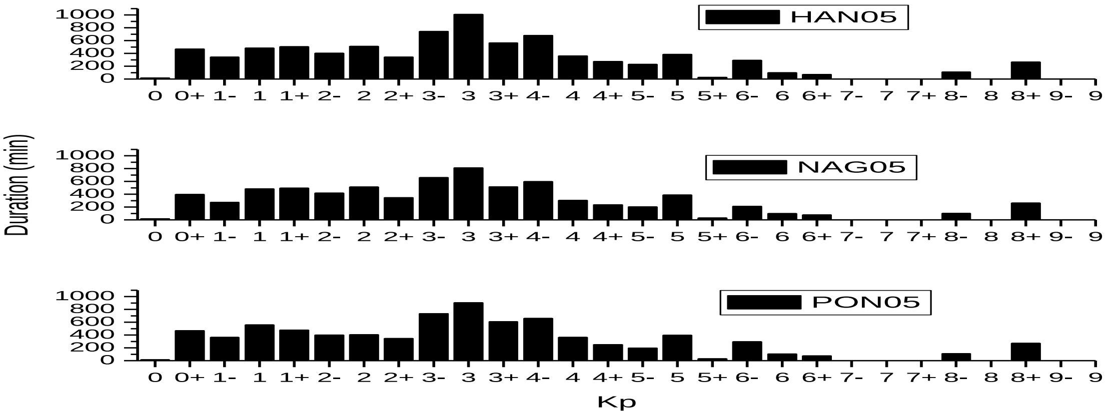

Fig.8: Variation of Pc4 Occurrence (in Minutes) with Kp for the Summer Season of 2005

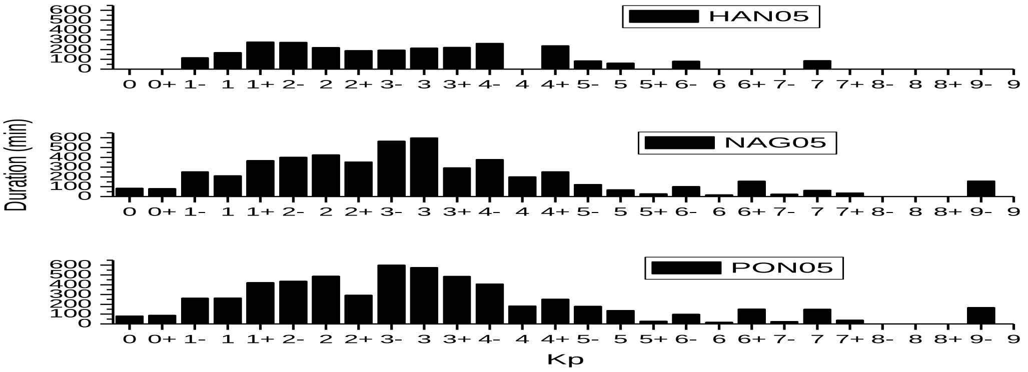

Fig.9: Variation of Pc4 Occurrence (in minutes) with Kp for the Autumn Season of 2005

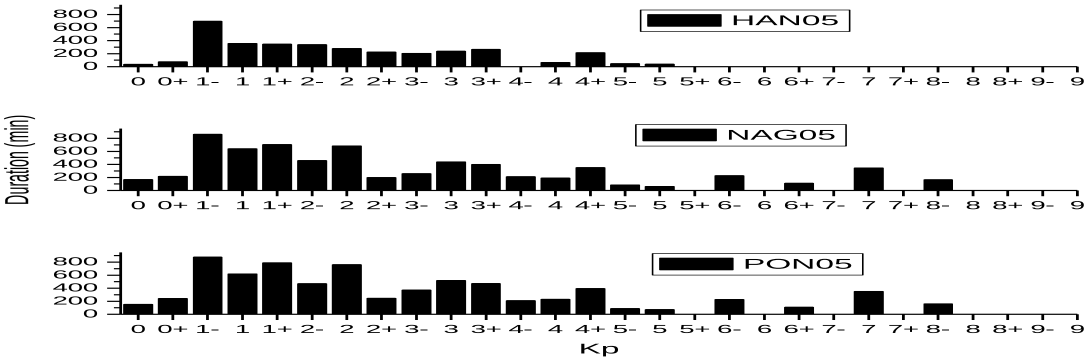

Fig.10: Variation of Pc4 Occurrence (in minutes) with Kp for the winter season of 2005

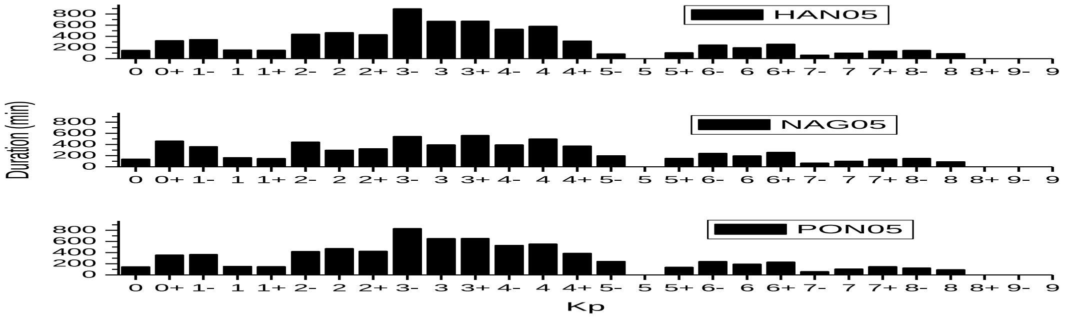

Fig.11: Variation of Pc4 Occurrence (in minutes) with Kp for the whole year 2005.