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ORIGINAL ARTICLE

Seasonal Variations of Kp Dependence with Interplanetary Magnetic Field at Equatorial Electrojet Effect on Geomagnetic Micropulsations at Low Latitude in India

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ABSTRACT

Oscillations of the geomagnetic field with periods between 10 sec and a few minutes have been studied using the Earth current technique at Indian Institute of geomagnetism at Navi Mumbai. The micropulsation data (Pc3–Pc4 range) from off-equatorial and equatorial stations Nagpur (NAG), Hanle (HAN) and Pondicherry (POND) in the Indian zone during 2005 are analyzed for delineating the electrojet effect. The results show that the lower frequencies undergo larger equatorial amplification. However, above a certain frequency the pulsation signal is found to attenuate rather than exhibit the general enhancement. The ratio becomes minimum around the period, 18 to 24 sec. At further higher frequencies, there is again the normal electrojet amplification. The explanation of such a behavior of the electrojet on the pulsation amplitude is rather difficult at the present stage and to some extent becomes controversial even if it is offered. For Pc4 pulsations, the diurnal variation of average period was 'u' shaped having longer periods at night than during the day. There was no simple relationship between period and K_p *index and, unlike Pc3, the percentage occurrence does not increase linearly with* K_p *index. The relation of observed MHD wave parameters with the solar wind and parameters of IMF may become useful for theory prediction for excitation and spreading processes. The recording stations having three axis fluxgate magnetometers were operated by IIG, Navi Mumbai, India. The work for dependence of Pc4 MHD wave's occurrence on the strength of interplanetary magnetic field was carried out for complete year 2005. The bulk of MHD Pc4 signatures occurred with a narrow range, 2-10 nT, of IMF magnitude however its dependence spread up to 22 nT. For the different months of the all Seasons 2005, nearly common behavior of Pc4 events with IMF magnitude was found at each station. This study shows that peak of occurrence for IMF range 3-5 nT.*

Keywords: *MHD waves, ultra-low frequency waves, magnetic micro-pulsations, interplanetary magnetic field, Kp indices*

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1. INTRODUCTION

The terrestrial magnetic field is confined in a cavity-like shape, called magnetosphere, in the interplanetary space due to the pressure exerted by the continuously impinging solar energetic ions and electrons known as solar wind [1]. The magnetosphere quite effectively shields the near-Earth space from direct entry of the solar wind particles. However, in narrow and funnel-shaped regions (around 75 latitudes in both the hemispheres), separating the day and night sides geomagnetic field lines, the solar wind has direct access to about 100 km altitude [2]. Moreover, magnetic flux eroded from the day side due to reconnection process, subsequently energizes the magnetotail on the night side and tremendous amount of energy and mass is further released into the inner magnetosphere and ionosphere [3]. The transfer of particles flux and energy into the inner magnetosphere or ionosphere results in various dynamic geophysical processes, namely geomagnetic storms, substorms and pulsations, etc. which may disturb the near-Earth electromagnetic environment on the global scale [4]. From the activity region in the magnetotail, energetic particles find path (i) across the geomagnetic field lines into the inner magnetosphere where they intensify the global scale "ring current" [5] and (ii) along the highly conducting field lines to the high latitude ionosphere resulting in magnificent auroral display and enhancement of the field-aligned and ionospheric currents [6]. These intensified currents produce strong magnetic field variations that may be globally observed by magnetometers. The ring current encircles the Earth in the equatorial plane at a distance of about 2-7 RE (where RE is the radius of the Earth = 6378 km). Due to enhanced population of the energetic charged particles and subsequent decay in the ring current region, a systematic magnetic field disturbance is observed at all local times in the equatorial region that is known as geomagnetic storm [7]. Meanwhile during storm times, a series of shorter duration but far more intense magnetic disturbances, known as substorms, are typically observed around 65 latitudes on the night side [8]. A geomagnetic substorm is essentially accompanied with visible auroral activity which is direct manifestation of energetic particles precipitation from the magnetotail. Moreover, various types of periodic magnetic field fluctuations having amplitudes about tens of nT and period range ~ 1-1000 s are observed during the geomagnetic activity [9]. These fluctuations, known as geomagnetic pulsations, are good indicator of the state of the magnetosphere and its interaction with the solar wind [10]. Magnetic disturbance recorded in different latitude regions are used to compute geomagnetic activity indices. The Dst index, which is an averaged magnetic disturbance observed at a set of globally distributed low latitude stations, monitors geomagnetic storms [11]. The auroral region (60-70 magnetic latitude) is far more dynamic during substorms than the lower latitudes and different current systems simultaneously exist at different local times. Often an eastward current (electrojet) flows in the dusk hours and westward electrojet prevails in the dawn and midnight local times. The maximum intensities of the eastward and westward electrojets are respectively determined by the AU and AL indices [12]. These indices are extremely relevant for the identification of geomagnetic substorms [13].

In this study we carry out a detailed analysis of whole year 2005 geomagnetic disturbance data collected at three Indian stations (NAG, HAN, POND) at low latitude. A digital three axes fluxgate magnetometer was operated to record variations of three components (X in magnetic north-south, Y in east-west and Z vertically upward) of the geomagnetic field. The data were originally sampled at 1 s interval with 0.1 nT sensitivity. However, for this study we suitably down-sampled the data by simple averaging, e.g., to 10 s for pulsation study and to 1 min for substorm study. The whole year-2025 magnetic data were available the diurnal variations (also known as Sq variations) prevalent on magnetically quiet days have been left for future. This study mainly focuses on magnetic disturbances not exceeding 2-3 hours.

2. DATA ANALYSIS

The research work is supported by digital 1s geomagnetic sampling data from three Indian stations located in a latitudinal array. From 01 January 2005 to 31 December 2005, the Earth's magnetic field's X (north–south), Y (east–west), and Z (vertical) components were measured using three pivotal flux-gate magnetometer clusters at the station: Hanle, Nagpur, and Pondicherry with 1s sampling data. In India, locations of the stations were at very low latitudes. The IIG, Navi Mumbai, set up and operated the magnetometer cluster. The exact locations for these stations are represented individually in Table 1. Time is constantly taken to in Universal Time (UT), i.e. IST= UT + 5:30 hr [12].

The data from a large number of stations was evaluated in a single second. The digital dynamic spectra of 24-hour time interval were built for all three sites in 2005 via

MATLAB programming. We were able to identify the pulsation events to these dynamic spectra. On various days, we detected micropulsation occurrences at all sites. Generally, pulsation events occurred at frequencies ranging from 10 to 30 mHz.

Table 1: Coordination of recording station details

Recording stations	Geographic co-ordinates		Geomagnetic co-ordinates	
	Longitude °E	Latitude °N	Longitude °E	Latitude°N
Pondicherry (PON)	79.92	11.93	152.00	02.52
Nagpur (NAG)	79.01	21.11	151.83	11.70
Hanle (HAN)	79.07	33.01	152.09	23.22

Following the determination of events of pulsation, the data was chosen in a short span of time, and chosen data were "filtered for the observed frequency range". The filtered data were plotted displaying the reasonable pulsation event. The power spectral densities were then calculated using the filtered data. Figures 1.1, 1.2, 1.3, and 1.4 show that the plotted time-series, dynamic spectra, filtered spectra, and power spectra for the pulsation event that occurred at Hanle on January 28th, 2005, respectively. The X and Y components were chosen by all three sites in 2005.

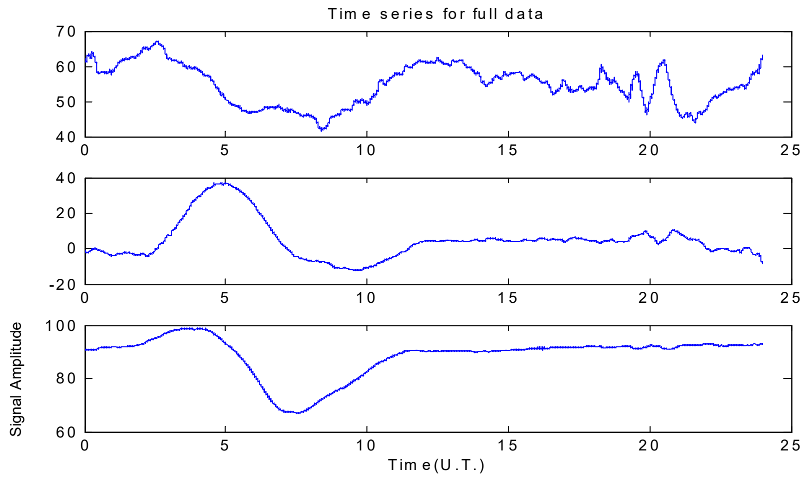

Figure 1.1: Time series of data of 28th January-2005 (Hanle)

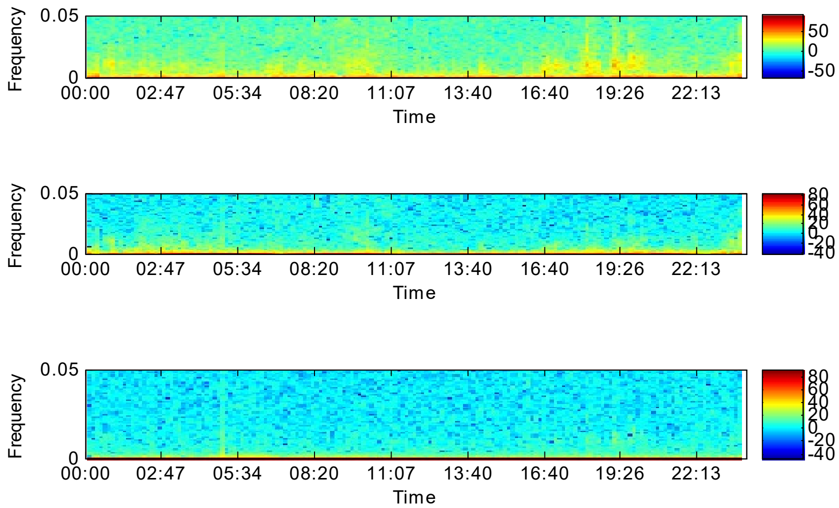

Figure 1.2: Digital Dynamic Spectra (DDS) of pulsation occurrence 28th January-2005 data (Hanle) in UT. (The X, Y, and Z components are represented by the top, middle, and bottom panels of the spectral spectrum, respectively, with different colors indicating relative intensities on a logarithmic scale)

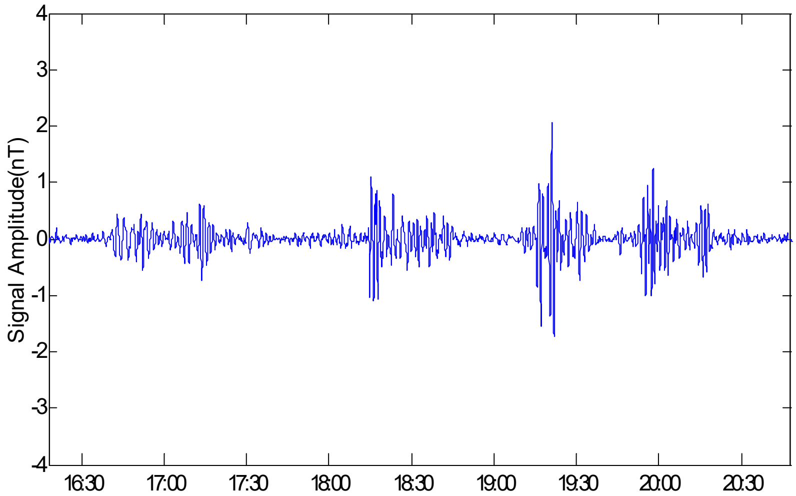

Figure 1.3: A time-series of filtered data for January 28th, 2005 (Hanle), in UT

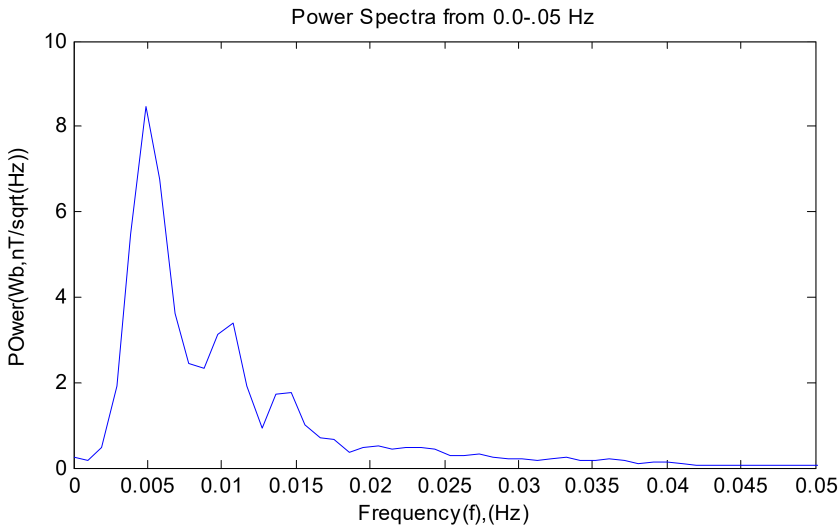

Figure 1.4: Power Spectra of pulsation event of 28th Janaury-2005 (Hanle)

3. RESULTS

In January 2005, Figure 2.1 illustrates the monthly change in Pc4 occurrence frequency relative to Kp at each of the three sites ("Nagpur, Hanle, and Pondicherry"). The vertical axis displays the monthly average frequency (AF), higher frequency (HF), and lower frequency (LF) on the Y-axis., while the X-axis displays the Kp values. For comparative studies, the LF, AF, and HF of all three stations are displayed cumulatively. Figure 2.1 shows that across all Kp values, all of the stations displayed a nearly identical pattern of frequency fluctuation.

All three of the stations' AF ranges were in between 12 - 16.17 mHz. The AF of the Pc4 event at Hanle was 10.17 - 15.13 mHz, with an average of 12.65 mHz. The HF range at Hanle was 12–22 mHz, whereas the LF range was 7 - 9.34 mHz. The AF range at Nagpur was 10.43–14.74 mHz, with an average of around 12.59 mHz. HF band in Nagpur was 12–22 mHz, whereas the LF band was 7-9.1 mHz. A more disturbed event is seen at Kp = 4+. At Pondicherry, the AF range was 10.7 – 16.18 mHz, with an average of roughly 13.12 mHz. High-frequency range was 13–22 mHz, while the low-frequency frequency range was 7–9.91 mHz. The majority of the peaks in Pc4 event of LF with Kp was identified over the 0+ to 6-Kp ranges and shows no variation Kp < 6, while the peaks of AF and HF with Kp were seen for all the 0+ to 8 Kp ranges. The entire graph showed no fluctuation in the center of the 5 to 5+ Kp range. This distinction is due to data that is not easily accessible.

Finally, the AF range at all stations gradually decreases over the 1- < Kp < 8 range. Over the range of Kp values, the HF at all three stations continuously drops, and the LF cut-off Pc4 activity gradually rises with Kp indices.

Figure 2.2 represents Pc4 incidence seasonal fluctuation with Kp for all three sites during the 2005 winter season. Across all Kp values, all of the stations showed identical pattern of frequency change. Hanle's average frequency range was 10.5–15.37 mHz, with an average of 12.94 mHz. The lower frequency range at Hanle was 7.0 to 10.38 mHz, while the higher frequency range was 14 to 22 mHz. In Nagpur, AF had a frequency range of 10.2 to 14.5 mHz, with a mean of 12.65 mHz. In Nagpur, the HF frequency range was 12.9 to 22.2 mHz, whereas LF range was 7.0 to 8.51 mHz. AF was seen in Pondicherry at frequencies between 9.9 and 14.5 mHz, at roughly 12.2 mHz on average. The high-frequency range was 12.8 to 22 mHz, whereas the low-frequency range was 7.0 to 8.62 mHz. The majority of the peaks in Pc4 incidence of HF and AF with Kp occurred across the whole range of 0+ to 8 Kp, However, LF variation with Kp was identified in the range of 0+ to 6 Kp. No change was seen in the entire diagram in the middle range of 5 to 5+ Kp. Data inaccessibility during the winter months is the cause of this distinction.

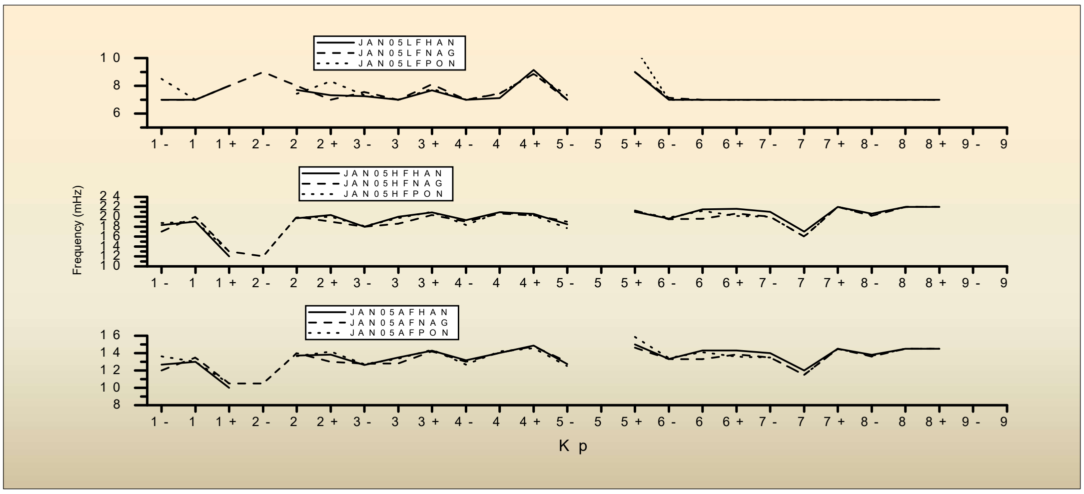

Fig 2.1: Frequency variation of Pc4 incidence during the day at HAN, NAG, and POND stations in January 2005

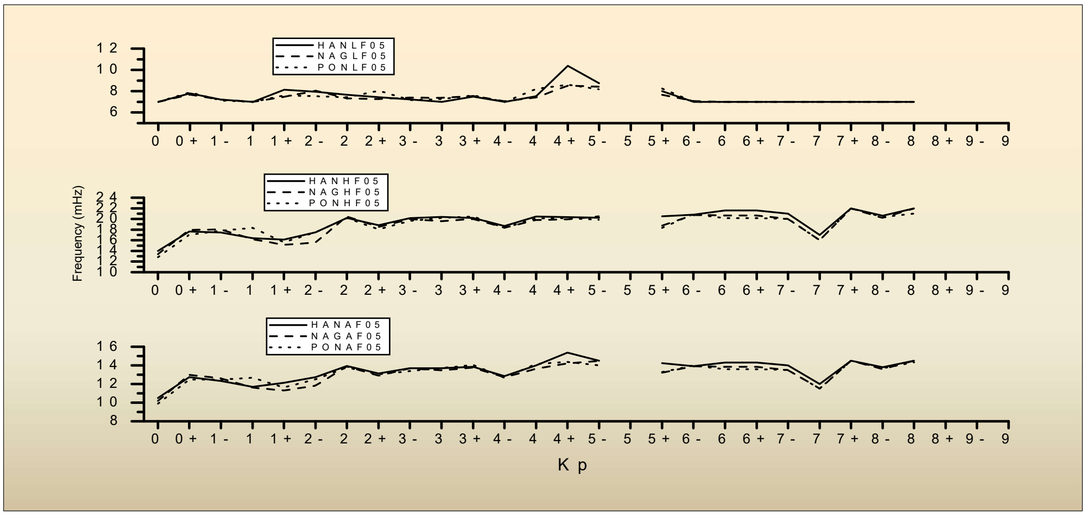

Figure 2.2: Seasonal variation in Pc4 incidence frequency at HAN, NAG, POND, and all three stations during the winter of 2005

Spring Season 2005

Figure 2.3 depicts the seasonal change in Pc4 event frequency with Kp for all three sites during the spring season of 2005 [166]. All of the stations displayed a nearly identical picture of frequency variance with Kp ranges. The average frequency range in Hanle was 9.52 to 15.67, with an average of around 12.59 mHz. Hanle had a higher frequency range of 12 to 22 mHz and a lower frequency range of 7-9.76 mHz.

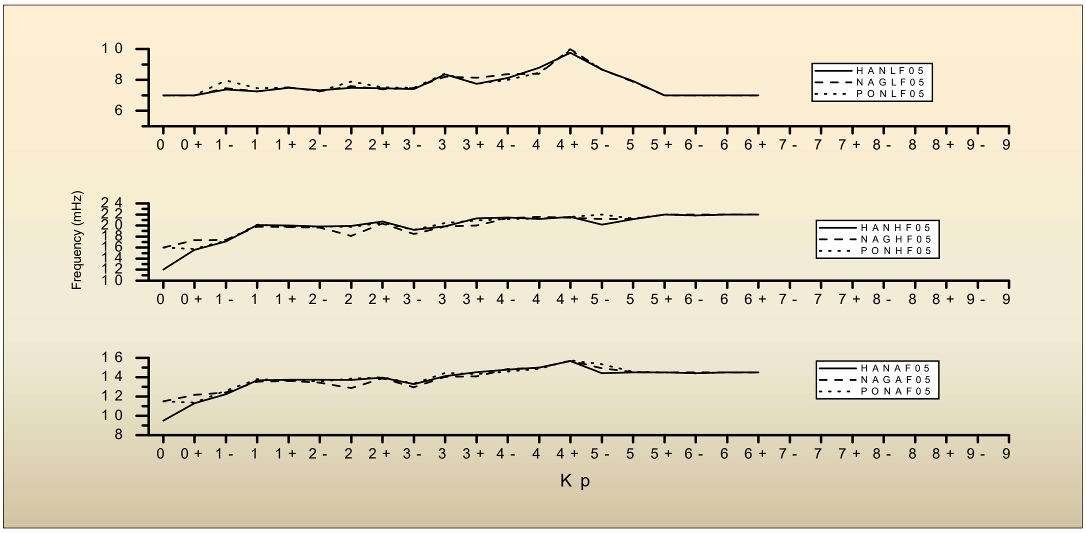

Figure 2.3: Seasonal variation in Pc4 incidence frequency at HAN, NAG, POND, and all three stations during the Spring of 2005

Average frequency at Nagpur was measured to range between 11.5 and 15.7 mHz, with a mean of 13.51 mHz. At Nagpur, the high-frequency range was 16-22 mHz, while the low-frequency range was 7-10 mHz. The frequency range of Average Frequency in Pondicherry ranged from 11.38 to 15.75 mHz, with 13.565 mHz as the mean. The low frequency range was 7 to 9.93 mHz, and the high frequency range was 16 to 22 mHz.

Summer Season 2005

During the 2005 summer season, Figure 2.4 depicts the seasonal variations in Pc4 event frequency with Kp across all three sites. Across all Kp values, all of the stations showed a roughly identical picture of frequency fluctuation. In Hanle, the average frequency range was between 11 and 17.34 mHz, with an average of roughly 14.17 mHz. In Hanle, higher frequency range was 15 to 22 mHz, whereas 7–12.67 mHz was the lower frequency range. Average frequency had a frequency range of 9.25 to 16.49 mHz in Nagpur, with a mean of 12.67 mHz. At Nagpur, the higher frequency was 11.5 to 22 mHz, while the lower frequency was 7-11.47 mHz. Average frequency was detected in Pondicherry at frequencies ranging from 10 to 15.60 mHz, with an average of around 12.80 mHz. The low-frequency signal's frequency range was 7 to 11.2 mHz, while the high-frequency signals were 13 to 22 mHz.

Autumn Season 2005

Figure 2.5 shows how the frequency of Pc4 occurrence varies seasonally with Kp for all three sites during the season 2005. Across all Kp values, all of the stations revealed a remarkably comparable pattern of frequency shift. The Average frequency range in Hanle was 9.3–16.25 mHz, with a mean of 12.775 mHz. High frequency range at Hanle was 11.5 to 22 mHz, and low-frequency range was 7-10.78 mHz. Nagpur had an average frequency range of 9.75 to 15.68 mHz, with an average of 12.715 mHz. In Nagpur, the High frequency range was 12.5 to 22.1 mHz, however, the lower frequency range was 7-13.67

mHz. In Pondicherry, average frequency occurred at a frequency of 10.58 to 15.17 mHz, with an average of 12.875 mHz. The low frequency range was 7 to 9.76 mHz, and 14.17 to 22 mHz was the highest frequency range.

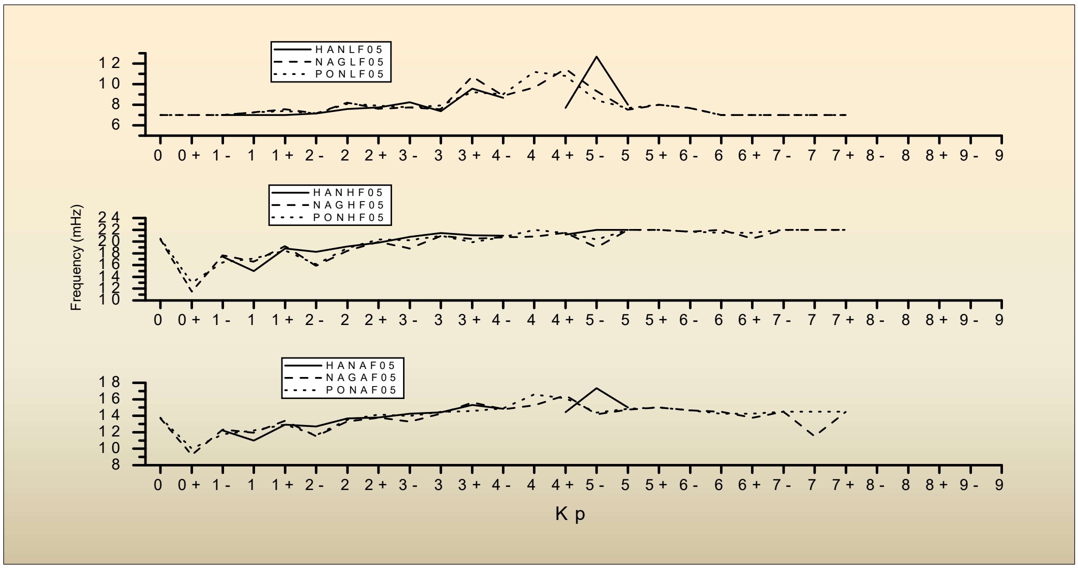

Figure 2.4: In the summer of 2005, there was a seasonal change in the Pc4 incidence frequency at HAN, NAG, and POND stations

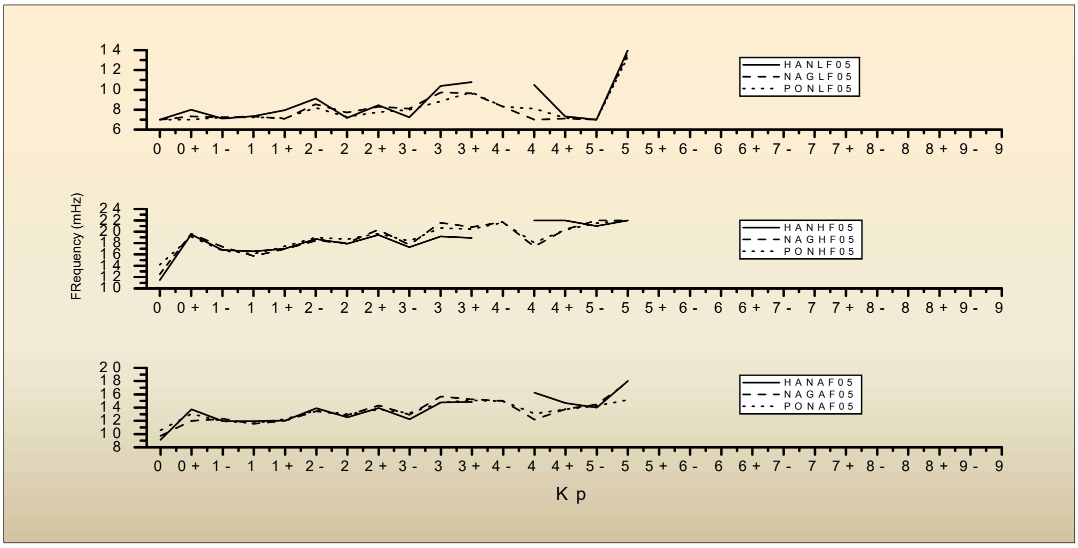

Figure 2.5: Seasonal variations in Pc4 frequency incidence at the sites in the autumn season of 2005: HAN, NAG, and POND

Figure 2.6 shows the yearly change in Pc4 incidence for all three sites in 2005 with Kp [166]. All of the stations represented a nearly identical pattern of frequency fluctuation across all Kp values. At Hanle, the average frequencies ranged from 10 to 15.26 mHz, with an average of roughly 12.63 mHz. The higher frequency range in Hanle was 13 to 22 mHz, whereas the lower frequency range was 7-9.17 mHz. The AF frequency range in Nagpur was 10.1 to 15.13 mHz, with a mean of 12.57 mHz. In Nagpur, the HF range was 14.6 to 22 mHz, while the LF range was 7-9.12 mHz. At Pondicherry, average frequencies ranged from 10.86 to 15.17 mHz, with an average of roughly 13.15 mHz. Higher frequencies ranged from 13.57 to 22 mHz, while lower frequencies ranged from 7 to 9.05 mHz.

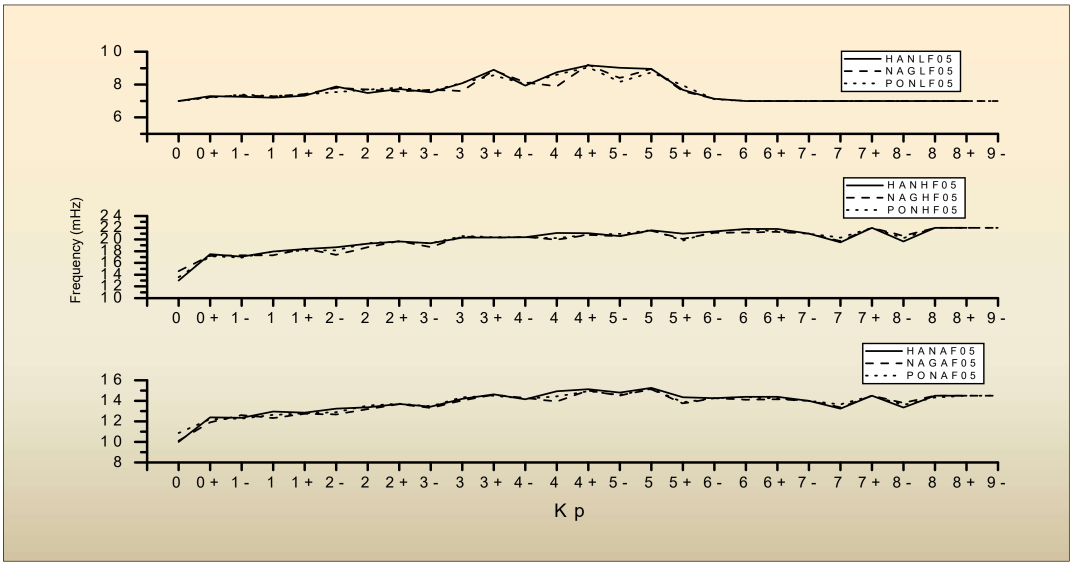

Figure 2.6: Yearly variation in the Pc4 incidence frequency in 2005 at HAN, NAG, and POND stations

The graphs for each month of Feb to Dec, 05 show varying shapes with frequency for every month with eminent Pc4 maxima. The monthly variation of Pc4 frequency occurrence with Kp index for each and every station (Nag, Han and Pond) for each month of February to December 05 is depicted in this paper. The range of average frequency (AF) at all three stations lied in between 9- 14 mHz giving average approx 11.50 mHz. The higher frequencies (HF) range was 11 to 22 mHz while the lower frequencies (LF) range was allying 7- 8 mHz. Most of the peaks in Pc4 occurrence with Kp were found over the 0+ to 5 Kp ranges and show no variation for Kp<5. This concurs with the precursory studied of Voelker [9], Orr and Channon [10], Gupta and Stening [11] and others. The seasonal variation in the frequency of Pc4 occurrence with Kp dependence for every station for the winter season 05 is depicted in Figure 4.Most of the peaks in Pc4 occurrence of average frequency and higher frequency with Kp were found at all the 0+ to 8 Kp ranges and lower frequency with Kp were found over the 0+ to 6- Kp ranges and show no variation Kp<6. There were observed no variation in the whole graph in between 5 to 5+ Kp range. The reason of this difference is the deficiency of the input data in winter season. The seasonal Kp dependence shows that Pc4 frequencies variation with Kp for Autumn and Spring seasons is more or less similarity for Kp≤5 and is consequently, unconventional of seasons over this range of Kp indices. In the seasonal Pc4 occurrence the prominent peaks were perceives at Kp = 3-, 3 for every seasons. Although supplementary peaks were detected 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+ [12-14].
For IMF magnitude up to 16 nT, occurrence was observed but majority of events were seen for 3-9 nT IMF strength with bulk occurrence observed in between IMF values 3–8 nT (Fig. 2.7 & Fig. 2.8). Nearly comparative occurrence was found at all places having 718 min. duration at Nagpur for 4-5 nT strength of IMF while for Hanle it was found 1030 min. and at Pondicherry 1020 min.Pc4 occurrence dependence for complete year is not shown. The occurrence was observed up to 22 nT range of IMF strength but bulk occurrence was observed for strength 2-10 nT with maxima in narrow range 3– 6 nT of magnitude of IMF. Due to missing of data for few days in some months for Hanle recording station, the observed Pc4 duration was less dominant for this place in compare to others.

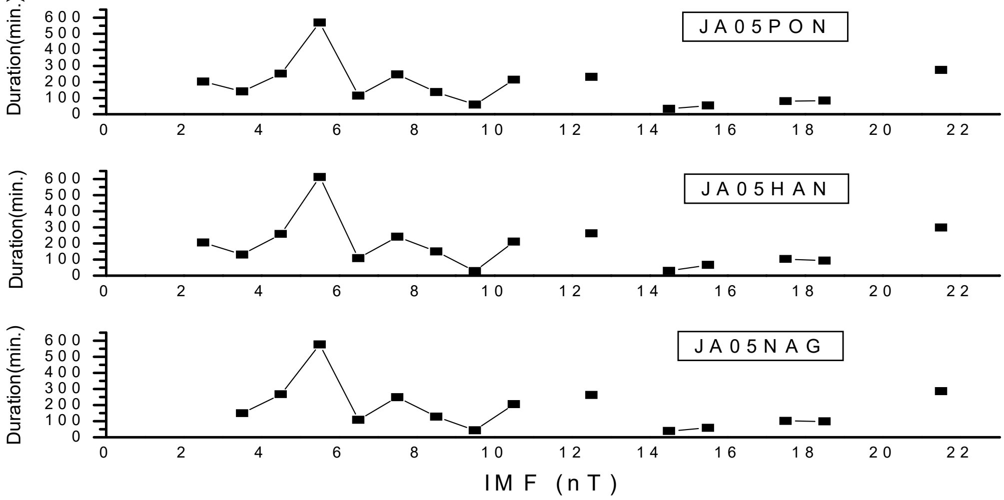

Figure 2.7: IMF magnitudes of occurrence events duration for stations Nag, Han and Pond in month January 2005

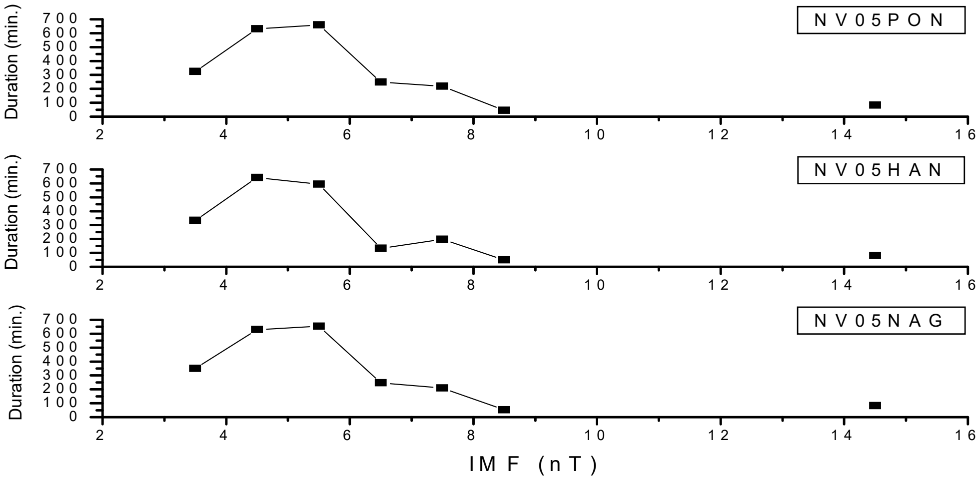

Figure 2.8: IMF magnitudes of occurrence events duration for stations Nag, Han and Pond in the month November 2005

In the view of the aforementioned discussions, excitation mechanisms and the perusal of the results of the diurnal as well as cyclic deviation of low latitude Pc4 pulsations; it is revealed that the upstream waves are a principal source of Pc4 pulsations observed at the night side, which were begun at the dayside and mostly by an augmented region of ULF waves. Furthermore, it is recommended that the plasmaspheric cavity mode resonance may have played significant role in filtering the broadband input to the magnetosphere. The observations presented in the study were also in concurrence with the characteristics of ULF upstream waves claimed by Heilig [13].

4. DISCUSSION AND CONCLUSION

Many authors also reported the correlation of the IMF magnitude with the Pc3-4 pulsations recorded at ground [14]. The strength of IMF is very important factor that governs the frequency of these MHD waves, although cone angle may have effect in frequency determination as reported by Le and Russell [15]. A study is presented by

Vellante [16] based on the MHD pulsation events found simultaneously by satellite CHAMP in space and by SEGMA at the ground and showed that the compressional wave frequency recorded by CHAMP was exceptionally near to the anticipated frequency of foreshock origin upstream waves as forecasted with the empirical formula f (mHz) ≈ 6 BIMF (nT). By comparing the distribution of energy of reflected ions in the transition region, as recorded with the satellite ISEE 3, with the compressional wave frequencies in the magnetosphere, Yumoto [17] showed his agreement with the ion cyclotron resonance mechanism model for upstream wave excitation. Findings of these studies indicates that upstream waves in the foreshock having frequencies correlated to the interplanetary magnetic field strength possibly convicted through the transition region and go forward in magnetosphere during small cone angle condition. In magnetosphere it may spread as compressional mode with having coupling with other modes of hydromagnetic wave and are registered as ultra-low frequency magnetic pulsations at the ground stations.
Measuring the monthly occurrence of ULF waves; their seasonal variation is fruitful for quantifying their proliferation and generation mechanism. Aiming the results of the different analyses of diurnal variations in the event of Pc4 geomagnetic pulsations for the whole year 2005 recorded at three stations located at low latitudes in India have been presented in this study. The seasonal deviation in the periodic observations (hourly) occurrence of these pulsations were investigated and presented. The most of the finding of Pc4 experiments in our investigation in between Kp= 3 to 5+ has also been presented in several earlier studies [21-24]. Various Pc4 experiments in local day time were also observed in the study of the present investigation. Finding of the investigations are in coherence with previously suggested by Takahashi [17]. They reported that pulsations observed in the nightside initiated in the dayside and mostly by an extended region of ULF waves against the bow shock; not from processes occurring in the nightside magnetosphere because there was nonappearance of substorm onsets or intensification. The same results were also presented by Villante [18]. The key peaks in Pc4 observation at local winter and autumn observed at the same time at all the three stations in accordance with the earlier studies of Ansari [20] and Kuwashima [19]. In these investigations, the main occurrence peaks in winter and equinox remain the same with time. The stations array was spread over a latitudinal range of 21° only; consequently, it was insufficient for observations of latitude dependence of Pc4 pulsation occurrence as the data from large-scale latitudinal separation is necessary for the investigations.

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