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Statistical Charecterstics of Pc4 Frequiencies at Low Latitudes in India

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Abstract— The quasi-sinusoidal variations in the Earth's magnetic field in the frequency range 6.7 – 22.2 mHz are designated as Pc4 magnetic pulsations. Using an array of three fluxgate magnetometers, established and operated by the Indian Institute of Geomagnetism (IIG) Navi Mumbai, these pulsations were recorded simultaneously at very low latitudes in India. The data recording stations were situated at Pondicherry (2.5º N), Nagpur (11.72º N), and Hanley (23.38º N) covering a geomagnetic latitudinal range of about 21º. Digital dynamic spectra for north-south (X), east-west (Y) and vertical (Z) components of the recorded data were constructed for each day for one year duration (01 January, 2005 to 31, December, 2005). The X- and Y-components of these dynamic spectra were investigated for undertaking the statistical study of the diurnal and seasonal variations of Pc4 events at all the three stations. The behavior of the analyzed data for the whole year exhibited coincident peaks in the frequencies occurring during the time interval 04 hr – 05 hr UT (09:30 hr – 10:30 hr IST). In addition the frequency variation showed 'U-type' pattern for the duration 00 hr – 10 hr UT (05:30 hr – 15:30 hr IST) and 'Inverted U-type' pattern during 12 hr – 24 hr UT (17:30 hr – 05:30 hr IST) time interval. The seasonal variations in the average frequencies were detected to be higher in local summer than in local winter. In general the average frequency tended to decrease slightly throughout the day in local winter at Hanley and Pondicherry.

Index Terms— Pc4 MAGNETIC PULSATIONS, SOLAR WIND – EARTH'S MAGNETOSPHERIC INTERACTIONS, MAGNETOHYDRODYNAMICS.

1 INTRODUCTION

NATURALLY occurring ultra-low frequency quasi-sinusoidal variations (1–1000 mHz) in the earth's magnetic field, termed as geomagnetic pulsations have been studied extensively in the past [1]. Continuous pulsations in the 7 to 22 mHz frequency range are termed as Pc4 pulsations. Observations of geomagnetic pulsations at low latitudes (L<3) indicate that significant hydromagnetic wave energy penetrates deep into the magnetosphere and the plasmasphere [2]. Vero and Hollo [3] have studied a summary of results on the comparison of pulsation data from the satellite ATS-6 and the surface station Nagycent for a year and found that in spite of the difference in L-value, strong similarities were observed. Vero et al [4] have reported that at low latitude, the pulsation activity was different in spectrum from the mid-latitude ones. Vero et al [5] have also compared pulsations data from equatorial and mid-latitude stations. They [5] found that similar to the results obtained in India (L ~1.1), Pc3 pulsations were practically absent, and a few Pc4 events were better correlated with the higher latitude station than with the lower latitude one. Ansari et al [6] have suggested that the observed diurnal characteristics of occurrence of Pc4 pulsations detected on the night side actually originated on the dayside by an extended origin of ULF waves in the bow shock. However the origin of these waves has not been fully established and it is important to determine whether they are generated with in or external to the magnetosphere and hence it is essential to accumulate the experimental properties.

Most of the daytime pulsations activity in the Pc3-4 range (07-100 mHz) is thought to be related to the waves generated upstream of the bow shock by energetic ions reflecting off the shock and creating conditions for the wave generation [7],[8]. This region, external to the magnetosphere, provides fast mode wave energy that may propagate across the magnetopause and with small radial damping, can cross the plasmapause and penetrate deep within the magnetosphere. The correlation between the occurrence of these waves and the values of the interplanetary magnetic field (IMF) cone angle (θ_{xB}), that is, the angle between the IMF direction and the sun-earth line, also supported the foreshock origin of these waves. A number of authors reported that the Pc3-4 activity occurs predominantly when the cone angle is low (< 45°) [9], [10], [11], [12]. Several studies have also showed that the signal frequencies of Pc3-4 pulsations recorded at ground are correlated with the IMF magnitude [13], [14], [15]. Le and Russell [16] found that the cone angle could also play a role in determining the frequency of upstream waves, although the IMF strength was the most important parameter that controlled this frequency. Yumoto [17] compared the compressional wave frequencies in the magnetosphere with the energy distribution of reflected ion beams in the earth's foreshock recorded by the ISEE satellite series and reported agreement with a model of upstream waves excitation by the ion cyclotron resonance mechanisms. These observations indicated that during small IMF cone angle, the upstream waves in the earth's foreshock whose frequencies were related to the magnitude of the IMF, could be convected through the magnetosheath and transmitted into the magnetosphere, where they propagated in the compressional mode and coupled to the other hydromagnetic wave modes, e. g., trapped oscillations of fast magnetosonic waves

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in the Alfven trough, fundamental and higher harmonic standing oscillations of local field lines and were registered deep in the magnetosphere and at ground stations as magnetic pulsations [7], [8]. Based on the detailed study of Pc3 events at an array between L=1.5 and 3 in central Europe, Vero at al [18] have found quick changes between upstream waves and field line resonance.

The diurnal variation of period and frequency of Pc3-4 waves recorded at ground stations and their dependence on latitude and geomagnetic indices Kp are also vital in identification of their source and propagation modes. The present study describes diurnal and seasonal frequency variation of Pc4 waves at very low latitudes in India.

TABLE 1
COORDINATE DETAILS OF THE THREE RECORDING STATIONS PONDICHERRY, NAGPUR AND HANLE.

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

2 DATA ANALYSIS

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 January 2005 to 31 December 2005) were recorded using three axis flux gate magnetometer array [19] at the stations Pondicherry, Nagpur and Hanle with one second sampling interval. The magnetometer array was established and operated by Indian Institute of Geomagnetism (IIG), Navi Mumbai. The coordinate details of these stations and the schematic representation of their locations are shown in Table 1 and Fig. 1 respectively. Time is always stated in Universal Time (UT) such that Indian Standard Time (IST) = UT + 5:30hr.

The analysis of temporal and spatial variations of the Pc4 pulsations involved several steps. The geomagnetic X, Y and Z components of the recorded time series at one second interval were filtered using a zero-phase shift sixth order Butterworth type "band pass" filter for the frequency ranges 5-40 mHz [20]. The analysis for each day of the whole year was carried out for X and Y components by selecting the events from the spectra of the whole day. The digital dynamic spectra for selected events was prepared taking the window of 1024 points with the sliding of half the window size. The frequency ranges and the occurrence periods were recorded from these spectra. Fig. 2 shows an example of the digital spectra of whole day and Fig. 3 shows 5-40 mHz filtered pulsation event recorded at Hanle for the time interval 15:24 hr to 16:36 hr UT on 19th Nov. 2005.

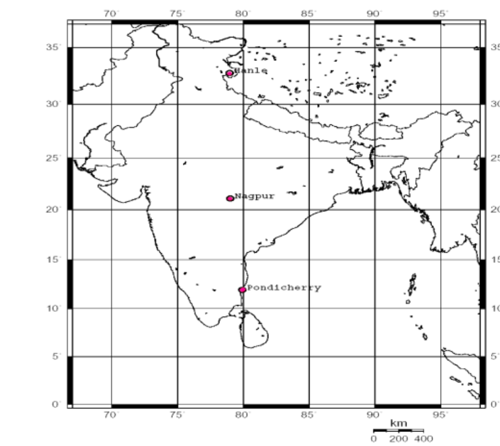

Fig.1. Schematic map showing locations of the three recording stations

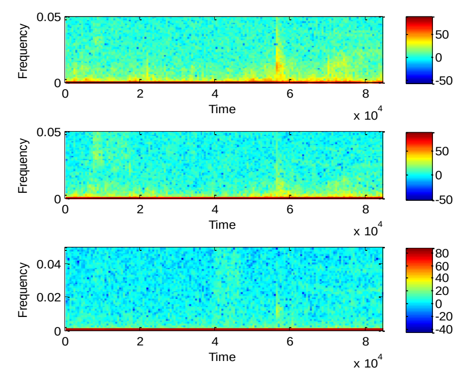

Fig.2. Dynamic spectra of full day on 19th Nov. 2005 at Hanle. Time (UT) is expressed in seconds and frequency in Hz. Relative intensities are indicated by various colours.

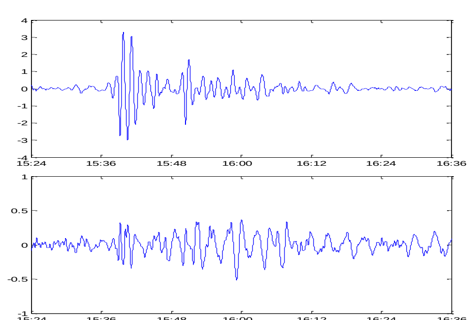

Fig.3. Filtered pulsations of X and Y components (in the interval 5-40 mHz) at Hanle on November 19, 2005. The signal amplitudes are expressed in nano Tesla (nT).

3 RESULTS AND DISCUSSION

The diurnal variation in frequency of Pc4 events observed at all the three stations viz. Nagpur, Hanle and Pondicherry for

January-2005 is plotted in Fig. 4. The time, expressed in UT, is shown in hourly bin on X-axis and frequency expressed in mHz is plotted on Y-axis. The lower (LF), higher (HF) and average frequencies (AF) of all the three stations are plotted collectively for comparative studies.

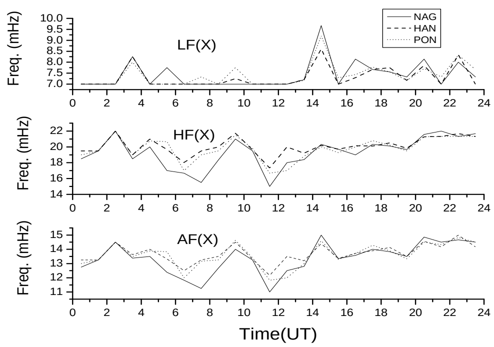

Fig.4. Diurnal variation in frequency of Pc4 for Jan. 2005 at all the three stations Nagpur, Hanle and Pondicherry.

It is evident from Fig. 4 that all the stations showed nearly similar pattern of frequency variation. Although peaks in the frequencies occur at different times before 08 hr UT, there are coincident peaks in the frequencies occurring between 8-9 hr UT, 14-15 hr UT, 20-21 hr UT and 22-23 hr UT. The general frequency occurrence was of slightly higher values after 12 hr UT than before that at all the three stations. At Nagpur the average frequency (AF) of occurrence lied in between 11 mHz and 15 mHz with a mean of about 13 mHz. The range of lower frequencies (LF) at Nagpur was 7 mHz to 9.67 mHz while the range of higher frequencies (HF) was in between 15 mHz to 22 mHz. The average frequency range at Hanle was 12.17 to 15 mHz giving a mean of about 13.18 mHz. The range of LF at Hanle was 7 mHz to 8.6 mHz and the range of HF was 17.3 to 22 mHz. At Pondicherry, the average frequency range was 12 to 15 mHz giving a mean of about 13.5 mHz.

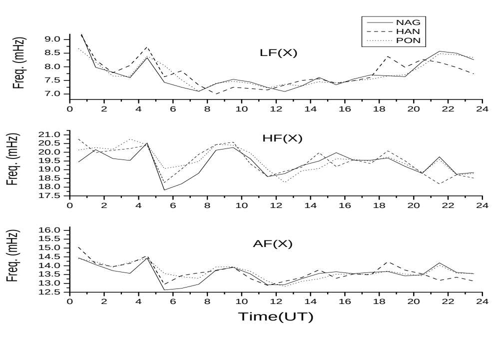

Fig.5. Diurnal variation in frequency of Pc4 for total year 2005 at all the three stations Nagpur, Hanle and Pondicherry.

The range of LF was 7 mHz to 9.2 mHz in the 14-15 hr UT interval. The range of HF lied from 16.67 to 22 mHz. The data of 20 January for Nagpur and of 16 January for Hanle were not available.

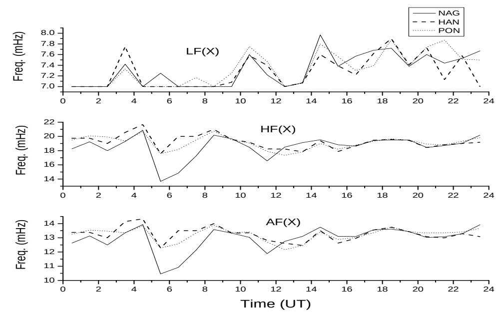

Fig.6. Diurnal variation in frequency of Pc4 for local winter at all the three stations Nagpur, Hanle and Pondicherry.

It was the main cause for the AF of Nagpur to be smaller than the AF of other stations in 08-14 hr UT interval. Frequency variation analyses for other months of the year (February to December, 2005) were also carried out that provided nearly similar results. These results are not depicted for the sake of brievity.

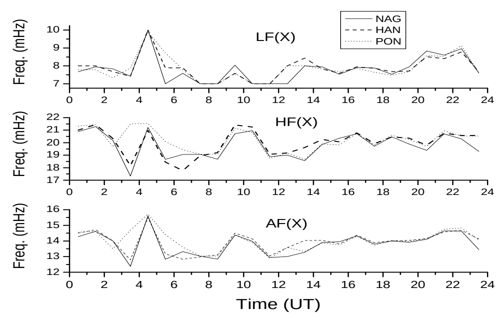

Fig.7. Diurnal variation in frequency of Pc4 for local spring at all the three stations Nagpur, Hanle and Pondicherry.

Diurnal variation in the frequency of Pc4 for the total year 2005 at all the 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 was 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 to be 17.78 mHz to 20.58 mHz while the average frequency range was observed from 12.89 to 14.58 mHz giving a mean of about 13.74 mHz. At Pondicherry, the average frequency range

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was found to be 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 [21] have also reported this type of behavior in frequency variation in south-east Australia corresponding to Australian Eastern Standard Time (AEST).

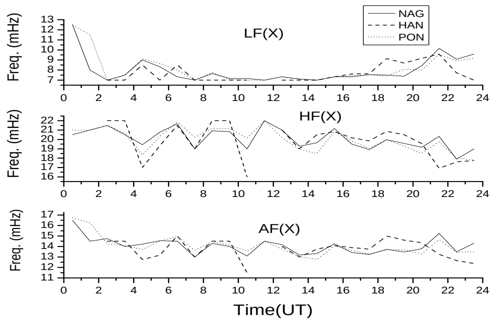

Fig.8. Diurnal variation in frequency of Pc4 for local summer at all the three stations Nagpur, Hanle and Pondicherry

The seasonal variations of frequency of these very low latitude Pc4 waves are presented in Figs. 6 to 9. The diurnal variation in frequency of Pc4 waves for local winter at all the three stations is shown in Fig. 6. It is evident from the plot that nearly similar pattern was observed at all the stations. The lower frequency was found at slightly higher values in the 14-22 hr UT interval at all the three stations. At Nagpur the value of HF was slightly less in comparison to other stations in between 05-12 hr UT.

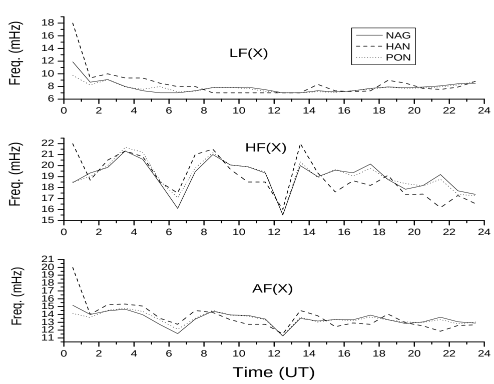

Fig.9. Diurnal variation in frequency of Pc4 for local autumn at all the three stations Nagpur, Hanle and Pondicherry.

At Nagpur the average frequency variation was from 10.46 mHz to 13.93 mHz with a mean of about 12.20 mHz. The range of lower frequencies at Nagpur was 7 mHz to 7.97 mHz and the range of higher frequencies was observed in between 13.67 mHz to 20.87 mHz. The values of HF and consequently of AF at Nagpur were found to be less in between 04-08 hr UT interval. The reason for this was the unavailability of data at Nagpur on 21st, 28th, 29th, 30th and 31st of December 2005. The average frequency range at Hanle was found to be from 12.28 to 14.33 mHz giving a mean of about 13.30 mHz. The range of LF at Hanle was 7 mHz to 7.9 mHz and the range of HF was 17.56 to 21.67 mHz. At Pondicherry, the average frequency range was found to be from 12.17 to 13.88 mHz giving a mean of about 13.02 mHz. The range of LF varied from 7 mHz to 7.88 mHz. The range of HF was found to be 17.33 to 20.75 mHz.

Fig. 7 shows diurnal variation in the frequency of Pc4 waves for local spring at all the three stations. The pattern of frequency variation was nearly similar at all the stations and a minor gradual increase was found in average frequency values after 11-12 hr UT interval while the maximum value of AF was found in the 4-5 hr UT interval. Fig. 8 shows diurnal variation in frequency of Pc4 waves for local summer at all the three stations. It is evident from the plot that the diurnal variation of frequency occurrence at Nagpur and Pondicherry was nearly similar but different at Hanle. The cause of different behavior at Hanle was the unavailability of data in most of the days in August. There was an event of high value of lower frequency observed at Nagpur and Pondicherry on 18 August 2005 in the 00-02 hr UT interval due to which the LF and HF were found to be high at these stations (Fig. 8). The data of that day for Hanle was not available. The diurnal variation in frequency of Pc4 events in local autumn is shown in Fig. 9. In this case also the diurnal variation of frequency of Pc4 events at Nagpur and Pondicherry was found to be nearly similar but different at Hanle. The cause of this difference at Hanle was once again the unavailability of data in most of the days in September and October, 2005. The seasonal variations in the average frequencies are found to be higher in the local summer than in the local winter as is evident from the plots of Fig. 6 to Fig. 9. These results do not agree with those of [22] who reported higher average frequencies in local winter than in local summer at the south-east Australian stations. Kuwashima et al. [23] have also reported peak frequency in winter and equinox which is contrary to our results. In addition, it is evident from Fig. 6 that in general the average frequency tends to decrease slightly throughout the day in local winter at Hanle and Pondicherry. Similar results have also been reported by [21],[24]. This trend has also been seen at synchronous orbit in Pc3 harmonic structure [25]. The average frequency variation trend found at Nagpur was slightly different from other stations.

4 CONCLUSION

The diurnal variation in frequency occurrence of ULF Pc3-4 waves and their seasonal variation are important for quantifying their propagation and generation mechanisms. We have reported the results of the analysis of diurnal variation in the frequency of Pc4 geomagnetic pulsations for the whole year 2005 recorded at the three stations situated at very low latitudes in India. The seasonal variation in the frequency 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 night time) has also been reported in several previous studies. The frequency variation at all the stations shows 'U-type' pattern between 00-10 hr UT and 'inverted U-type' pattern in between 12-24 hr UT interval, which is similar to the results of [21]. The seasonal variations in the average frequencies found to be higher in the local summer than in the local winter are in contrast to the study of [21]. These findings do not agree with the results reported by [23]. However, in general the average frequency tends to decrease slightly throughout the day in local winter at Hanle and Pondicherry, which is similar to the results reported by [21], [24]. This trend has also been seen at synchronous orbit in Pc3 harmonic structure [25].

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