REVIEW OF RESEARCH
ISSN: 2249-894X
IMPACT FACTOR : 5.7631(UIF)
VOLUME - 9 | ISSUE - 6 | MARCH - 2020

VARIATIONS OF Pc4 WAVE WITH Kp VALUES AND THEIR DEPENDENCE WITH INTERPLANETARY MAGNETIC FIELD (IMF)

M. A. Khan
Associate Professor, Dept. of Physics, G. F. College, Shahjahanpur (UP).

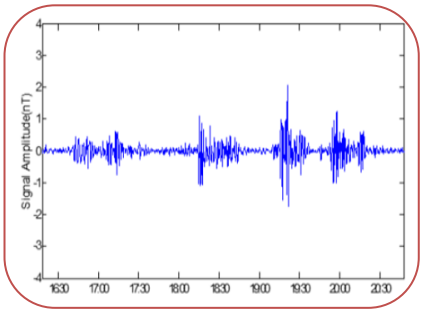
ABSTRACT :

Geomagnetic Pulsations noted on the earth are the mark of the unified signals from the earth's magnetosphere. Pc4 MHD (6.7 to 22 mHz) wave oscillation 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. In this paper is initiated for describing Diurnal and Seasonal Variations on Pc4 MHD wave occurrence with Kp indices at equatorial latitude and their dependence with 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. Data analysis of complete year 2005 provided same 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 IMF dependence of Pc4 occurrence for the year 2005 has shown that even though at all the three stations, it extended 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 peak of occurrence for IMF range 3-5 nT.

KEYWORDS : *MHD waves, Ultra-low frequency waves, Magnetic micro-pulsations, Interplanetary Magnetic Field.*

INTRODUCTION:

Magneto hydrodynamic (MHD) waves are generated when physical systems experience disturbance. MHD waves are generated by the interconnection of mechanical stresses waves that happen in plasma. The research on these ultra-low-frequency MHD waves recorded near to the earth has attracted significant attention since last century and electromagnetic interactions. These are the least recurrence. These naturally happening quasi-sinusoidal fluctuations (1–1000 mHz) in magnetic field of the earth are termed geomagnetic micropulsations. The later theories and interpretation of these geomagnetic field oscillations was mostly based on the theory related to the MHD waves initiated by Alfv´en [1]-[3]. The magnetohydrodynamic geomagnetic oscillations in the 6.7- 100 mHz frequency range, termed as Pc3 and Pc4, are mostly observed in daytime and predicted to have connection with the waves created by reflection of energetic ions back to the bow shock which causes the wave excitation at the boundary of magnetosphere [4]-[13]. Russell and Elphic [22] already suggested the source of ultra-low frequency (ULF) geomagnetic micropulsation energy is related to IMF and reported flux-transfer events which happen at magnetopause with the southward orientation of interplanetary magnetic field. The dependence of occurrence and some other properties of Pc3-4 geomagnetic micropulsations on solar wind conditions and also on magnitude and direction of IMF



have been reported by several authors [8]-[10]. Ansari et al. [11] was also reported external source for these waves and excitation by a prolonged region of perturbation upstream to the bow shock was recommended by them.

Day to day variation of event and frequency of Pc4 MHD waves noted at earth station and their dependence on latitude and magnetic indices Kp and also essential recognition their origin and generation modes [14]. In this paper expresses day to day and Seasonal Variations on Pc4 wave occurrence with Kp values at equatorial latitude and their dependence with Interplanetary Magnetic Field (IMF).

DATA ANALYSIS

The analysis of this paper is planted on digitized 1s (one second) examine magnetic data on the latitudinal array of three Indian stations. Magnetic data of X (north-south), Y (east-west) and Z (vertical) components of earth's magnetic field for the period of the research work (01 Jan. 2005 to 31 Dec. 2005) were noted employing three axis flux gate magnetometer array [5] -[6] at the stations Hanle, Nagpur and Pondicherry with 1s sampling interval. All the tthree stations were located 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 previous paper. Time is always represented in UT such that IST= UT + 5:30 hr [7]. IMF magnitude information was taken from the website of National Aeronautics and Space Administration.

The recorded time series of magnetic intensity with 1- second interim period were filtered using a zero-phase shift sixth order Butterworth type "band pass" filter with limits of the frequency ranges 5-40 x 10^{-3} Herz [8]. Figure 1 shows the filtered time series of pulsations for Hanle measurement station on January 28, 2005. Firstly, the dynamic spectra of full day were well prepared by which we recognized the sudden pulsation events. Fig.2 shows the full day dynamic spectra on 1st April, 2005 at Hanle. By pointing out the abrupt variation events from the full day spectra, the study for all days in complete year was completed for X and Y elements. After finding the pulsation event in particular time interval in the dynamic spectra of a day, digital dynamic spectra of pointed out events were prepared using the technique of sliding of half window size for the window of 1024 points. From these DDS occurrence duration were recorded.

The occurrence relation of these pulsations on IMF magnitude was analyzed with found hourly occurrence duration and information of IMF magnitude for every month individually. The result of two months January and May with the plot for whole year is presented in this paper.

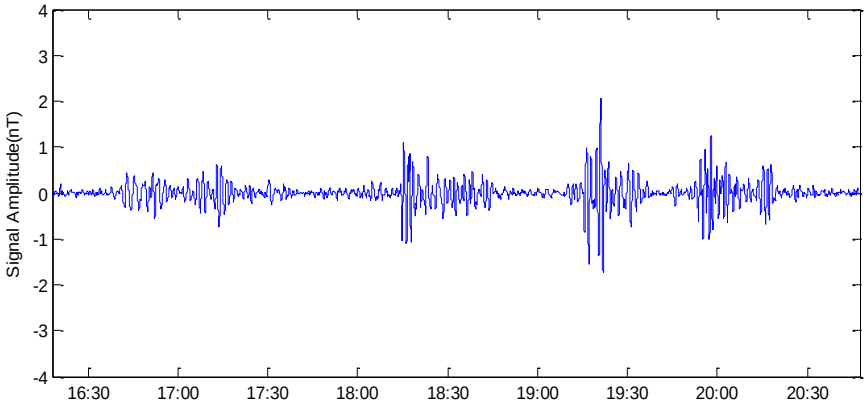


Figure 1: Filtered time series of selected data of 28th Jan.-2005(Hanle) in UT

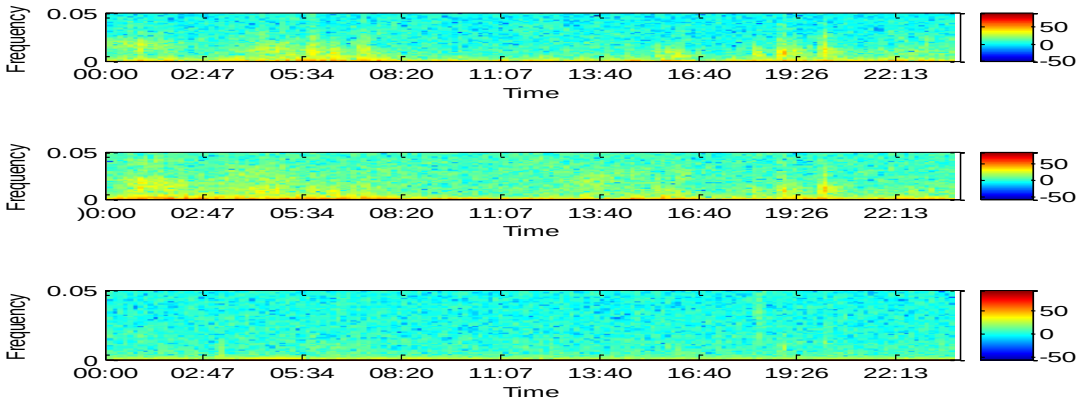


Figure 2: Dynamic Spectra of pulsation event of 01st April-2005 (Hanle) in UT

RESULTS

The monthly variation in frequency of Pc4 occurrence with Kp for the recording stations (Nag, Han and Pond) for the month of Jan. 05 is depicted in Figure 3. The Kp values are expressed on X-axis and the vertical axis denotes the lower frequency (LF), average frequency (AF), higher frequency (HF) for the total month on Y-axis. The lower (LF), average (AF), and higher frequencies (HF) of the recording stations are graphically represented for comparative studies. Figure 3 showed almost same pattern of frequency variation with all Kp ranges in all the stations. The range of average frequencies for all the three stations lied in between 12- 16.17 x 10^{-3} Herz. At Hanle the range of average frequencies of Pc4 occurrence lied in between 10.17 – 15.13 x 10^{-3} Herz giving a average approx 12.65 x 10^{-3} Herz . HF range at Han was 12-22 x 10^{-3} Herz while LF ranges was in between 7.2 to 9.34 x 10^{-3} Herz. At Nagpur, AF range lied in between 10.43 to 14.74 x 10^{-3} Herz giving average approx 12.59 x 10^{-3} Herz. The higher frequencies range at Nagpur was 12 to 22 mHz while LF range was in between 7- 9.1 x 10^{-3} Herz. More varied occurrence is observed at Kp = 4+. The range of average frequencies at Pondicherry was 10.7 – 16.17 x 10^{-3} Herz giving a mean of about 13.12 x 10^{-3} Herz. The range of higher frequencies was 13 to 22 x 10^{-3} Herz while the LF range was in between 7 to 9.91 x 10^{-3} Herz. Most of the peaks in Pc4 occurrence of average frequencies and higher frequencies with Kp were found for all the 0+ to 8 Kp ranges and lower frequencies with Kp were found over the 0+ to 6- Kp ranges and shows no variation Kp<6. There were observed no variation in the whole graph in between 5 to 5+ Kp range. The reason of these dissimilarities is the missing of data. The graph for the separate months of Feb to Dec, 05 is not shown. But all the stations in each mongth showed almost same pattern of frequency alteration with each and every Kp ranges.

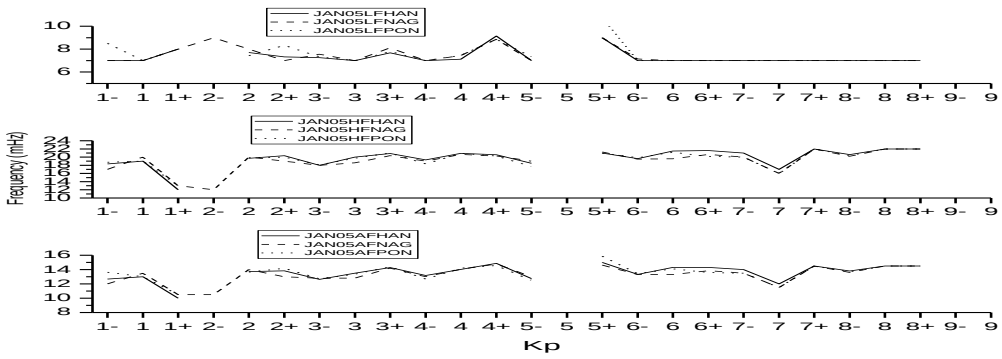


Figure: 3 Day to Day alteration in frequency of Pc4 occurrence at all three stations Hanle (HAN), Nagpur (NAG) and Pondicherry (POND) in January 2005.

Finally the range of AF at all the three station gradually decreases over the 1- ≤ Kp ≤ 8 range. The higher frequencies at all the three stations gradually decrease over the range of Kp values and the low frequency cut off Pc4 activity gradually increases with Kp values.

All these results are not shown for carrying out brief reporting. Only one of the representative results for the individual session of summer, 2005 represented in Figure4. The seasonal variation in frequency of Pc4 occurrence with Kp for each recording stations for the summer season 2005 is shown in Figure4. All the stations showed almost same shape of frequency variation with all Kp ranges. The average frequencies (AF) reang at Hanle was allying 11 to 17.34 x 10^{-3} Herz giving a mean approx 14.17 x 10^{-3} Herz. The higher frequencies range (HF) at Hanle was 15 to 22 x 10^{-3} Herz while lower frequencies range (LF) were allying 7- 12.67 mHz. At Nagpur, the range of average frequencies was in between 9.25 – 16.49 x 10^{-3} Herz giving a mean approx 12.67 x 10^{-3} Herz.

The higher frequencies (HF) range at Nagpur was 11.5 to 22 x 10^{-3} Herz while the LF range was in allying 7- 11.47 x 10^{-3} Herz. The graph for the separate months of Feb to Dec, 05 is not shown. But all the stations in each month showed almost same shape of frequency alteration with every Kp ranges.

The average frequencies (AF) range at Pondicherry was 10 to 16.60 mHz giving average approx 13.30 mHz. The range of higher frequencies was 13 to 22 mHz while the LF range was in between 7 to 11.2 mHz. The yearly variation in frequency of Pc4 occurrence with Kp for every stations for the **year** 05 is not shown. Every station dipicted almost same pattern of frequency variation with each Kp ranges. The average frequencies (AF) range at Hanle was in between 10 to 16.26 mHz giving average approx 12.63 x 10^{-3} Herz. . The HF range at Hanle was 13 to 22 mHz while the lower frequencies (LF) range was in between 7- 9.17 mHz.

At Nagpur, the range of average frequencies was in between 10.1 – 15.13 x 10^{-3} Herz giving a mean of about 12.57 x 10^{-3} Herz. The range of higher frequencies at Nagpur was 14.6 to 22 x 10^{-3} Herz while the range of lower frequencies was in between 7- 9.21 mHz. The range of average frequencies at Pondicherry was 10.86 to 15.17 x 10^{-3} Herz giving a mean of about 13.15 x 10^{-3} Herz. The range of higher frequencies was 13.57 to 22 x 10^{-3} Herz while the LF range was in between 7 to 9.05 x 10^{-3} Herz. For clearly investigation of the generation and propagation mechanisms of ultra-low frequency MHD waves, with the parameters of solar wind and IMF condition would have good strength. In this paper, the dependence of excitation of Pc4 geomagnetic pulsations on strength of IMF observed at equatorial latitudes in India is reported. In the whole year, the dependence found at all above quoted places (Nagpur, Pondicherry and Hanle) for two individual months January and November -2005 are shown in Fig.5 and Fig.6.

The strength of Interplanetary Magnetic Field, given on the X-axis, is in nT and on the Y-axis, corresponding periods of occurrence are represent in minutes. From the observed occurrence pattern in month of January, we perceived that in spite of the fact that events were recognize to the 22 nT strength of IMF, superiority of events was in between 3-11 nT with bulk occurrence found in between 7– 9 nT IMF. About comparative manner of occurrence was observed at Nagpur, Pondicherry and Hanle with the most extreme event term 640 min. for the Nagpur recording station. At Hanle, the maxima were 640 minutes while 660 minutes at Pondicherry with same values of IMF. In May, data of few days were not available for Nagpur which is the reason for some dissimilarity observed here in compare to other places. Figure 7 is giving the pattern for Pc4 magnetic pulsations in month of November.

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. 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.

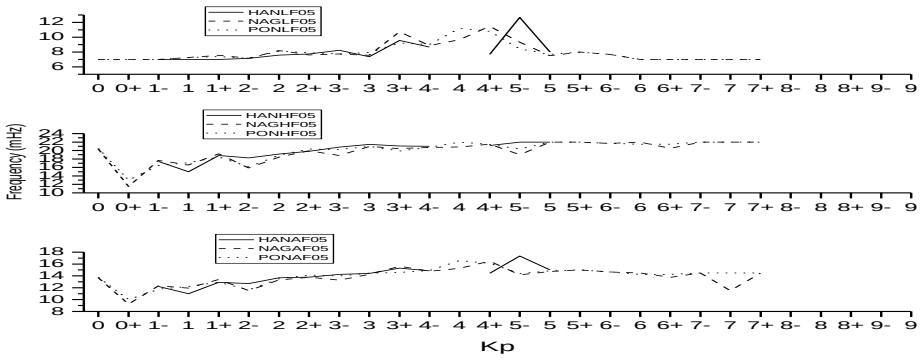


Figure: 4 Seasonal alterations in frequency of Pc4 occurrence at all three stations Hanle (HAN), Nagpur (NAG) and Pondicherry (POND) in summer season 2005

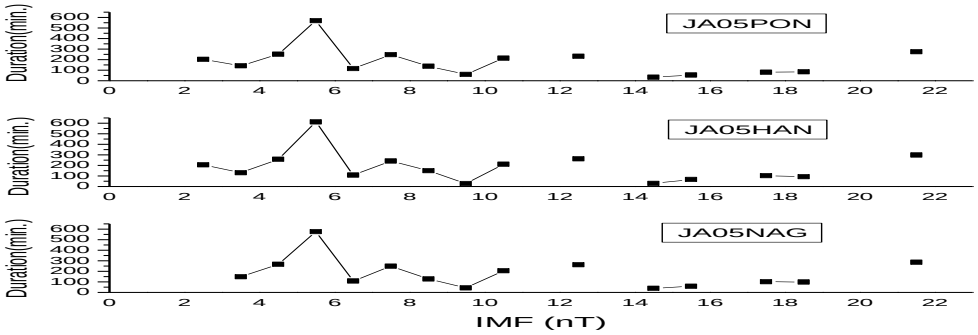


Figure: 5 IMF magnitudes of occurrence events duration for stations Nag, Han and Pond in month January 2005

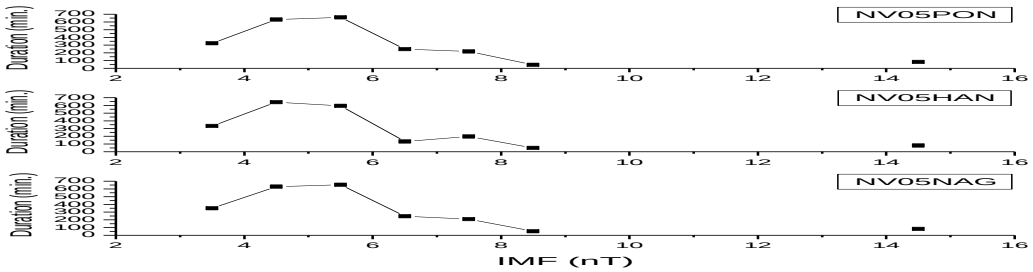


Figure: 6 IMF magnitudes of occurrence events duration for stations Nag, Han and Pond in the month November 2005

Pc4 occurrence dependence for complete year is not shown. The occurrence was observed up to 22 nT range of IMF sthregth 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.

DISCUSSION AND CONCLUSION

The graphs for the each months 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 stations (Nag, Han and Pond) for each month of February to December 05 are depicted in this paper. The range of average frequency (AF) at all three stations lied in between 9- 14 x 10^{-3} Herz

giving average approx 11.50 x 10^{-3} Herz. The higher frequencies (HF) range was 11 to 22 x 10^{-3} Herz while the lower frequencies (LF) range was allying 7- 8 x 10^{-3} Herz. 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 concur with the precursory studied of Voelker [9], Orr and Channon (1970) [10], Gupta and Stening (1971) [11] and others. The seasonal variation in the frequency of Pc4 occurrence with Kp dependence for every stations 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 detect 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].

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 et al. [13].

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 et al. [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]. 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 et al [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 et al [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 etal [20] and Kuwashima et al [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.

REFERENCES

[1] Saito, T. "Magnetic pulsations", Space Sci. Rev., 10(3), p. 319-412, 1969 .
[2]Tomomura K, Sakurai T and Kato Y, Satellite observations of magnetic fluctuations in the magnetosheath and the magnetosphere, Proc of the Faculty of Engineering, Tokai University (Japan), 9 p, 1, 1983.
[3] McPherron, R. L. "Magnetospheric dynamics", in Introduction to space physics, Eds. M. G. Kivelson and C. T. Russell. New York, Melbourne, Cambridge Uni. Press, pp. 01- 569, 1995.
[4] Jacobs, J. A., "Geomagnetic Micropulsations", Springer-Verlag Berlin, Germany, pp. 01- 179, 1970.
[5] Pathan, B. M., Kleimenova, N. G., Kozyreva, O. V., Rao, D. R. K. and Asinkar, R. L.: Equatorial enhancement of Pc5-6 magnetic storm time geomagnetic pulsations, Earth Planet Space, 51, p. 959, 1999.
[6] Khan, M.T et.al. "Statistical Characteristic of Pc4 Magnetic Micropulsations at low latitude in India" Remarking an Analisation Vol.3 Issue 4, PP. 16-26, 2018.
[7] Ansari, I. A. and Fraser, B. J. : A statistical study of low latitude Pc3 geomagnetic pulsations, Indian J. of Radio & Space Phys.,Vol 14, p. 42-49, 1985.
[8] Takahashi, K., McPherron, R. L. and Greenstadt, E. W. "Factors Controlling the Occurrence of Pc 3 Magnetic Pulsations at Synchronous Orbit", J. Geophys. Res. 86(A7), p. 5472–5484, 1981.
[9] Otnes, R. K. and Enochson, L. (1978), "Applied Time Series Analysis", V.1 Basic Techniques, p. 449, Wiley-Interscience, New York.
[10] Voelker, H (1968), Ann Geophys (France), **24**, pp. 245.
[11] Yumoto, K., Saito, T., Tsurutani, B. T., Smith, E. J., and Akasofu, S.-I. "Relationship between the IMF magnitude and Pc3 magnetic pulsations in the magnetosphere", J. geophys. Res. 89, p. 9731-9740, 1984.
[12]Channon, M J & Orr D (1970), Planet Space Sci, **18**, pp. 229.
[13] Gupta, J C and Stening, R J (1971), J Geomagn & Geoelectr (Japan), **23**, pp.213.
[14] Khan, M.T et.al. "Statistical Characteristic of Pc4 Magnetic Micropulsations at low latitude in India" Remarking Analisation Vol.3 Issue an 4, PP. 16-26, 2018.
[15] Heillig B, Luhr and Rother M (2007), "Comprehensive study of ULF waves observed in the topside ionosphere by CHAMP and the ground", An Geophys (France), **27**, pp. 737.
[16] Troitskaya, V. A. (1994), "Discoveries of sources of Pc2-4 waves- areview of research in the former USSR", in Solar Wind Sources of Magnetospheric Ultra-Low-Frequency Waves, Geophys. Monogr. Ser., vol. 81, edited by M. J. Engebretson, K. Takahashi and M. Scholer, p.45, AGU, Washington.
[17] Le, G., and Russell, C. T. (1996), "Solar wind control of upstream wave frequency", J. Geophys. Res., 101, p. 2571-2575.
[18] Vellante, M., Lühr, H., Zhang, T. L., Wesztergom, V., Villante, U., Lauretis, M. De., Piancatelli, A., Rother, M., Schwiegenschuh, K., Koren,W., and Magnes,W. (2004), "Ground/satellite Signatures of Field Line Resonance: A test of theoretical predictions", J. Geophys. Res., 109, A06 210, doi:10.1029/2004JA010392.
[19] Yumoto, K. (1985), "Low frequency upstream waves as a probable source of low-latitude Pc3-4 magnetic pulsations", Planet. Space Sci., 33, p. 239-249.
[20] Takahashi, K., Liou, K., Yumoto, K., kitamura, K., Nose, M. and Honary, F. (2005), "Source of Pc4 pulsation observed on nightside", J. Geophys. Res., 110, A12207, doi:10.1029/2005JA011093.
[21] Villante, U., Lepidi, S., Francia, P., Vellante, M., Meloni, A., Lepping, R. P. and Mariani F.,: Pc3 pulsations during variable IMF conditions, Ann. Geophysicae, 17, p. 490, 1999.
[22] Ansari, I. A. and Fraser, B. J. "A statistical study of low latitude Pc3 geomagnetic pulsations", Indian J. Radio Space Phys., Vol. 14, pp. 42-49, 1985.

[23]Ansari, I.A & Khan, M.T.: Pc4 occurrence and itd dependence on Kp values at low latitudes in India, Indian J. of Radio & Space Phys., Vol 41, pp. 42-49, 2012.
[24] Russell, C. T. and Elphic, R. C. "ISEE observations of flux trasfer events at the dayside magnetopause", Geophys. Res. Lett., vol. 6, p. 33-36, 1979.