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Cosmic ray anisotropy along with interplanetary transients

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Abstract - The present work deals with the study of first three harmonics of low amplitude anisotropic wave trains of cosmic ray intensity over the period 1991-1994 for Deep River neutron monitoring station. It is observed that the diurnal time of maximum remains in the co-rotational direction; whereas, the time of maximum for both diurnal and semi-diurnal anisotropy has significantly shifted towards later hours as compared to the quiet day annual average for majority of the LAE events. The occurrence of low amplitude anisotropic wave trains is dominant during average solar wind velocity but their appearance during high-speed solar wind streams is also possible. The disturbance storm time index i.e. Dst remains consistently negative only throughout all the low amplitude wave train events. The phase of tri-diurnal anisotropy for LAE events is found to shift towards earlier hours with the increase of geomagnetic activity index Ap, showing a significant anti-correlation.

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Keywords: cosmic ray, anisotropy, geomagnetic activity and disturbance storm time index.

1. Introduction

The days having abnormally high or low amplitudes in daily variation of cosmic rays have been reported several times earlier with explanation of sources and sinks in anti-garden-hose and garden-hose directions [1-3]. The existence of high and low amplitude anisotropic wave trains has been revealed through the long-term study of cosmic ray intensity. Periods of unusually large amplitude often occur in trains of several days. The average characteristics of cosmic ray diurnal anisotropy are adequately explained by the co-rotational concept [4-6]. This concept supports the mean diurnal amplitude in space of 0.4% along the 1800 Hr direction using the worldwide neutron monitor data. However, the observed day-to-day variation both in amplitude and time of maximum, and the abnormally large amplitudes or abnormally low amplitudes on consecutive days cannot be explained in co-rotational terms. Moreover, the maximum intensity of diurnal anisotropy has not appeared in the direction of 1800 Hr, which is the nominal co-rotational phase [7-8].

The average daily variation of cosmic ray intensity generally consists of diurnal variation, semi-diurnal variation and tri-diurnal variation. The amplitude of the diurnal variation at a high / middle latitude station has been found to be of the order of 0.3 to 0.4%; whereas, the amplitudes of two higher harmonics are of the order of 0.02% and 0.08% respectively [9]. The average characteristics have also been found to vary with solar cycle, where the variation is much larger at higher energies. A number of investigators have reported the short-term characteristics of the daily variation, where they have selected continually occurring days of high and low amplitudes of diurnal variation [3, 10, 11]. These results have pointed out significant departures in the time of maximum as well as their association with higher harmonics.

Number of high/low amplitude events has been studied and it was observed that the diurnal time of maximum consistently remains along the corotational direction for majority of the events or shifts towards later/earlier hours [12-15]. The occurrence of LAE is dominant for the positively directed Bz component of IMF polarity [16].

2. Data Analysis

The pressure corrected data of Deep River Neutron Monitor (NM) station has been subjected to Fourier analysis for the period 1991-94 after applying the trend correction. While performing the analysis of the data all those days are discarded having more than three continuous hourly data missing.

Using the long term plots of the cosmic ray intensity data as well as the amplitude observed from the cosmic ray pressure corrected hourly neutron monitor data using harmonic analysis the Low amplitude wave train events (LAE) have been selected on the basis of following criteria:

- Low amplitude wave train events of continuous days have been selected when the amplitude of diurnal anisotropy remains lower than 0.3% on each day of the event for at least five or more consecutive days.

- In the selection of events, special care has been taken, i.e. if there occurred any pre-Forbush decreases or post-Forbush decreases before or after the event or the event is in recovery phase or declining phase, is not considered.

On the basis of above selection criteria, we have selected 14 low amplitude wave train events during the period 1991-94. The hourly cosmic ray intensity data for Deep River neutron monitoring station [Geog. Lat. 46.10 Deg., Geog. Long. 282.50 Deg., Vertical cutoff rigidity 1.02 GV] has been investigated in the present study.

Quiet day annual average values have been taken as a reference line for all the respective LAE events.

3. Results and Discussion

The amplitude (%) and phase (Hr) of cosmic ray diurnal/semi-diurnal/tri-diurnal anisotropy along with the respective quiet day annual average values, statistical error bars (I) and best fit lines (The linear best fit line is observed by calculating the least squares fit for a line represented by the equation: $y = mx + b$, where m is the slope and b is the intercept) are plotted and shown in Fig 1 (a, b and c) for all the LAE events. The amplitude of the diurnal anisotropy as depicted in Fig 1 (a) is observed to remain significantly low as compared to the quiet day annual average value for majority of the events throughout the period; whereas, the phase shifts towards earlier hours as compared to quiet day annual average value for majority of the events. Further, the amplitude of the semi-diurnal anisotropy has no definite trend; whereas, the phase shifts towards later hours as compared to quiet day annual average values for majority of the events as shown in Fig 1 (b). Furthermore, the amplitude of the tri-diurnal anisotropy is significantly higher as compared to the quiet day annual average value throughout the period as shown in Fig 1 (c); whereas, the phase has a tendency to shift towards later hours as compared to quiet day annual average value for majority of the events.

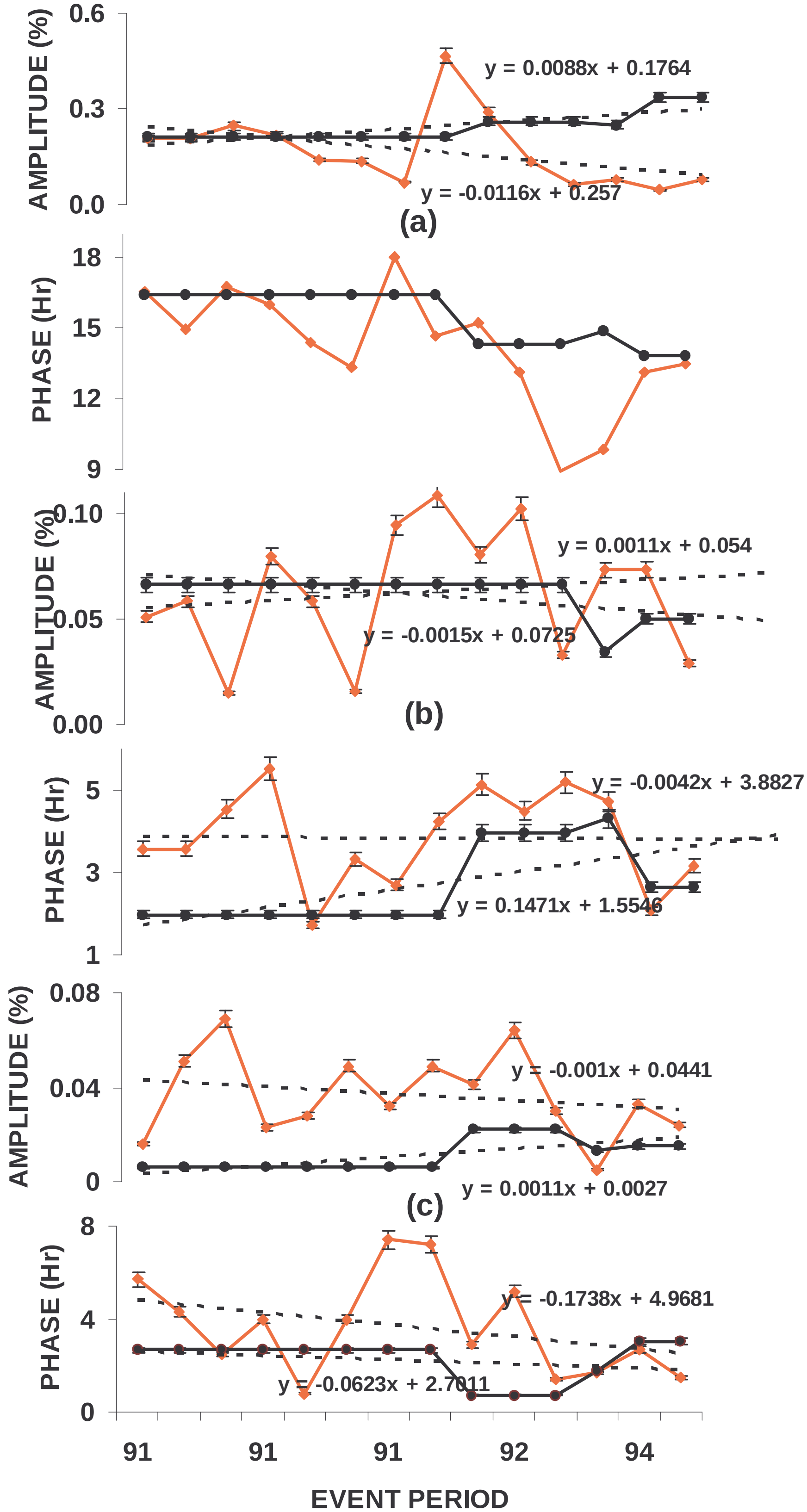

Fig. 1. Amplitude and phase of the (a) diurnal, (b) semi-diurnal and (c) tri-diurnal anisotropy for LAEs along with the quiet day annual average values, statistical error bars (I) and best fit line during the period 1991-94.

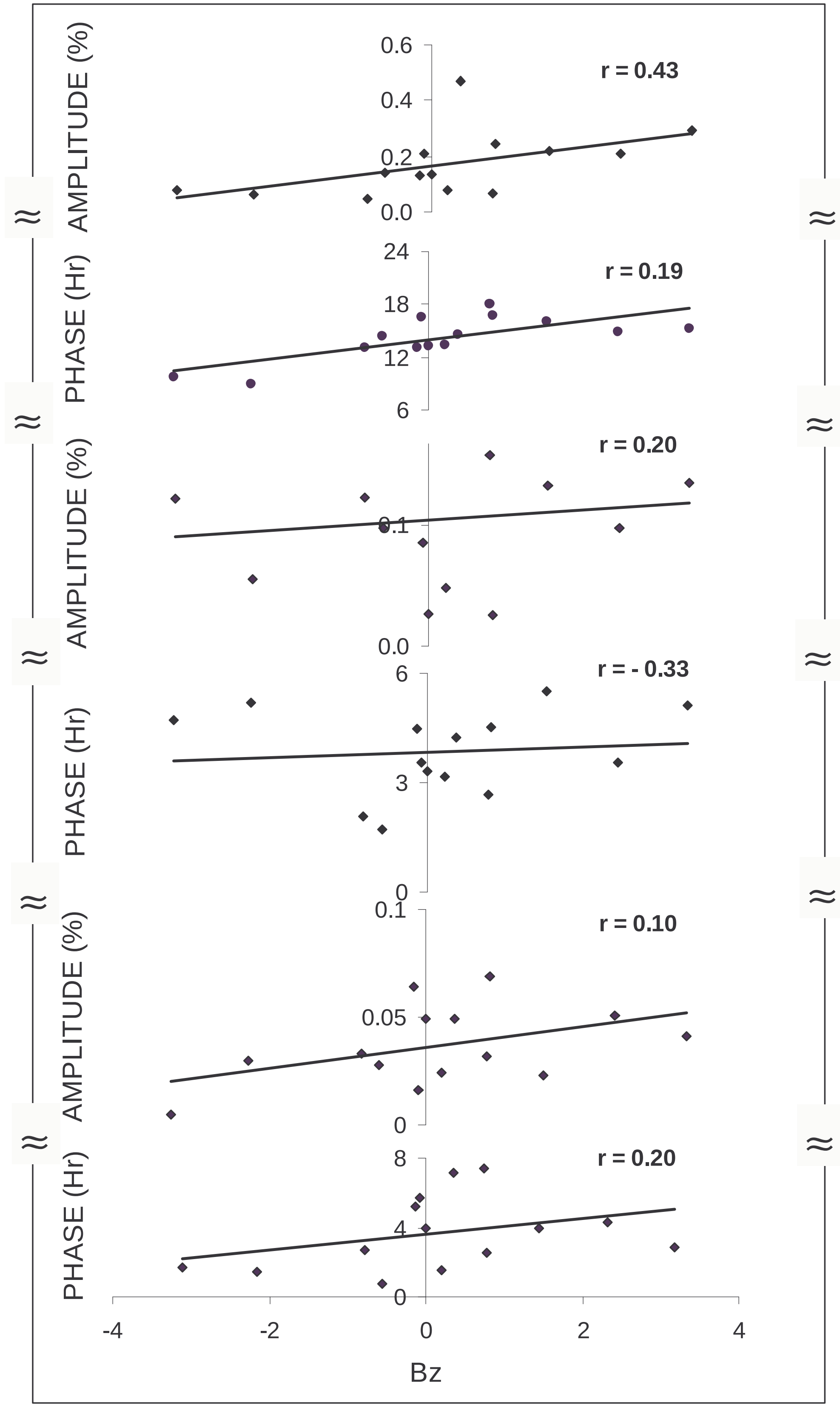

Fig. 2. Amplitude and Phase of the (a) diurnal, (b) semi-diurnal and (c) tri-diurnal anisotropy for each LAE with the variation in associated values of Bz component of IMF

The amplitude (%) and phase (Hr) of cosmic ray diurnal/semi-diurnal/tri-diurnal anisotropy along with the variation in associated value of Bz component of interplanetary magnetic field (IMF) and the regression line is plotted and shown in Fig 2 (a, b and c) for all the LAE events. The amplitude of the diurnal anisotropy for LAE events is found to remain high for positive polarity of Bz component of IMF; whereas, it is found to remain low for negatively directed Bz component of IMF showing the positive correlation as depicted in Fig 2 (a). The diurnal time of maximum for both positive and negative polarity of Bz is observed to remain in corotational direction for majority of the LAE events.

The amplitudes of the semi-diurnal anisotropy for LAE events do not have a definite correlation with Bz component of IMF due to large scattering of points for both positive and negative polarity of Bz as shown in Fig 2 (b); whereas, the phase has weak negative correlation with Bz. The amplitude of the tri-diurnal anisotropy for LAE events is observed to remain low for negative polarity of Bz component of IMF as shown in Fig 2 (c); whereas, it is observed to remain slightly high for positive polarity of Bz showing a positive correlation. The phase of tri-diurnal anisotropy is observed to shift slightly towards later hours as the polarity of Bz component of IMF is directed from negative to positive values showing a positive correlation as depicted in Fig 2 (c).

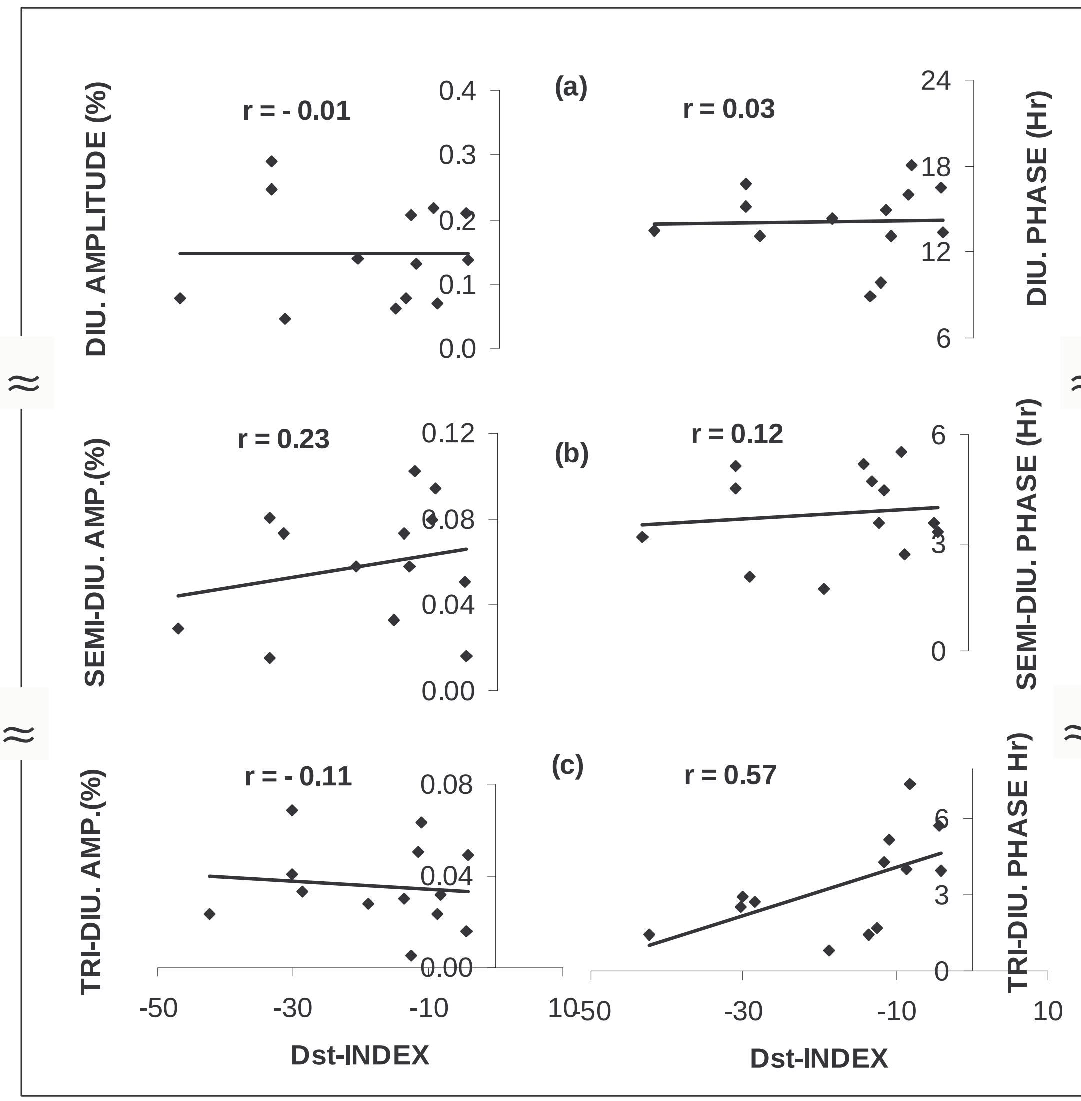

Fig. 3. Amplitude and Phase of (a) diurnal, (b) semi-diurnal and (c) tri-diurnal anisotropy for each LAE along with Dst-index.

The amplitude (%) and phase (Hr) of cosmic ray diurnal/semi-diurnal/tri-diurnal anisotropy along with the variation in associated value of disturbance storm time index (Dst) and the regression line is plotted and shown in Fig 3 (a, b and c) for all the LAE events. The diurnal anisotropy vector for LAE events has no significant correlation with Dst-index. The amplitude of semidiurnal anisotropy is observed to increase with the increase in the value of Dst-index showing a positive correlation; whereas, the phase has a weak positive correlation with Dst-index. The amplitudes of tri-diurnal anisotropy do not show any significant trend due to large scattering of points; whereas, the tri-diurnal phase is observed to shift towards later hours with the increase in the value of Dst-index showing a positive correlation. One of the significant observations is that the Dst-index remains consistently negative only throughout all the low amplitude wave train events.

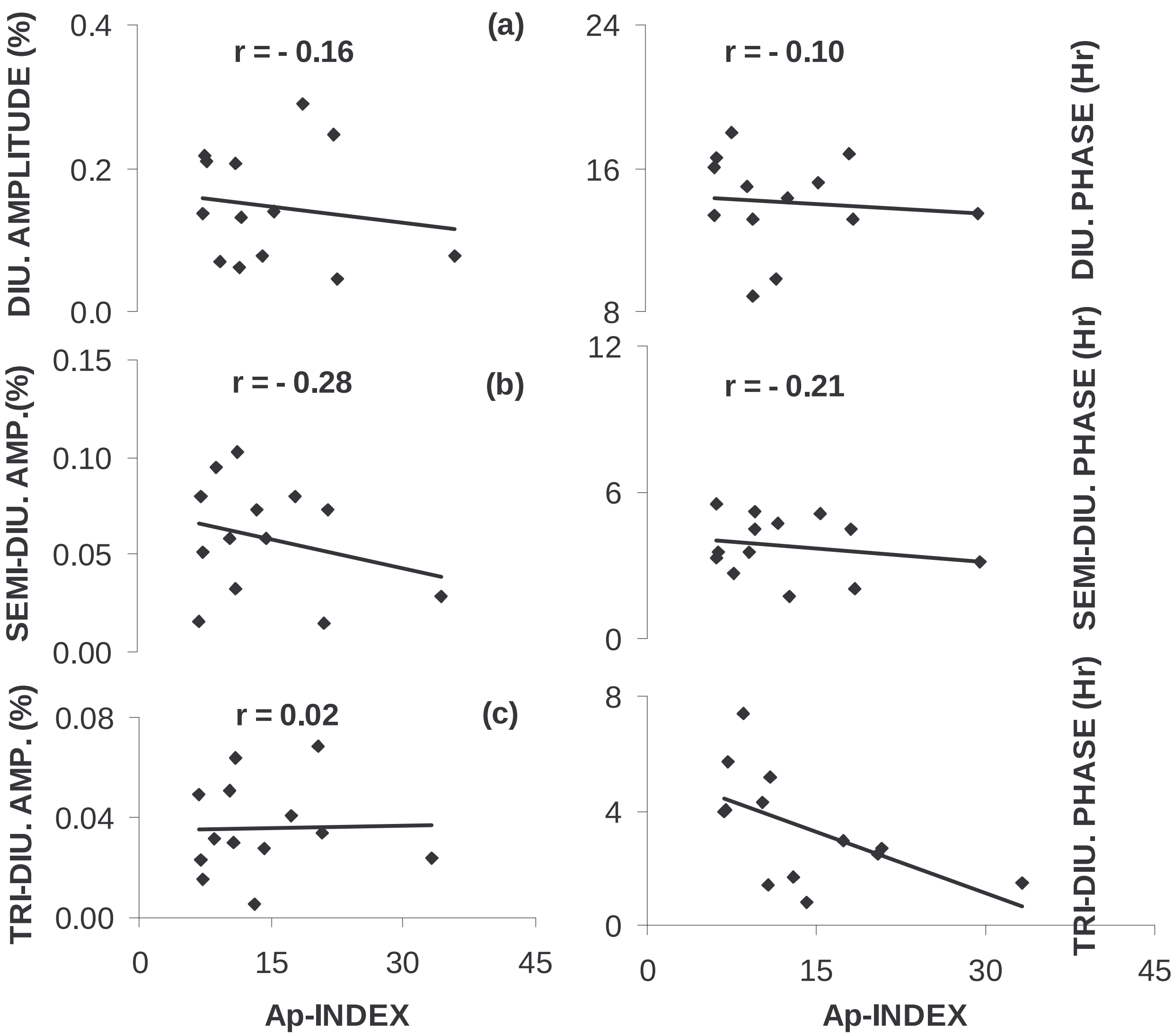

Fig. 4. Amplitude and Phase of (a) diurnal, (b) semi-diurnal and (c) tri-diurnal anisotropy for each LAE along with Ap-index

The amplitude (%) and phase (Hr) of cosmic ray diurnal/semi-diurnal/tri-diurnal anisotropy along with the variation in associated value of geomagnetic activity index (Ap) and the regression line is plotted and shown in Fig 4 (a, b and c) for all the LAE events. The weak correlation has been observed with Ap-index for diurnal, semi-diurnal anisotropy vectors and tri-diurnal amplitude for the LAE events. However, the phase of tri-diurnal anisotropy for LAE events is found to shift towards earlier hours with the increase of Ap-index showing a significant negative correlation.

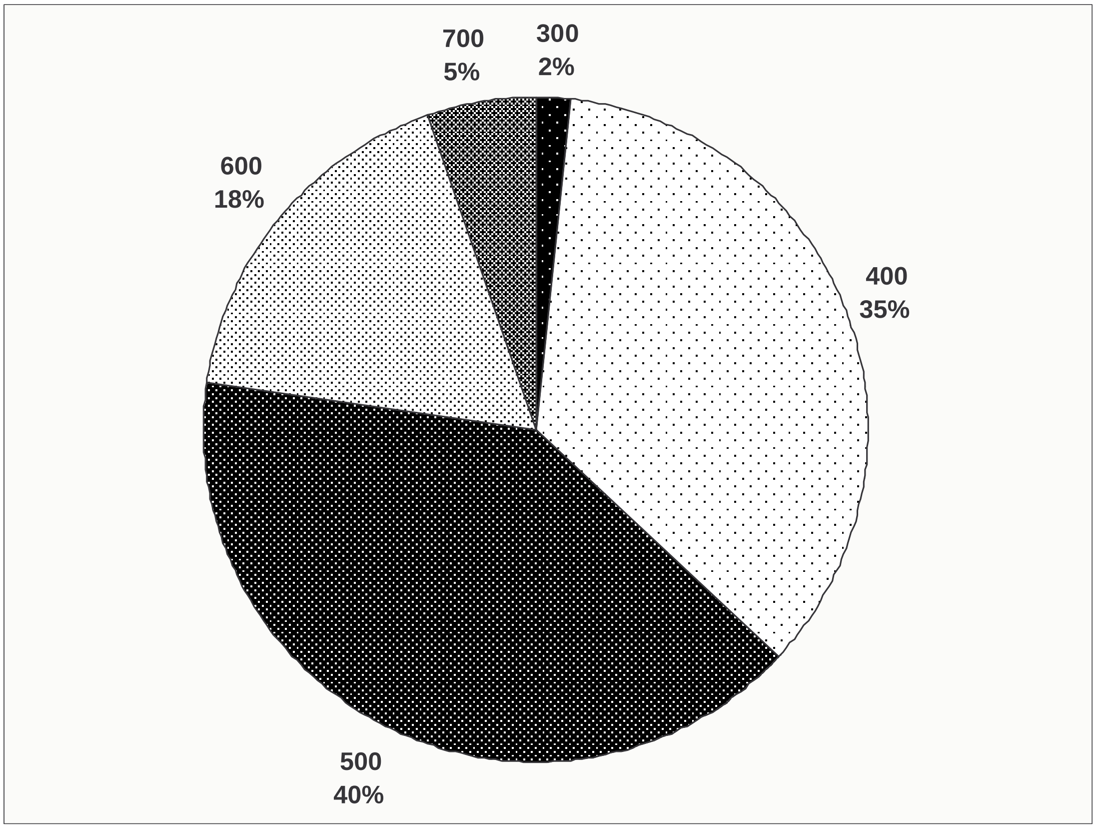

Fig. 5. The frequency pie diagram of the solar wind velocity for all LAEs

The frequency pie diagram of solar wind velocity for all LAEs has been plotted in Fig 5. It is quite observable from these plots that the majority of the LAE events have occurred when the solar wind velocity lies in the interval 400-500 km/s i.e., being nearly average. Usually, the velocity of high-speed solar wind streams (HSSWSs) is 700 km/s [17]. It is also observed from the diagram that only few events (5%) have occurred, when the solar wind velocity remain ~ 700 km/s i.e. during HSSWs. Thus the LAEs are also found to occur during the periods of HSSWs. So, we may conclude that the occurrence of LAEs is dominant during average solar wind velocity but their appearance during HSSWs is also possible. Thus, we may infer that LAEs are weakly dependent on solar wind velocity, which is in agreement with earlier findings [17] and significantly contradicts with the earlier results reported by Iucci *et al.* [18] and Dorman *et al.* [19], that the solar diurnal amplitude is enhanced during the HSSWSs coming from coronal holes. According to Ahluwalia and Riker [20] there is no relation between solar wind speed and diurnal variation in high rigidity region. The modulation of solar diurnal anisotropy is weakly or less dependent on the solar wind velocity [17].

4. Summary and conclusion:

On the basis of above investigations we may summarize as follows:

- The diurnal time of maximum remains in the corotational direction as compared to the quiet day annual average for LAE events.

- The phase of semi-diurnal anisotropy for LAE shifts towards later hours as compared to the quiet day annual average for majority of the events. However, the phase of tri-diurnal anisotropy for LAE shifted to later hours as compared to the quiet day annual average values for majority of the events.

- The amplitude of the diurnal anisotropy for LAE events is found to remain high for positive polarity of Bz component of IMF; whereas, it is found to remain low for negatively directed Bz component of IMF showing the positive correlation. The diurnal time of maximum for both positive and negative polarity of Bz is observed to remain in corotational direction for majority of the LAE events.

- The amplitude of the semi-diurnal anisotropy for LAE events do not have a definite correlation with Bz component of IMF due to large scattering of points for both positive and negative polarity of Bz; whereas, the phase has weak negative correlation with Bz.

- The amplitude of the tri-diurnal anisotropy for LAE events is observed to remain low for negative polarity of Bz component of IMF; whereas, it is observed to remain slightly high for positive polarity of Bz showing a positive correlation. The phase of tri-diurnal anisotropy is observed to shift slightly towards later hours as the polarity of Bz component of IMF directed from negative to positive values showing a positive correlation.

- The occurrence of low amplitude anisotropic wave trains is dominant during average solar wind velocity but their appearance during high-speed solar wind streams is also possible.

- The diurnal anisotropy vector for LAE events has no significant correlation with Dst-index. The amplitude of semidiurnal anisotropy is observed to increase with the increase in the value of Dst-index showing a positive correlation; whereas, the phase has a weak positive correlation with Dst-index. The amplitude of tri-diurnal anisotropy do not show any significant trend due to large scattering of points; whereas, the tri-diurnal phase is observed to shift towards later hours with the increase in the value of Dst-index showing a positive correlation.

- One of the significant observations is that the Dst-index remains consistently negative only throughout all the low amplitude wave train events (LAEs).

- The weak correlation has been observed with Ap-index for diurnal, semi-diurnal anisotropy vectors and tri-diurnal amplitude for the LAE events. However, the phase of tri-diurnal anisotropy for LAE events is found to shift towards earlier hours with the increase of Ap-index showing a significant negative correlation.

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References

[1] D.K. Jadhav, M. Shrivastava, A.K. Tiwari, and P.K. Shrivastava, Proc. 18th Int. Cosmic Ray Conf.,

Bangalore, **3**, 337 (1983).
[2] U.R. Rao, A.G. Ananth, and S.P. Agrawal, Planet. Space Sci., **20**, 1799 (1972).
[3] A.K. Tiwari, Ph.D. thesis, A.P.S. University, Rewa (1994).
[4] E.N. Parker, Planet. Space Science, **12**, 735 (1964).
[5] W.I. Axford, *Planet. Space Science*, **13**, 115 (1965a).
[6] W.I. Axford, Planet. Space Science, **13**, 1301 (1965b).
[7] K.G. McCracken, and U.R. Rao, Proc. 9th Int. Cosmic Ray Conf., London, **1**, 213 (1965).
[8] U.R. Rao, Space Sci. Rev., **12**, 719 (1972).
[9] M.A. Pomerantz, S.P. Agrawal, and V.R. Potnis, J. Franklin Inst., **269**, 235 (1960).
[10] S.P. Agrawal, A.G. Ananth, M.M. Bemalkhedkar, L.V. Kargathra, and U.R. Rao, J. Geophys. Res., **79**, 2269 (1974).
[11] A.K. Tiwari, Proc. 24th Int. Cosmic Ray Conf., Rome, **3**, 948 (1995).
[12] S. Kumar, and M.L. Chauhan, Ind. J. Radio & Space Phys., **25**, 106 (1996a).
[13] S. Kumar, and M.L. Chauhan, Ind. J. Radio & Space Phys., **25**, 232 (1996b).
[14] S. Kumar, M.L. Chauhan, and S.K. Dubey, Solar Phys., **176**, 403 (1997).
[15] Rajesh K. Mishra, Ph.D. thesis, R.D. University, Jabalpur, India (2006).
[16] S. Kumar, R.K. Mishra, R.A. Mishra, and S.K. Dubey, 29th Int. Cosmic Ray Conf., Pune, **2**, 69 (2005).
[17] K. Munakata, S. Mori, J.Y. Ryu, S.P. Agrawal, and D. Venkatesan, Proc. 20th Int. Cosmic Ray Conf., Moscow, **4**, 39 (1987).
[18] N. Iucci, M. Parisi, M. Storini, and G. Villoressi, I1 Nuovo Cimento, 6**C**, 145 (1983).
[19] L. I. Dorman, N.S. Kaminer, A.E. Kuj'micheva, and N.V. Mymrina, Geomagnetism and Aeronomy, **24**, 452 (1984).
[20] H.S. Ahluwalia, and J.F. Riker, Planet Space Sci., **35**, 39 (1987).