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HARMONICS OF DAILY VARIATION IN COSMIC RAY INTENSITY IN CONTEXT TO UNUSUALLY HIGH/LOW AMPLITUDE EVENTS

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The high/low amplitude anisotropic wave train events (HAE/LAE) in cosmic ray (CR) intensity have been investigated during the period 1991-94 using the Deep River neutron monitoring data. In all, 16 HAE and 13 LAE cases have been studied. An inter-comparison of the first three harmonics during these events has been made so as to understand the basic reason causing the occurrence of these types of events. It has been observed that the phase of diurnal anisotropy shifts towards earlier hours for HAEs; similarly, it shifts towards earlier hour as compared to 18-Hr direction for LAEs. For semi-diurnal anisotropy phase remains statistically the same for both HAE as well as for LAE. Further in case of tri-diurnal anisotropy phase is evenly distributed for both types of events. The interplanetary magnetic field (IMF) and solar wind plasma (SWP) parameters during these events are also investigated. It has also been observed that HAE/LAEs are weakly dependent on solar wind velocity.

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1 Introduction

Cosmic ray (CR) intensity exhibits a daily variation composed of a prominent diurnal component and also a semi-diurnal component of lesser amplitude. The diurnal, semi-diurnal as well as the tri-diurnal variation play an important role in constructing the whole picture of the modulation mechanism of the cosmic ray intensity in interplanetary space. The diurnal anisotropy is caused by the streaming of particles in interplanetary space, due to convection, diffusion, adiabatic deceleration, and particle drifts. Subramanian and Sarabhai [1] and Quenby and Lietti [2] both attributed the origin of semi-diurnal anisotropy to symmetric latitudinal cosmic ray density gradient in the heliosphere with particle density rising on both sides of the equatorial plane [3]. According to Nagashima *et al.* [4] semi-diurnal anisotropy arises mainly as a result of the contribution from the pitch angle scattering rather than in the manner suggested by Subramanian and Sarabhai [1] and Quenby and Lietti [2].

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Recent data acquired by Ulysses spacecraft during its fast heliolatitude scan shows that the latitude distribution of GCR has both symmetric and asymmetric components [5,6]. According to Ahluwalia and Fikani [7,8] the contribution of the symmetric transverse gradient to semi-diurnal anisotropy is minimal and the larger contribution comes from some other source(s). Nagashima's treatment also implies that semi-diurnal and tri-diurnal anisotropies have common features. It is observed by many workers [9-11]. Theoretical interpretation regarding the modulation mechanism responsible for the tri-diurnal wave was given by Fujii [12], on the basis of the loss cone model. Ahluwalia and Fikani [13] argued that cause of tri-diurnal variation lies in the pitch angle scattering of GCR protons in the tangled fields that permeate the heliosphere. Bieber and Pomerantz [14] proposed the unified theory of cosmic ray diurnal variation.

Mavromichalaki [15] has been observed that the enhanced diurnal variation was caused by a source around 1600 Hr or by a sink at about 0400 Hr. It was pointed out that this diurnal variation by the superposition of convection and field-aligned diffusion due to an enhanced density gradient of $\approx 8\%$ AU^{-1}. Ananth *et al.* [16] studied the long-term changes in diurnal anisotropy of cosmic rays for the two solar cycles (20 and 21) during the period 1965-1990. They observed that the amplitude of the anisotropy is related to the characteristics of high and low amplitude days. The occurrence of high amplitude days is found to be positively correlated with the sunspot cycle. Further, the variability of the time of maximum of the anisotropy indicates that it is essentially composed of two components; one in the 1800 Hr (corotation) direction and the other, an additional component in the 1500 Hr direction (45° east of the S-N line) apparently caused by the reversal of the solar polar magnetic field. They also suggest that the direction of the anisotropy of high amplitude days contribute significantly to the long-term behaviour of the diurnal anisotropy as it produces an additional component of cosmic rays in the radial (1200 Hr) direction. Ananth *et al.* [17] suggested that the enhanced wave trains do not reveal any correlation with the solar or geomagnetic activity index and the direction of the anisotropy lies along the $\approx$1800 Hr (corotational) direction. They also noticed that the spectral index 'n' of the cosmic ray power spectrum is distinctly different with a higher value for the enhanced wave train event. Which indicates that the enhanced wave train event caused by different magnetic field configuration.

The average amplitude of diurnal and semi-diurnal anisotropy are found to be larger than normal during the initial phase of the stream while it is smaller as compared to the normal during the decreasing phase of the stream and phase is observed to remain almost constant [10], which infer that the diurnal as well as semi-diurnal variation of galactic cosmic ray intensity may be influenced by the solar polar coronal holes. The changes have also been observed in the amplitude and phase during the high speed solar wind streams (HSSWS) coming from coronal holes [18,19]. The diurnal variation might be influenced by the polarity of the magnetic field [20], so that the largest diurnal variation is observed during the days when the daily average magnetic field is directed outward from the Sun. The solar diurnal variation of CR intensity shows a large day-to-day variability. This variability is a reflection of the continually changing conditions in the interplanetary space [21]. The average diurnal anisotropy of cosmic radiation has generally been explained in terms of azimuthal/corotation [22]. The systematic and significant deviations of amplitude as well as phase for diurnal/semi-diurnal anisotropies from the average values are known to occur in association with strong geomagnetic activity [23]. The enhanced diurnal variation of high amplitude anisotropic events (HAEs) exhibits a maximum intensity in space around the anti-garden hose direction and a minimum intensity around the garden hose direction. A number of HAEs and low amplitude anisotropic events (LAEs) have been observed with a significant shift towards later or earlier hours [24,25,26]. An inter-comparison of diurnal/semi-diurnal/tri-diurnal anisotropy during 1991-94 for HAE/LAE has been presented in this paper to investigate the basic reason causing the occurrence of these types of unusual events.

2 Data Analysis

The pressure corrected data of Deep River Neutron monitor NM (cut off rigidity=1.02 GV, Latitude=46.1° N, Longitude=282.5° E, Altitude=145M) has been subjected to Fourier Analysis for the period 1991-94 after applying the trend correction to have the amplitude (%) and phase (Hr) of the diurnal and semi-diurnal anisotropies of cosmic ray intensity for unusually high/low amplitude events. Using the long term plots of cosmic ray intensity data as well as the amplitude calculated from the cosmic ray pressure corrected hourly neutron monitor data using harmonic analysis, the High amplitude wave train events (HAE) and Low amplitude wave train events (LAE) have been selected. The high amplitude events for consecutive days have been selected when the diurnal amplitude found higher than 0.5% for each day of the event for atleast five or more days. The low amplitude wave train events of consecutive days have been selected when the diurnal amplitude remains less than 0.3% for each day of the event for at least five or more days. On the basis of these selection criteria we have selected 16 unusually high amplitude anisotropic wave train events (HAEs) and 13 unusually low amplitude anisotropic wave train events (LAEs) during the period 1991-94. The pressure corrected hourly neutron monitor data after applying trend correction are harmonically analysed to have amplitude (%) and phase (Hr) of the diurnal, semi-diurnal and tri-diurnal anisotropies of cosmic ray intensity for HAE and LAE. The data related with interplanetary magnetic field and solar wind plasma parameters have also been investigated.

3 Results and discussion

Solar wind and IMF plays an important role in controlling the electrodynamics of the heliosphere [27]. Solar wind speed V and IMF parameters, such as vector **B**, spiral angle and tilt are important for the transport of energetic cosmic ray particles in the heliosphere, for the modulation of CR and creation of CR anisotropy in the interplanetary space. Kondoh *et al.* [28] found that the peak solar wind velocity have good anti-correlation with the high-energy galactic cosmic ray intensity. Recent enhancements of solar wind velocity are closely associated with the long-term decreases in the galactic cosmic ray intensity. The IMF magnitude and fluctuations are responsible for the depression of CR intensity during high-speed solar wind events [29]. The frequency histograms of solar wind velocity for HAE/LAE have been plotted in Figs. 1a, b. It is observable from these Figs. 1a, b that the majority of the HAE and 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 [18]. Therefore it is quite apparent from Figs. 1a, b that HAE/LAE events are not caused either by the HSSWS or by the sources on the Sun responsible for producing the HSSWS such as polar coronal holes (PCH) etc. Thus, we may infer that HAEs/LAEs are weakly dependent on solar wind velocity. Similar findings reported by Munakata *et al.* [18] for LAEs. Duggal and Pomerantz [30] and Iucci *et al.* [31] pointed out

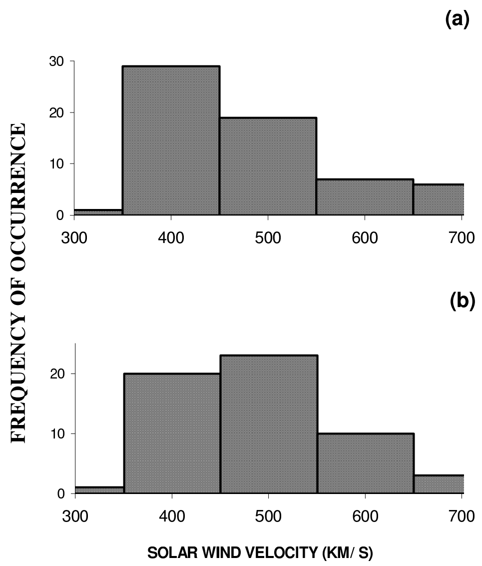

Fig. 1. Frequency histogram of solar wind velocity for all the (a) HAE and (b) LAE events during 1991-94.

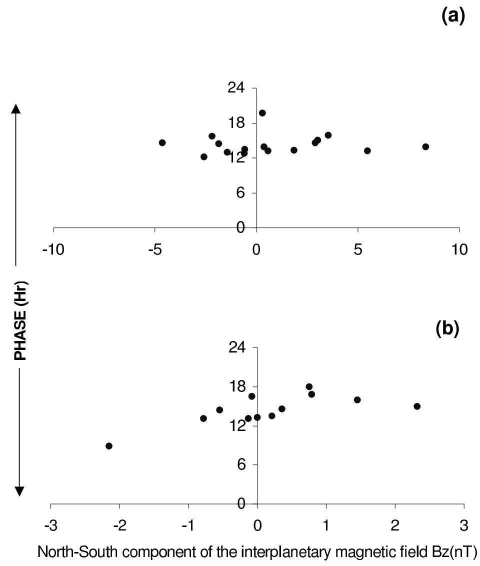

Fig. 2. The phase of the diurnal anisotropy for all the (a) HAE and (b) LAE events with the variation in associated values of Bz during 1991-94.

that the effect of HSSWS on CR intensity is -0.5% per 100km/s in the case of high-speed wind emerging from the coronal holes. An analysis using groups of days with high and low solar wind speeds shows greater amplitude of both the tri-diurnal and semi-diurnal waves for the group of days with high wind speed [10,32]. Agrawal *et al.* [32] suggested that the solar polar coronal holes could influence both semi/tri-diurnal variations.

The dependence of the IMF sense on solar diurnal variation has been studied by many researchers [33]. Annual mean amplitudes of the diurnal anisotropy observed with Deep River NM for 'away' and 'towards' polarity of IMF for the period 1965-93, the amplitude for the 'away' group exceeds that for the 'toward' group for the period 1965-68 and from 1969-73, the amplitude for the 'toward group exceeds that for the away group [34]. At the most northerly viewing latitudes the amplitude of the solar diurnal variations for the toward polarity days is greater than that for the away polarity days (northward pointing gradient) while as the viewing latitudes become more southerly, there are greater and greater years in which the amplitude for the away polarity days is greater than that for the toward polarity days (a predominant southward gradient) [35]. The phases (Hr) of diurnal, semi-diurnal and tri-diurnal anisotropies for HAEs/LAEs with the variations in the associated values of North-South component of the interplanetary magnetic field field B, i.e. Bz (nT) have been plotted in Figs. 2, 3, and 4 during the period 1991-94. It is observed form these Figs. 2a, b that phase of diurnal anisotropy is evenly aligned for both HAE and LAE; whereas, the phase of semi-diurnal anisotropy as depicted if Figs. 3a, b is more aligned for LAE as compared to HAE. It is noteworthy that diurnal time of maximum shifts towards earlier hours as compared to the co-rotational values for most of the HAE/LAE events for both positive and negative polarity of North-South component of the interplanetary magnetic

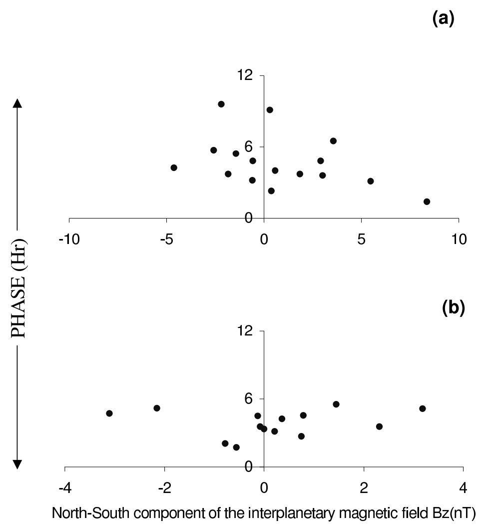

Fig. 3. The phase of the semi-diurnal anisotropy for all the (a) HAE and (b) LAE events with the variation in associated values of Bz during 1991-94.

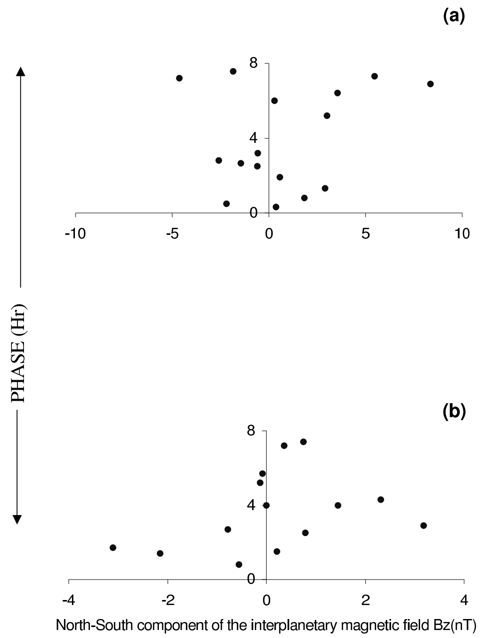

Fig. 4. The phase of the tri-diurnal anisotropy for all the (a) HAE and (b) LAE events with the variation in associated values of Bz during 1991-94.

field Bz (nT); or, it remains in the corotational direction for rest of the events. Further, for tri-diurnal anisotropy as depicted in Figs. 4a, b, the phase is more aligned for HAE as compared to LAE. On the basis of these anisotropic events for all the three harmonics, it is deduced that North-South component of the interplanetary magnetic field Bz (nT) remains lower for LAEs as compared to HAE events, which shows that when Bz attains higher values, the occurrence of HAEs is dominant and when North-South component of the interplanetary magnetic field Bz (nT) attains lower values the occurrence of LAEs is dominant. An enhanced mean amplitude of diurnal anisotropy correlates with positively directed sectors while the amplitude of the diurnal anisotropy seems to decrease during sector boundaries [36]. Kananen *et al.* [37] have found that for positive polarity of IMF the amplitude is high and phase shifts to early hours; whereas, for negative polarity of IMF the amplitude is lower and phase shifts to early hours as compared to corotational value. Sabbah [38] also observed that the days characterized by high IMF magnitude are associated with higher diurnal variation amplitudes as well as higher solar plasma parameters. The North-South component of the interplanetary magnetic field Bz (nT) component of IMF does not usually contribute to the solar modulation of cosmic rays since the long-term average of this component near the Earth is $\sim$0. However, Swinson [39] and Swinson *et al.* [40] have demonstrated that on occasions it can contribute to a field dependent anisotropy especially to the extended trains of enhanced solar diurnal variation observed in 1974. They contend that this enhancement resulted from the constructive interference of the regular solar diurnal variation, By$\times\nabla$Ny streaming. Caballero and Valdes-Galicia [41] noticed the presence of a 38-day fluctu-

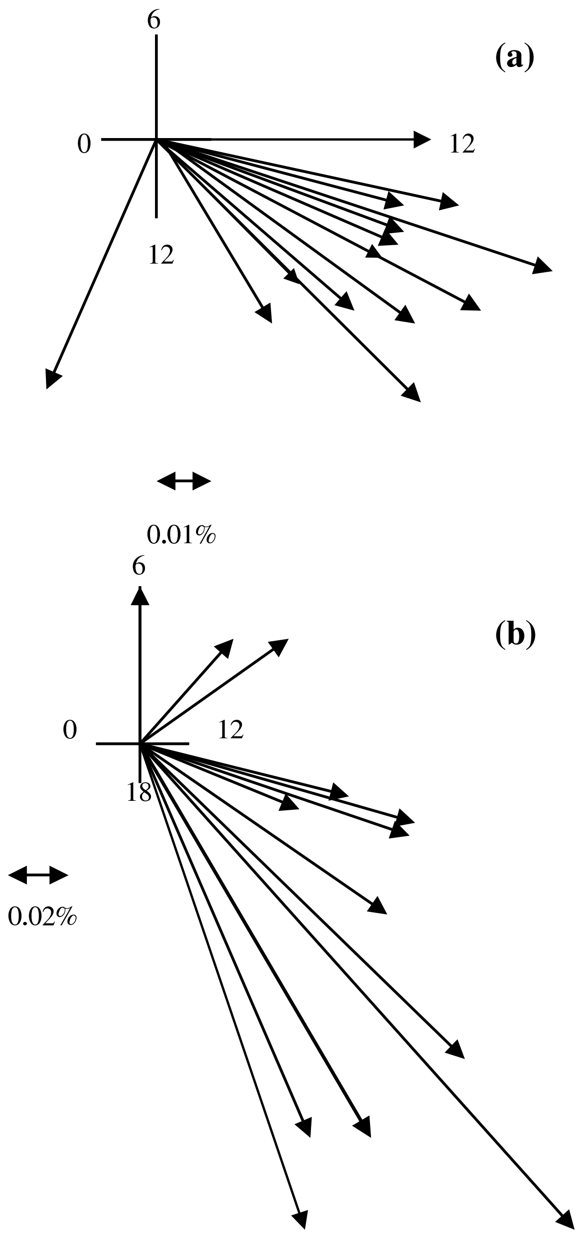

Fig. 5. The amplitude and phase of the diurnal anisotropy of all the (a) HAE and (b) LAE events plotted on harmonic dial during 1991-94.

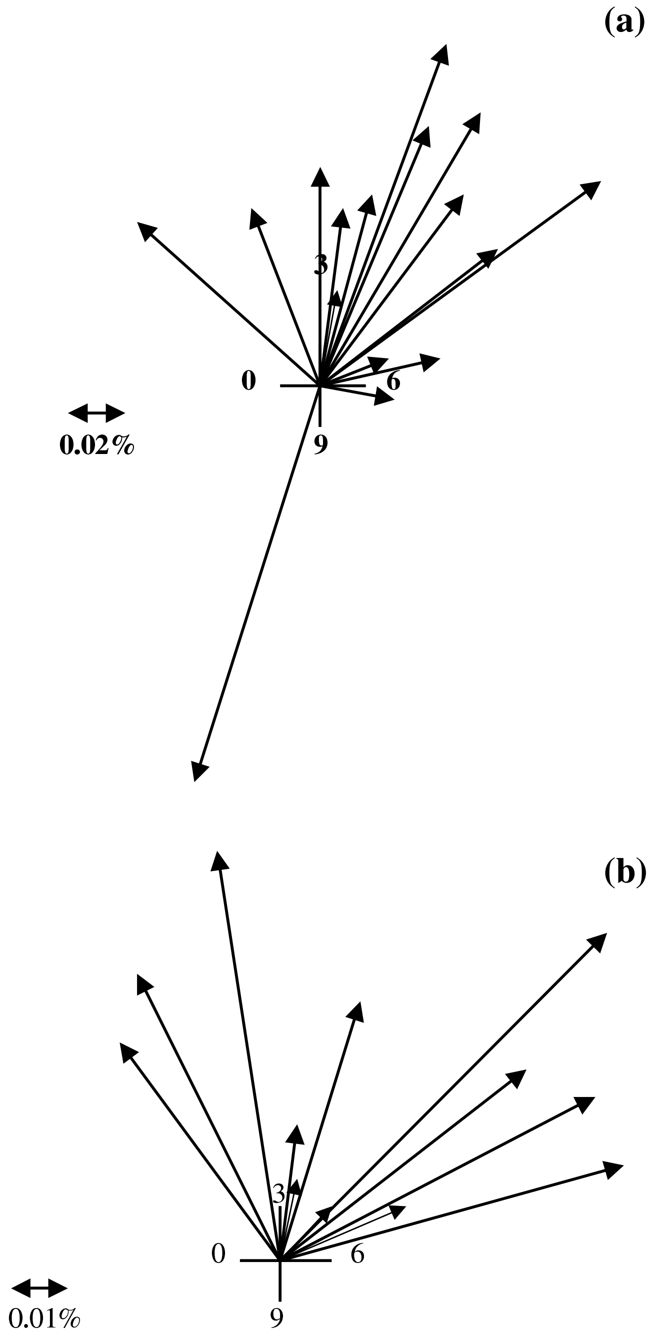

Fig. 6. The amplitude and phase of the semi-diurnal anisotropy of all the (a) HAE and (b) LAE events plotted on harmonic dial during 1991-94.

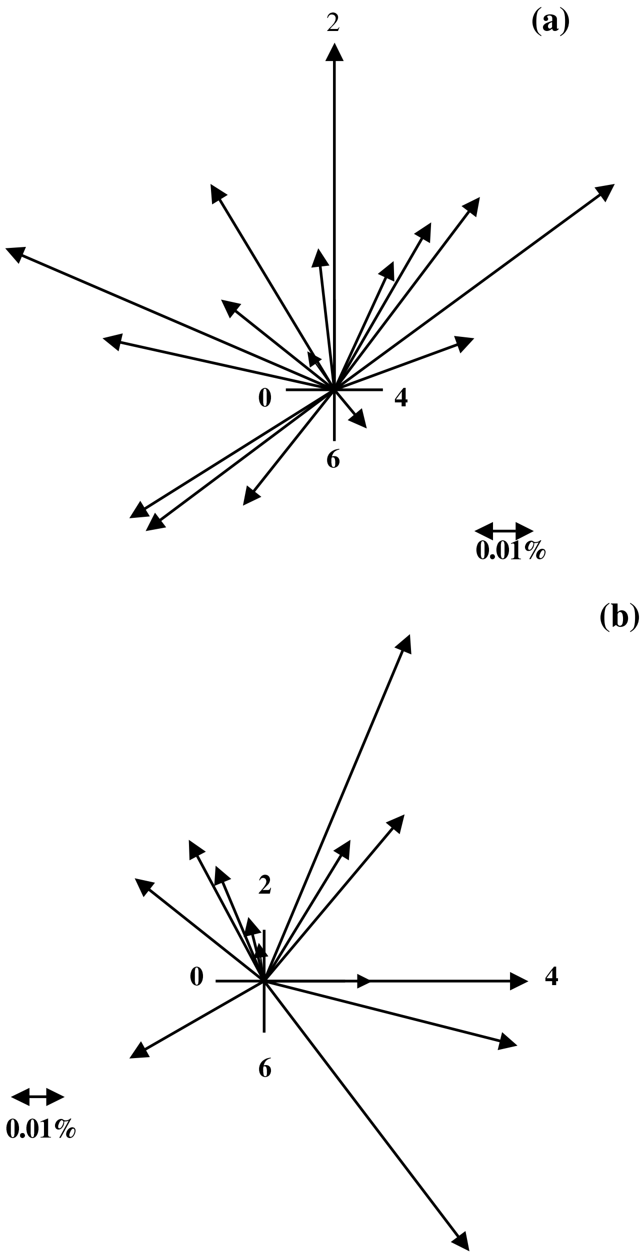

Fig. 7. The amplitude and phase of the tri-diurnal anisotropy of all the (a) HAE and (b) LAE events plotted on harmonic dial during 1991-94.

ation as a stable characteristic for all periods (1990-1999) and parameters (In IMF and in cosmic rays: sunspots, flares, hard X-rays, Bz-IMF, Cr-cosmic rays). This fluctuation does not depend on the cutoff rigidities of the stations or the level of solar activity. This indicates that the 38-day fluctuation is present in the Sun, in the IMF z component and in the cosmic ray intensities. The interaction between interplanetary Alfven waves of solar origin and cosmic rays is most probably the physical mechanism explaining this relation.

The amplitude (%) and phase (Hr) of the diurnal, semi-diurnal and tri-diurnal anisotropies for each HAE/LAE events are plotted graphically on a harmonic dial or clock diagram as a cloud of points having their origin at fixed point in Figs. 5, 6, and 7. As depicted in Figs. 5a, b the phase of the diurnal anisotropy shifts to earlier hours for most of the HAE events as compared to co-rotational value; whereas, the phase of the diurnal anisotropy also has a tendency to shifts towards earlier hour as compared to co-rotational value for most of the LAEs. For semi-diurnal anisotropy, the distribution of phase, as shown in Figs. 6a, b, is quite similar for both HAE/LAE cases. Further, the phase of tri-diurnal anisotropy, as depicted in Figs. 7a, b, is evenly distributed in all the quadrants for HAEs as well as for LAEs.

4 Conclusion

On the basis of present investigations the following conclusions have emerged:

1. High Speed Solar Wind Streams do not play any significant role in causing the HAE/LAE.
2. The phase of diurnal anisotropy shifts towards earlier hours for HAEs as well as for LAEs. For semi-diurnal anisotropy phase remains statistically the same for both HAE/LAE events; while, phase is distributed evenly in case of tri-diurnal anisotropy for both types of events.
3. The diurnal time of maximum for HAE/LAE shifts towards earlier hours or it remains in the corotational/azimuthal direction for both the polarity of North-South component of the interplanetary magnetic field Bz (nT).

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References

[1] G. Subramanian, V. Sarabhai: *Astrophys. J.* **149** (1967) 417
[2] J.J. Quenby, B. Lietti: *Planet. Space Sci.* **16** (1968) 1209
[3] J. Kota: *J. App. A* **8** (1975) 1349
[4] K. Nagashima, H. Ueno, K. Fujimoto, Z. Fujii, I. Kondo: *Rep. Inos. Space Res., Japan* **26** (1972) 1
[5] J.A. Simpson, M. Zhang, S. Bame: *Astrophys. J.* **465** (1996) 69
[6] B. Heber, W. Droge, H. Kunow, R. Muller-Mellin, G. Wibberenz: *Geophys. Res. Lett.* **23** (1996) 1513
[7] H.S. Ahluwalia, M.M. Fikani: *J. Geophys. Res.* **101** (1996) 11075
[8] H.S. Ahluwalia, M.M. Fikani: *J. Geophys. Res.* **101** (1996b) 11087

[9] H.S. Ahluwalia: *15th Int. Cosmic Ray Conf., Plovdiv* **11** (1977) 298
[10] S.P. Agrawal: *J. Geophys. Res.* **86** (1981) 10115
[11] H.S. Ahluwalia, M.M. Fikani: *22nd Int. Cosmic Ray Conf., Ireland* **3** (1991) 461
[12] K. Fujii: *Iono. Space Res., Japan* **25** (1971) 242
[13] H.S. Ahluwalia, M.M. Fikani: *25th Int. Cosmic Ray Conf., Durban* **2** (1997) 125
[14] J.W. Bieber, M.A. Pomerantz: *Geophys. Res. Lett.* **10** (1983) 920
[15] H. Mavromichalaki: *Astrophys. and Space Sci.* **71** (1980a) 101
[16] A.G. Ananth, D. Venkatesan, S. Pillai: *Solar Phys.* **143** (1993) 187
[17] A.G. Ananth, K. Kudela, D. Venkatesan: *Solar Phys.* **159** (1995) 191
[18] Y. Munakata, S. Mori, J.Y. Ryu, S.P. Agrawal, D. Venkatesan: *20th Int. Cosmic Ray Conf., Moscow* **4** (1987) 39
[19] N. Iucci, M. Parisi, M. Storini, G. Villoressi: *17th Int. Cosmic Ray Conf., Paris* **10** (1981) 238
[20] E.N. Parker: *22nd Int. Cosmic Ray Conf., Ireland* **5** (1991) 35
[21] E.O. Flueckiger: *22nd Int. Cosmic Ray Conf., Dublin* **5** (1991) 273
[22] D. Venkatesan, Badruddin: *Space Sci. Rev.* **52** (1990) 121
[23] S. Kumar, R. Agarwal, R. Mishra, S.K. Dubey: *Int. J. Mod. Phys. D* **11** (2002) 1243
[24] S. Kumar, M.L. Chauhan: *Ind. J. Radio & Space Phys.* **25** (1996a) 106
[25] S. Kumar, M.L. Chauhan: *Ind. J. Radio & Space Phys.* **25** (1996b) 232
[26] S. Kumar, M.L. Chauhan, S.K. Dubey: *Solar Phys.* **176** (1997) 403
[27] E.N. Parker: *Interplanetary Dynamical Process-Wiley Inter Science*, NewYork, 1963
[28] K. Kondoh, N. Hasebe, T. Doke, J. Kikuchi, M.N. Kobayashi, J. Medina, J. Sequeiros, T. Takashima, T. Yanagimachi, B. Wilken: *26th Int. Cosmic Ray Conf., Utah* **7** (1999) 179
[29] I. Sabbah, A. Darwish, A. Bishara: *Solar Phys.* **181** (1998) 469
[30] S.P. Duggal, M.A. Pomerantz: *15th Int. Cosmic Ray Conf., Plodiv* **4** (1977) 370
[31] N. Iucci, M. Parisi, M. Storini, G. Villoresi: *Nuovo Cimento* **2C** (1979) 421
[32] S.P. Agrawal, B.L. Mishra, S.P. Pathak, R.S. Yadav, S. Kumar, Badruddin: 17th *Int. Cosmic Ray Conf., Paris* **4** (1981) 119
[33] M. Ichinose, I. Morishita, K. Nagashima: *20th Int. Cosmic Ray Conf., Moscow* **4** (1987) 148
[34] H.S. Ahluwalia: *J. Geophys. Res.* **101** (1996) 13549
[35] A.A. Darwish, M.A. El-Borie, A.A. Bishara: *24th Int. Cosmic Ray Conf., Rome* **1995** (936)
[36] H. Mavromichalaki: *17th Int. Cosmic Ray Conf., Paris* **10** (1981) 183
[37] H. Kananen, H. Komori, P. Tanskanen, J. Oksman: *17th Int. Cosmic Ray Conf. Paris* **10** (1981) 190
[38] I. Sabbah: *J. Geophys. Res.* **101** (1996) 2485
[39] D.B. Swinson: *Bulletin of the American Astronomical Society* **12** (1981) 812
[40] D.B. Swinson, T. Saito, S. Mori: *J. Geophys. Res.* **86** (1981) 8845
[41] R. Caballero, J.F. Valdes-Galicia: *28th Int. Cosmic Ray Conf.* (2001) 3787