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Cosmic Ray Modulation on Geomagnetically Most Quiet Days

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Abstract - The aim of this work is to study the first three harmonics of cosmic ray intensity on geo-magnetically most quiet days over the period 1980-1990 for Deep River and Tokyo neutron monitoring station. The main characteristic of these events is that the amplitude of first harmonic remains high for Deep River having low cutoff rigidity compared to Tokyo neutron monitor having high cutoff rigidity on quiet days. The diurnal amplitude significantly decreases in 1987 at Deep River and in 1986 at Tokyo close to solar activity minimum years. The diurnal time of maximum significantly shift to an earlier time compared to the corotational/1800 Hr direction at both the stations of different cutoff rigidity. The time of maximum for first harmonic significantly shifts towards later hours and for second harmonic it shifts towards an earlier hours at low cutoff rigidity station i.e. Deep River compared to the high cut off rigidity station i.e. Tokyo on quiet days. The amplitude of semi/tri-diurnal anisotropy have a good positive correlation with solar wind velocity, while the others (i.e. amplitude and phase) have no significant correlation on quiet days for Deep River and Tokyo having different cutoff rigidity during 1980-1990. The solar wind velocity significantly remains in the range 350 to 425 km/s i.e. being nearly average on quiet days for two neutron monitoring station of low and high cutoff rigidity threshold. The semi-diurnal amplitude has a significant anti-correlation, whereas the amplitude of third harmonic and direction of first harmonic has a good anti-correlation with IMF Bz and the product V x Bz on quiet days at Deep River station. However, the direction of first harmonic has a significant anti-correlation and the direction of second harmonic has a good anti-correlation with IMF Bz and the product V x Bz on quiet days at Tokyo station.

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Keywords: cosmic ray, quiet days, diurnal, semi-diurnal anisotropy, solar wind, interplanetary magnetic field and geomagnetic activity.

1. Introduction

The anisotropic variations of galactic cosmic rays and their characteristics are studied through the diurnal and semi-diurnal components mainly and the level of the isotropic intensity collectively provides fingerprint for identifying the modulating process and the electromagnetic state of interplanetary space in the neighborhood of the Earth. Many workers have attempted to derive relationship between the mean daily variation and the level of solar and geomagnetic activity [1]. Yearly average values of the first harmonic of solar daily variation experience strong changes from year to year and with the cycle of solar activity. Amplitude and phase of diurnal anisotropy changes with the cycle and phase of solar activity cycle [2-4]. Lockwood and Webber [5] found a close relationship between the magnitude and frequency of Forbush decreases and the eleven-year cosmic ray variation and concluded that the effect of Forbush and other transient decreases is a dominant factor in the long-term cosmic ray intensity modulation.

Forbush [6] showed that annual means of the cosmic ray diurnal anisotropy resulted from the addition of two distinct diurnal components. One, W has its maximum in the asymptotic direction of 128° E of the Sun and is well approximated by a wave W with a period of two solar cycles and the other component V has its maximum in the asymptotic direction 90° E of the Sun. Ahluwalia [7] has reported that diurnal anisotropy is unidirectional during 1957-70 with direction along 18-Hr LT (East-West) and during 1971-79 it consists of two components; one is in the East-West direction and the other is the radial component with direction along 12-Hr LT. Sabbah [8] characterized the diurnal anisotropy by two components. Only one anisotropy is dominant during each magnetic state of the solar cycle. The direction of the dominant anisotropy vector points towards the 18-Hr LT direction during the negative state of the solar cycle and toward earlier hour during the positive state.

Ballif *et al.* [9] correlated geomagnetic activity index (Kp and Ap) with the mean fluctuations in amplitude of interplanetary magnetic field (IMF), which in turn is related to diffusive component of convection-diffusion theory. Ap is also found to related with solar wind velocity, which is related to convective component of convection-diffusion theory. An attempt has been made to study the variation features of diurnal time of maximum and its amplitude on different groups of days selected under different criteria depending on Ap values. Agrawal [10] and Bieber and Evenson [11] have preferred to investigate the daily variation in cosmic ray intensity on long/short term basis performing the analysis for all days (AD) in a year; whereas, Kumar *et al.* [12-13] have studied long/short term daily variation on geomagnetically 60 quiet days (QD). Jadhav *et al.* [14], Kumar *et al.* [15] studied daily variation during days of low and high amplitude anisotropic wave trains. Sabbah [16] calculated the diurnal variation for days with high, intermediate and low IMF magnitude.

2. Analysis of Data

The amplitude and phase of the harmonics of the daily variation in cosmic ray intensity are derived by Fourier analysis [17] by noting the hourly counting rate of the observed cosmic ray intensity over a period of twenty-four hours.

The Fourier analysis yields reliable measures of the amplitude and phase on a day-to-day basis, provided the time series is reasonably stationary. However, this method cannot estimate the amplitude of the ambient anisotropy, which, for small amplitudes, contributes to large uncertainties in the Fourier coefficients.

2.1. Harmonic Analysis

Time dependent harmonic function F (t) with 24 equidistant points in the interval from t = 0 to t = 2π can be expressed in terms of Fourier series

$$F(t) = a_0 + \sum_{n=1}^{24} \left(a_n \cos(nt) + b_n \sin(nt) \right)$$

$$F(t) = a_0 + \sum_{n=1}^{24} r_n \cos(nt - \phi_n) \tag{1}$$

where a_0 is the mean value of F (t) for the time interval from t = 0 to 2π and a_n, b_n are the coefficients of n^{th} harmonics, which can be expressed as follows:

$$a_0 = \frac{1}{12}\sum_{r=1}^{24} r_i$$
$$a_n = \frac{1}{12}\sum_{i=1}^{24} r_i \cos nt$$
$$b_n = \frac{1}{12}\sum_{i=1}^{24} r_i \sin nt \tag{2}$$

The amplitude r_n and phase ϕ_n of the n^{th} harmonic are expressed as

$$r_n = \left(a_n^2 + b_n^2\right)^{1/2}$$
and
$$\phi_n = \tan^{-1}\left[\frac{a_n}{b_n}\right] \tag{3}$$

The daily variation of the cosmic ray intensity can be adequately represented by the superposition of first, second, third and fourth harmonics as follows:

$$F(t) = a_1\cos t + b_1\sin t + a_2\cos 2t + b_2\sin 2t + a_3\cos 3t + b_3\sin 3t + a_4\cos 4t + b_4\sin 4t. \tag{4}$$

2.2. Trend Correction

The daily variation in cosmic ray intensity is not strictly periodic. Thus, if the number to be analysed represents bi-hourly (or hourly) means of cosmic ray intensity, the mean for hour t_0 (0^{th} hour) will not, in general be the same as the mean for hour t_{24} (or 24^{th} hour) this difference on account of secular changes, is allowed for in practice by applying a correction known as trend correction, to each of the terms.

If y_0 is the value of the ordinate at x = 0 (0^{th} hour) and y_{12} is the value of the ordinate at x = 2π (24^{th} hour) then the trend corrected value for any hour is given by the equation

$$\bar{y}_k = y_k \frac{\left(\pm\delta_y \times k\right)}{12} \tag{5}$$

where k = 0, 1, 2, 3, ………..12.

y_k = uncorrected value
$\pm\delta_y$ = secular changes i.e. $\pm\delta_y = y_{12} - y_0$

2.3. Mode of Analysis

The pressure corrected data of Deep River (Vertical cutoff rigidity = 1.02 GV, Geog. Latitude = 46.1°N, Geog. Longitude = 282.5°E) and Tokyo (Vertical cutoff rigidity = 11.61 GV, Geog. Latitude = 35.75°N, Geog. Longitude = 139.72°E) Neutron Monitor (NM) station has been subjected to Fourier analysis for the period 1980-90 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.

2.4. Criteria for selection of 60 Quiet Days

Days on which the transient magnetic variations are regular and smooth are said to be magnetically quiet or calm or Q days. These are the days with low values of Ap and Kp. According to solar geophysical data (SGD) five quietest days in a month thus, 60 Q days in a year are selected. These days are called the International quiet-quiet-days or QQ days. Kumar *et al.* [13,18] have studied long/short term daily variation on geomagnetically 60 QD. The 60 QD are better suited for long/short term studies of daily variation. The distribution of phase and amplitude on 60 QD are more regular and some of the variations are observed more clearly [19].

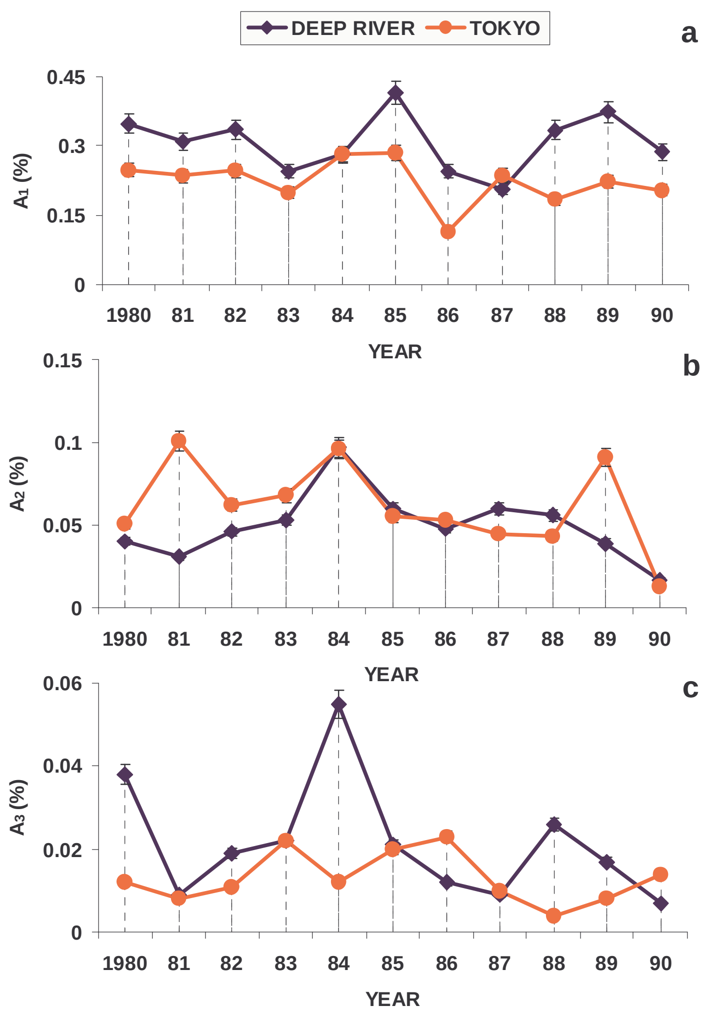

Fig. 1. Average values of the amplitude (%) of first three harmonics of daily variation in cosmic ray intensity along with statistical error bars (I) on 60 QD for Deep River and Tokyo NM stations.

3. Results and Discussion

Annual average values of the amplitude of first three harmonics of daily variation in cosmic ray intensity along with statistical error bars on 60 quiet days has been plotted for two different neutron monitoring stations Deep River with low cut off rigidity (1.02 GV) and Tokyo with high cutoff rigidity (11.61 GV) in Fig1 (a, b, c). One can clearly see from the plot that the amplitude of first harmonic (A_1) remains high for Deep River compared to Tokyo neutron monitor having high cutoff rigidity throughout the period of investigation. The amplitude A_1 found to remain low (~ 0.2%) showing dips during the years 1983 and 1987 and remains high (~ 0.4%) showing peaks during 1985 and 1989 at Deep River. The amplitude A_1 is found to remain statistically constant (~ 0.25%) throughout the period except for the year 1986, where it has significantly low values (~ 0.1%) at Tokyo station. Thus, we observe that the diurnal amplitude A_1 significantly decreases in 1987 at Deep River and in 1986 at Tokyo close to solar activity minimum years.

The semi-diurnal amplitude A_2 as depicted if Fig 1b is found to increase gradually from 1980 and reaches it's maximum (0.1%) during 1984 and then decreases up to 1990 at Deep River. However, A_2 found to remain high (0.1%) during 1981, 1984 and 1989 showing peaks during these years and significantly decrease (0.01%) during 1990 at Tokyo station. It is also found that semi-diurnal amplitude A_2 found to remain same (~0.1%) during 1984 and (~0.01%) during 1990 at both the stations of different cutoff rigidity. The semidiurnal amplitude A_2 is found to anti-correlated for the two stations during the years 1981 and 1989 as amplitude reaches to its maximum for one station and to minimum for the other during the same year.

The tri-diurnal amplitude A_3 as depicted in Fig 1c is found to remain high during 1980 and 1984 showing peaks during these years and remains low (~0.008%) during 1981, 1987 and 1990 showing dips during these years at Deep River. The amplitude A_3 shows its maximum (~0.02%) during the year 1983 and 1986 and minimum (~0.004%) during 1988. It is also found that tri-diurnal amplitude A_3 found to remain same during 1981, 1983, 1985 and 1987 at both the stations of different cutoff rigidity. However, the amplitude A_3 is found to anti-correlated for the two stations during 1984 and 1988 having the maximum for one and minimum for the other station in the same year.

Annual average values of the time of maximum (Hr) of first three harmonics of daily variation in cosmic ray intensity along with statistical error bars on 60 quiet days has been plotted for two different neutron monitoring stations Deep River and Tokyo in Fig 2 (a, b, c). It is clearly seen from Fig 2 that the time of maximum (phase) φ_1 of diurnal anisotropy shift towards an earlier time at Tokyo compared to the phase at Deep River throughout the period of investigation. The time of maximum at both the stations is seems to be positively correlated during the period 1980-88. To further confirm these trends we also calculated the correlation coefficient between these two amplitude and we found a good positive correlation (r = 0.54%) between them during the period 1980-88. However, the phase is found to remain constant at Deep River and decreases sharply at Tokyo during 1988 onwards. It is also noted that the time of maximum φ_1 significantly shift to an earlier time compared to the corotational/1800 Hr direction at both the stations during the entire period.

The time of maximum of semi-diurnal anisotropy φ_2 reaches its maximum (11.40 Hr) during 1986 i.e. close to solar activity minimum and its minimum (05.58 Hr) during 1990 i.e. close to solar activity maximum at Tokyo station. The phase φ_2 is found to remains statistically constant for rest of the period at Tokyo. The phase φ_2 reaches its maximum (~ 06 Hr) during 1980, 1984 and 1989 and its minimum (~03 Hr) during 1982, 1985 and 1988 at Deep River station. It is also noteworthy that time of maximum significantly shift towards an earlier time at Deep River station compared to the time of maximum at Tokyo station throughout the period. It is also observed that the time of maximum φ_2 changes quite frequently from higher to lower values at Deep River throughout the period.

The time of maximum φ_3 of tri-diurnal anisotropy reaches its maximum (08 Hr) on 1983, 1986 showing peaks during these years and its minimum during 1982, 1988 showing dips during these years at Tokyo station. On the other hand the phase φ_3 reaches to its maximum on 1982, 1987-89 showing peaks during these years and its minimum (~ 0.50 Hr) on 1980, 1984 showing dips during these years. As seen from the figure it is also noteworthy that the time of maximum for these two stations is found to significantly anti-correlated throughout the period. To further confirm these trends we have also calculated the correlation coefficient between these two phases and found a significant anti-correlation (r = - 0.73%) between them during the entire period 1980-90.

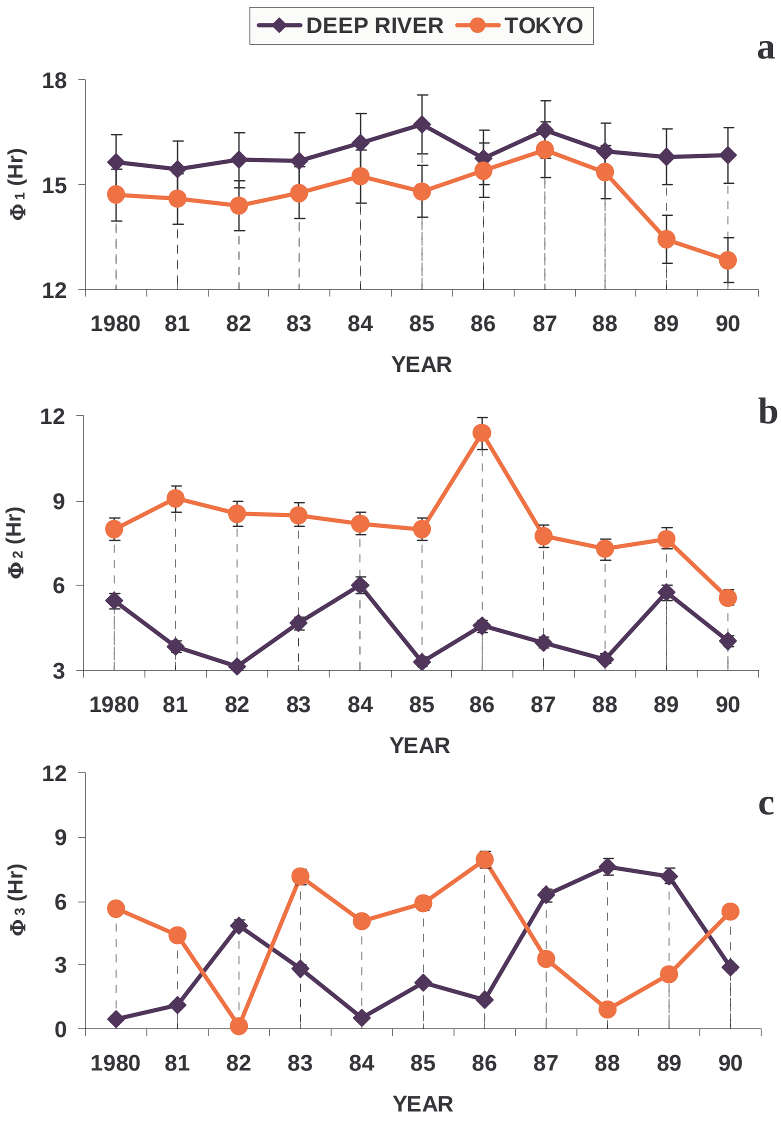

Fig. 2. Average values of the phase (Hr) of first three harmonics of daily variation in cosmic ray intensity along with statistical error bars (I) on 60 QD for Deep River and Tokyo NM stations.

To find out the possible dependence of amplitude and time of maximum on solar wind and IMF, we have plotted the scatter diagram between amplitude/phase and solar wind velocity (V), north south component of IMF (Bz), the product (V x Bz) for the two neutron monitoring stations.

The amplitude (%) and phase (Hr) of cosmic ray diurnal/semi-diurnal/tri-diurnal anisotropy along with the variation in associated value of solar wind velocity (V), correlation coefficient (r) and the regression line (---) is plotted and shown in Fig 3 (a, b, c) for Deep River on quiet days during 1980-90.

The amplitude A_1 of the diurnal anisotropy is found to slightly decrease as the solar wind velocity increases and shows some negative correlation (r = -0.12). The, phase ϕ_1 is found to significantly remain in a direction earlier then co-rotational/18-Hr direction and slightly decreases with the increase of solar wind velocity and shows a weak negative correlation (r= - 0.11) as depicted in Fig 3a. The amplitude A_2 of semi-diurnal anisotropy increases with the increase of solar wind velocity and shows a good positive correlation (r = 0.38). The direction of the semi-diurnal anisotropy ϕ_2 is observed to shifts towards earlier hour with the decrease of solar wind velocity and shows some positive correlation (r = 0.22) as depicted in Fig. 3b. The amplitude A_3 of tri-diurnal anisotropy on quiet days is observed to increase with the increase of solar wind velocity and shows a positive correlation (r = 0.34). The phase ϕ_3 of the tri-diurnal anisotropy does not show significant correlation with V due to large scattering of points and shows a weak negative correlation (r = - 0.19) with V as depicted in Fig 3c. Thus, from the above investigations we may infer that only the amplitude of semi/tri-diurnal anisotropy have a good positive correlation, while the others (i.e. amplitude and phase) have no significant correlation with solar wind velocity on quiet days at Deep River station during 1980-1990. It is also observed from these plots that the solar wind velocity significantly remains in the range 350 to 425 km/s i.e. being nearly average on quiet days.

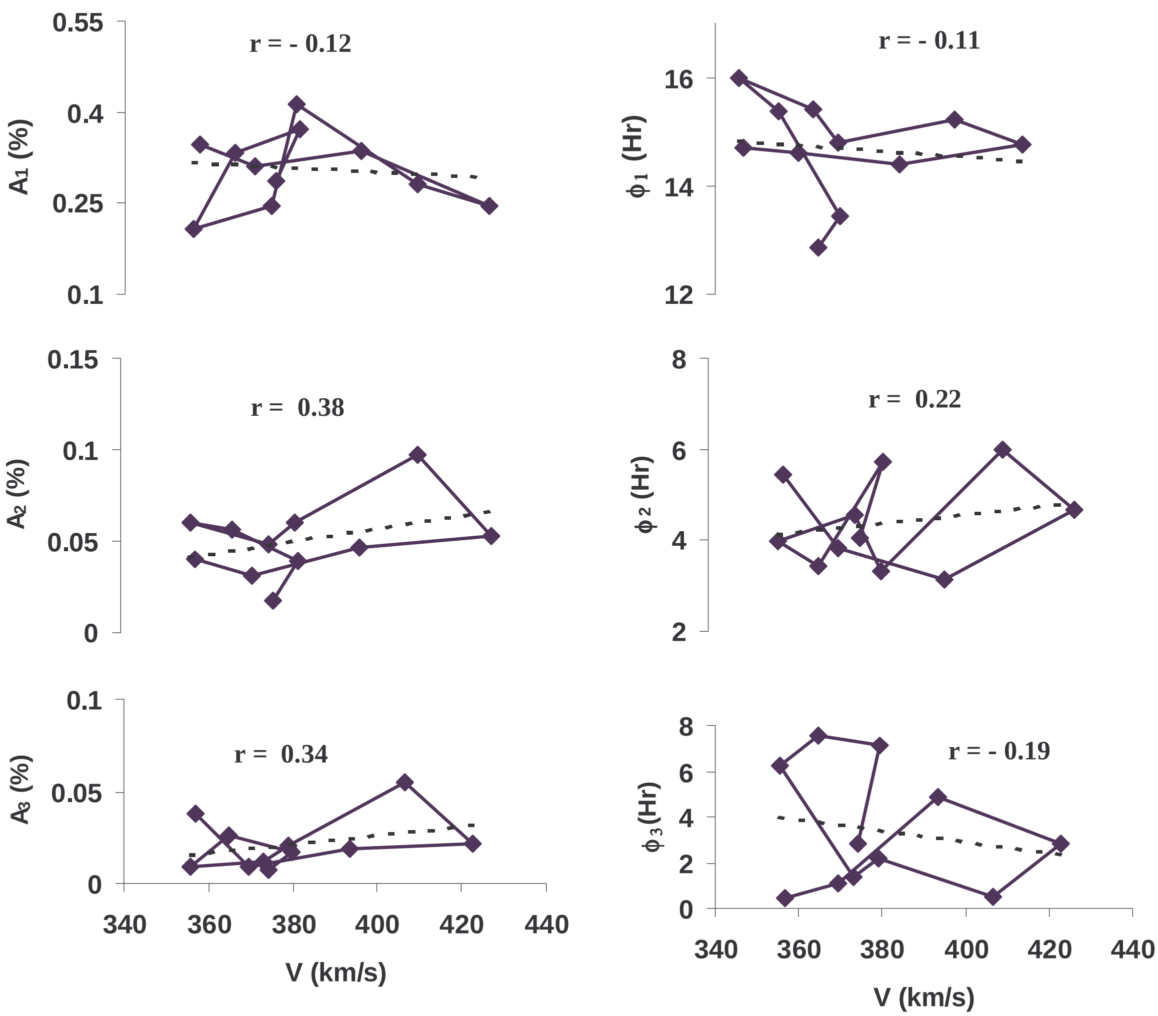

Fig. 3. Amplitude and Phase of the (a) diurnal, (b) semi-diurnal and (c) tri-diurnal anisotropy on quiet days along with solar wind velocity, regression line (---) and correlation coefficient (r) at Deep River station during 1980-1990.

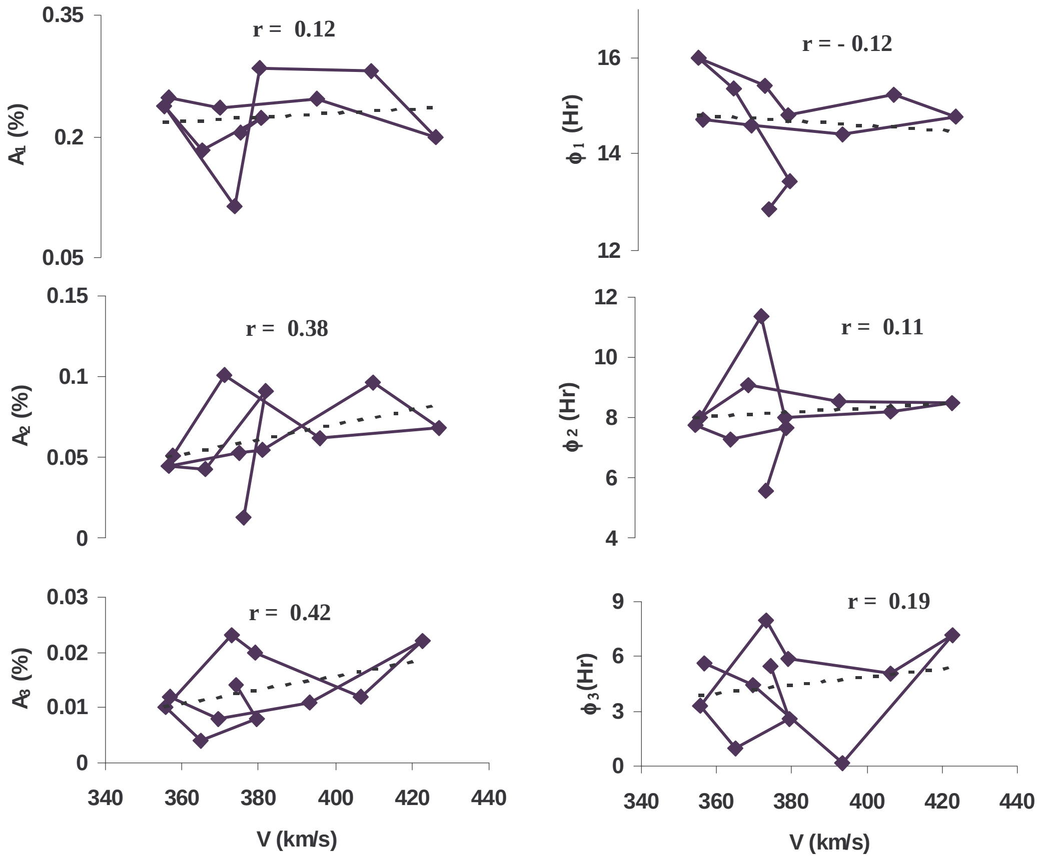

Fig. 4. Amplitude and Phase of the (a) diurnal, (b) semi-diurnal and (c) tri-diurnal anisotropy on quiet days along with solar wind velocity (V), regression line (---) and correlation coefficient (r) at Tokyo station during 1980-1990.

The amplitude (%) and phase (Hr) of cosmic ray diurnal/semi-diurnal/tri-diurnal anisotropy along with the variation in associated value of solar wind velocity (V), correlation coefficient (r) and the regression line (---) is plotted and shown in Fig 4 (a, b, c) for Tokyo on quiet days during 1980-90. As depicted in Fig 4 a the amplitude A_1 of the diurnal anisotropy is found to slightly increase as the solar wind velocity increases and shows some positive correlation (r = 0.12). The phase ϕ_1 is found to significantly remain in a direction earlier then co-rotational/18-Hr direction and slightly decreases with the increase of solar wind velocity and shows a weak negative correlation (r= - 0.12) as depicted in Fig 4a. The amplitude A_2 of semi-diurnal anisotropy increases with the increase of solar wind velocity and shows a good positive correlation (r = 0.38). The direction of the semi-diurnal anisotropy ϕ_2 is observed to shift towards earlier hours with the decrease of solar wind velocity and shows some positive correlation (r= 0.11) as depicted in the Fig. 4b. The amplitude A_3 of tri-diurnal anisotropy on quiet days is observed to increase with the increase of solar wind velocity and shows a good positive correlation (r = 0.42). The phase ϕ_3 of the tri-diurnal anisotropy is found to slightly shift towards earlier hours with the decrease of solar wind velocity and shows a weak positive correlation (r = 0.19) with V as depicted in Fig 4c. Thus, from the above investigations we may infer that only the amplitude of semi/tri-diurnal anisotropy have a good positive correlation, while the others (i.e. amplitude and phase) have no significant correlation with solar wind velocity on quiet days at Tokyo station during 1980-1990. It is also observed from these plots that solar wind velocity significantly remains in the range 350 to 425 km/s i.e. being nearly average on quiet days.

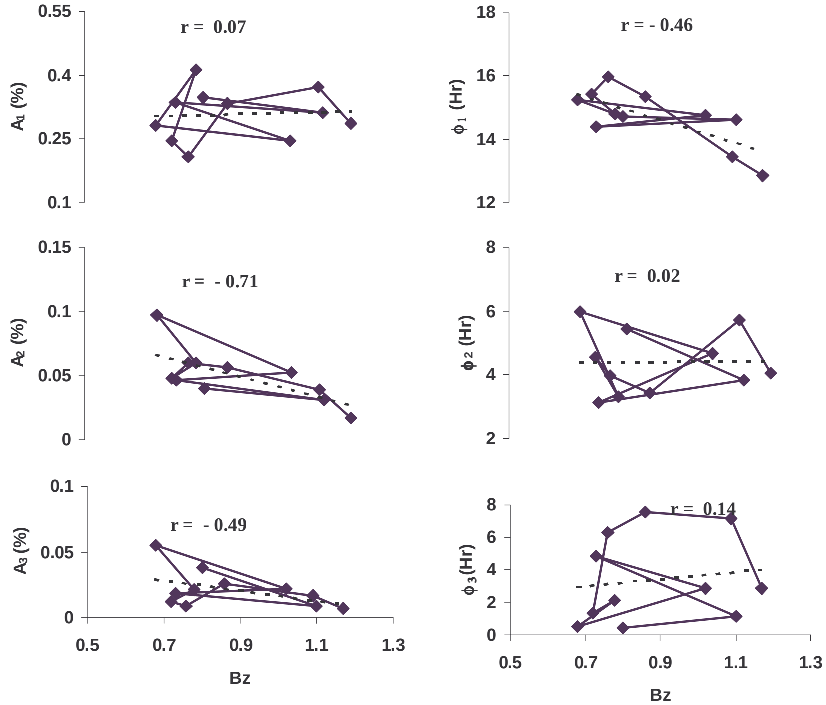

Fig. 5. Amplitude and Phase of the (a) diurnal, (b) semi-diurnal and (c) tri-diurnal anisotropy on quiet days along with north south component of IMF (Bz), regression line (---) and correlation coefficient (r) at Deep River station during 1980-1990.

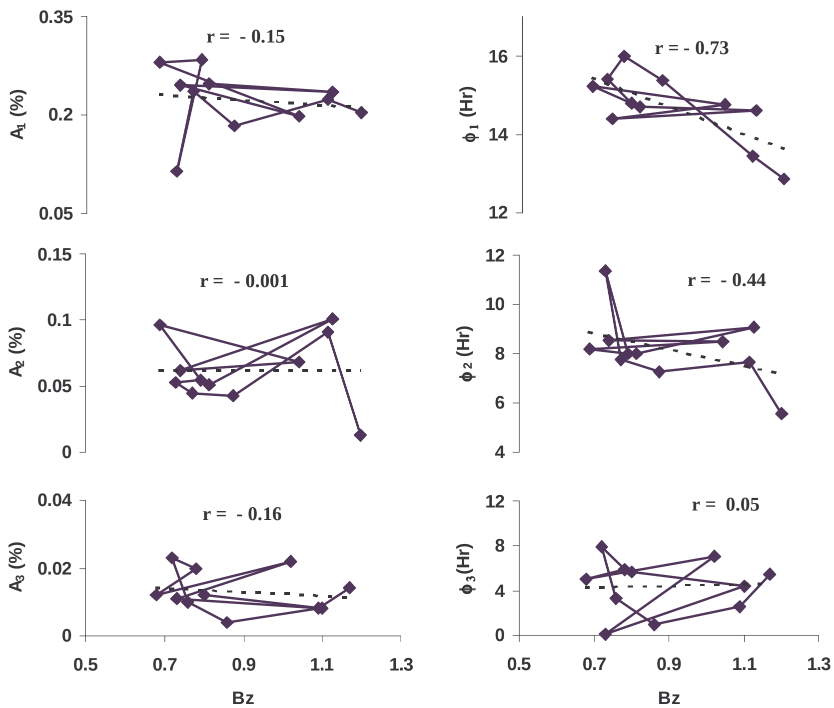

Fig. 6. Amplitude and Phase of the (a) diurnal, (b) semi-diurnal and (c) tri-diurnal anisotropy on quiet days along with north south component of IMF (Bz), regression line (---) and correlation coefficient (r) at Tokyo station during 1980-1990.

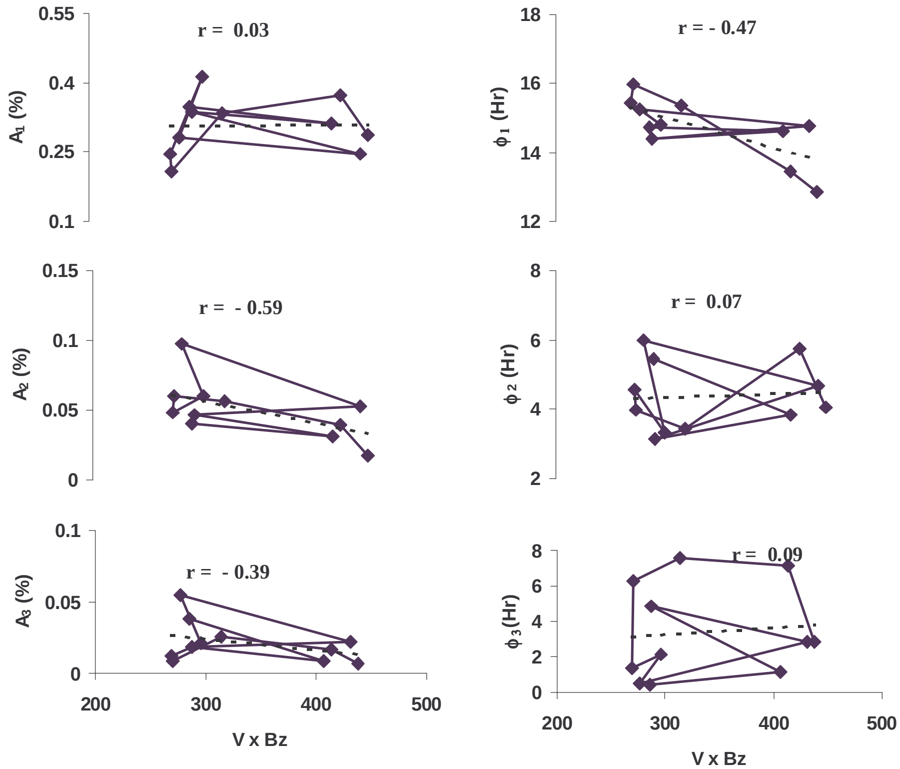

Fig. 7. Amplitude and Phase of the (a) diurnal, (b) semi-diurnal and (c) tri-diurnal anisotropy on quiet days along with V x Bz, regression line (---) and correlation coefficient (r) at Deep River station during 1980-1990.

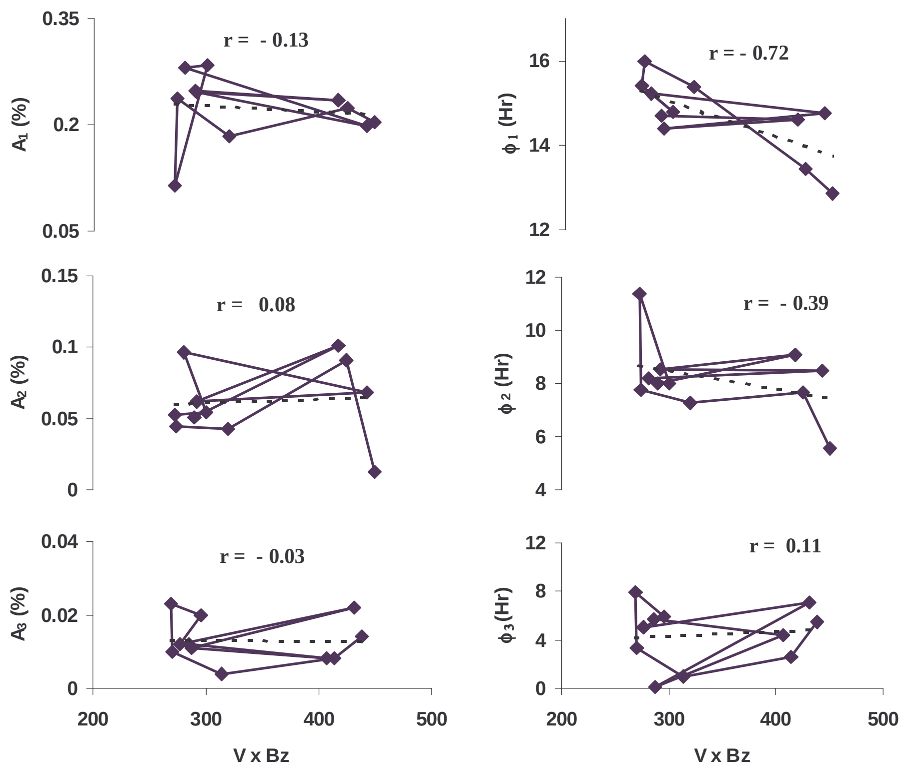

Fig. 8. Amplitude and Phase of the (a) diurnal, (b) semi-diurnal and (c) tri-diurnal anisotropy on quiet days along with V x Bz, regression line (---) and correlation coefficient (r) at Tokyo station during 1980-1990.

We have also plotted the scattered diagram for the amplitude (%) and phase (Hr) of cosmic ray diurnal/semi-diurnal/tri-diurnal anisotropy along with the variation in associated value of north south component of IMF (Bz), the product (V x Bz) in Fig 5-8 and calculated the correlation coefficient (r) between them on quiet days for Deep River and Tokyo stations. We observed that the semi-diurnal amplitude A_2 have a significant anti-correlation with Bz (r = - 0.71) and the product V x Bz (r = - 0.59) at Deep River. The tri-diurnal amplitude A_3 have a good anti-correlation with Bz (r = - 0.49) and the product V x Bz (r = - 0.39) at Deep River. The time of maximum of first harmonic ϕ_1 also shows a good anti-correlation with both Bz (r = - 0.46) and V x Bz (r = - 0.47) at Deep River. The other components (amplitude and phase) do not have a significant correlation with IMF Bz and the product V x Bz.

On the other hand the time of maximum of first harmonic ϕ_1 shows a significant anti-correlation with north south component Bz (r = - 0.73) and the product V x Bz (r = - 0.72) at Tokyo. The time of maximum of second harmonic ϕ_2 also shows a good anti-correlation with north south component Bz (r = - 0.44) and the product V x Bz (r = - 0.39) at Tokyo. While the remaining parameters (i.e. amplitude and phase) does not show any significant characteristics associated with Bz and V x Bz at Tokyo on quiet days. Thus, from the above findings we may infer that the semi-diurnal amplitude have a significant anti-correlation, whereas the amplitude of third harmonic and direction of first harmonic has a good anti-correlation with IMF Bz and the product V x Bz on quiet days at Deep River station. However, the direction of first harmonic has a significant anti-correlation and the direction of second harmonic has a good anti-correlation with IMF Bz and the product V x Bz on quiet days at Tokyo station.

4. Summary and Conclusions

On the basis of above investigations we may summarize as:

1. The amplitude of first harmonic remains high for Deep River having low cutoff rigidity as compared to Tokyo neutron monitor having high cutoff rigidity on quiet days. The diurnal amplitude significantly decreases in 1987 at Deep River and in 1986 at Tokyo close to solar activity minimum years.
2. The diurnal time of maximum significantly shift to an earlier time as compared to the corotational/1800 Hr direction at both the stations of different cutoff rigidity.
3. The time of maximum for first harmonic significantly shifts towards later hours and for second harmonic it shifts towards an earlier hours at low cutoff rigidity station i.e. Deep River as compared to the high cut off rigidity station i.e. Tokyo on quiet days.
4. The amplitude of semi/tri-diurnal anisotropy have a good positive correlation with solar wind velocity, while the others (i.e. amplitude and phase) have no significant correlation on quiet days for Deep River and Tokyo having different cutoff rigidity during 1980-1990.
5. The solar wind velocity significantly remains in the range 350 to 425 km/s i.e. being nearly average on quiet days for two neutron monitoring station of low and high cutoff rigidity threshold.
6. The semi-diurnal amplitude has a significant anti-correlation, whereas the amplitude of third harmonic and direction of first harmonic has a good anti-correlation with IMF Bz and the product V x Bz on quiet days at Deep River station. However, the direction of first harmonic has a significant anti-correlation and the direction of second harmonic has a good anti-correlation with IMF Bz and the product V x Bz on quiet days at Tokyo station.

Further studies can aid in understanding the results reported here and help to exploit this information to constrain models of solar modulation. Studies of correlations between the cosmic ray intensity and IMF/SWP parameter(s) should be useful for identifying the parameter(s) that control the amplitude of the intensity modulation. It will also be of interest to determine how the correlation slopes depend on the time scale over which the data are averaged since the spatial extent of the structures in the heliosphere that control the modulation on short time scales must be smaller than those that produce long term effects.

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References

[1] D. Venkatesan and Badruddin, Space Sci. Rev., **52**, 121 (1990) and references therein.
[2] H. S. Ahluwalia and M. M. Fikani, Proc. 25th Int. Cosmic Ray Conf., Durban, **2,** 125 (1997).
[3] M. A. El-Borie, I. Sabbah, A. Darwish and A. Bishara, Proc. 24th Int. Cosmic Ray Conf., Rome, **4,** 603 (1995).
[4] G. V. Sikripin, V. P. Mamrukova, Izvestia of Russian Academy of Sciences, Ser. Phys., v.57, N7, 51 (1993).
[5] J. A. Lockwood and W. R. Webber, J. Geophys. Res., **89**, 17 (1984).
[6] Schott E. Forbush, J. Geophys. Res., **78**, 7933 (1979).
[7] H. S. Ahluwalia, J. Geophys. Res. Letters, **15**, 287 (1988).
[8] Sabbah, Solar Physics, **181**, 469 (1998).
[9] J. R. Ballif, D. E. Jones and P. J. Coleman, J. Geophys. Res., **74,** 2289 (1969).
[10] S.P. Agrawal, S.P. Pathak, and B.L. Mishra, Proc. 18th Int. Cosmic Ray Conf., Bangalore, **3**, 304 (1983).
[11] J. W. Bieber and Paul Evenson, Proc. 25th Int. Cosmic Ray Conf., Durban, **2**, 81 (1997).
[12] S. Kumar, and R.S. Yadav, 17th Int. Cosmic Ray Conf., Paris, **10**, 242 (1981).
[13] S. Kumar, U. Gulati, D. Khare, M. Tripathi, and M. Sharma, J. Pure & App. Phys., **5**, 12 (1993).
[14] D. K. Jadhav, M. Shrivastava, A. K. Tiwari and P. K. Shrivastava, Proc. 18th Int. Cosmic Ray Conf., Bangalore, **3**, 337 (1983).
[15] S. Kumar, M. L. Chauhan and S. K. Dubey, Solar Physics, **176**, 403 (1997).
[16] I. Sabbah, Solar Phys., **188**, 403 (1999).
[17] S. Chapman, and Bartels, Geomagnetic II, Oxford University Press (1940).
[18] S. Kumar, S.K. Shrivastava, S.K. Dubey, M.K. Richhariya, and U. Gulati, Ind. J. Radio and Space Phys., **27**, 150 (1998).
[19] S. Kumar, Rekha Agarwal, Rajesh Mishra, and S.K. Dubey, Proc. 27th Int. Cosmic Ray Conf., Hamburg, **3**, 3966 (2001).