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Cosmic ray modulation at neutron monitor energies

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The present work deals with the study of the first three harmonics of cosmic ray intensity on geo-magnetically quiet days from 1981 to 1993 for the Deep River and Inuvik neutron monitoring stations having mid and low cutoff rigidity. The amplitude of the first harmonic remains high for Deep River having mid cutoff rigidity as compared to the Inuvik neutron monitor having low cutoff rigidity on quiet days. The diurnal amplitude significantly decreases and phase shifts towards an earlier time during solar activity minimum years at both Deep River and Inuvik. The amplitude of the second harmonic significantly enhanced during solar activity minimum as well as maximum at Deep River and remains low during solar activity maximum at Inuvik, whereas the phase shifts towards an earlier time during solar maximum for both the stations. The amplitude of the third harmonic significantly enhanced during solar activity minimum at Deep River and during solar activity minimum at Inuvik, whereas the phase does not show any significant characteristics and fluctuates quite frequently. The amplitude of semi/tri-diurnal anisotropy has a good positive correlation, while the others (i.e., amplitude and phase) have a very weak correlation with solar wind velocity on quiet days at the Deep River station during 1981—1993. The solar wind velocity significantly remains in the range from 350 to 425 km/s, i.e., it is nearly average on quiet days. The amplitude and direction of the anisotropy on quiet days depend only weakly on high-speed solar wind streams for the two neutron monitoring stations of mid and low cutoff rigidity threshold. The amplitude as well as direction of the second harmonic has a good anti-correlation with interplanetary magnetic field B_z and the product $V \times B_z$ on quiet days at the Deep River station. The direction of the second and third harmonics has a good anti-correlation with interplanetary magnetic field B_z and the product $V \times B_z$ on quiet days at Inuvik station.

INTRODUCTION

Cosmic ray anisotropic variations and their characteristics are studied through the diurnal and semi-diurnal components mainly and the level of the isotropic intensity provides fingerprint for identifying the modulating process and the electromagnetic state of interplanetary space in the neighbourhood of the Earth. Many workers attempted to derived relationship between the mean daily variation and the level of solar and geomagnetic activity [57]. 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 change with solar activity cycles [4, 18, 54]. Lockwood and Webber [36] found a close relationship between the magnitude and frequency of Forbush decreases and the eleven-year cosmic ray variation. They concluded that the effect of Forbush and other transient decreases is the dominant factor in the long-term intensity modulation. Forbush [19] showed that annual means of the CR diurnal anisotropy resulted from the addition of two distinct components. One, *W* has its maximum in an 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 an asymptotic direction of 90° E of the Sun. Ahluwalia [3] reported that diurnal anisotropy is unidirectional during 1957—1970 with the direction along 1800 hr LT (east—west) and during 1971—1979 it consisted of two components; one is in the east—west direction and the other is the radial component with the direction along 1200 hr LT. Sabbah et al. [52] 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 1800 hr LT direction during the negative state of the solar cycle and toward earlier hours during the positive state. Ballif et al. [10] correlated K_p and A_p with the mean fluctuations in amplitude of IMF, which in turn is related to diffusive component of convection-diffusion theory. A_p is also found to be related with solar wind velocity, which is related to the convective component of convection-diffusion theory. Agrawal [2] and Bieber and Evenson [12] preferred to investigate the daily variation in cosmic ray intensity on the long/short term basis performing the analysis for all days in a year; whereas, Kumar et al. [33, 35] have studied long/short term daily variation on geomagnetically 60 quiet days (QD). Jadhav et al. [25] and Kumar et al. [32] studied daily variation during days of low and high amplitude anisotropic wave trains. Sabbah [49] calculated the diurnal variation for days with high, intermediate and low interplanetary magnetic field (IMF) magnitude.

A special type of consecutive days having abnormally high or low amplitudes in the daily variation of cosmic rays was reported several times earlier with an explanation of sources and sinks in anti-garden-hose and garden-hose directions [25, 46, 56]. The existence of anisotropic wave trains of high and low amplitude was 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 [8, 9, 43]. 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 of consecutive days, cannot be explained in co-rotational terms. Moreover, the maximum intensity of diurnal anisotropy has not appeared in a direction of 1800 hr, which is the nominal co-rotational phase [38, 45].

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 was 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 [44]. The average characteristics were found to vary with solar cycle as well, where the variation is much larger at higher energies.

A number of investigators reported the short-term characteristics of the daily variation, where they selected continually occurring days of high and low amplitudes of diurnal variation [1, 55, 56]. These results have pointed out significant departures in the time of maximum as well as their association with higher harmonics.

Many workers [28, 42, 46] used a new concept for the interpretation of the diurnal variation. McCraken et al. [39] first suggested the extension of this new concept from the solar cosmic events to the observed diurnal variation and theoretical formulation was provided by Forman and Gleeson [20]. Several workers have attempted to find the possible origin of the «large amplitude wave trains» of cosmic ray neutron intensity to develop a suitable realistic theoretical model which can explain the diurnal anisotropy on individual days.

Hashim and Thambyahpillai [22] and Rao et al. [46] showed that the enhanced diurnal variation of large amplitude events exhibits a maximum intensity in space around the anti-garden-hose direction (2100 hr) and a minimum intensity in space around the garden-hose direction (0900 hr). Kane [27] and Bussoletti [15] have noticed that quite often an enhanced intensity is presented along the corotational direction and it is not correlated with the garden-hose direction.

The diurnal anisotropy is well understood in terms of a convective-diffusive mechanism [20]. Mavromichalaki [37] 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 was caused by the superposition of convection and field-aligned diffusion due to an enhanced density gradient of 8 % AU^{-}.

Analysis of Data. The amplitude and phase of the harmonics of the daily variation in cosmic ray intensity are derived by Fourier analysis [16], by noting the hourly counting rate of the observed cosmic ray intensity over a period of 24 hr.

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.

Harmonic Analysis. Time dependent harmonic function $F(t)$ with 24 equidistant points in the interval from $t = 0$ to $t = 2\pi$ can be expressed in terms of the Fourier series:

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

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

Here 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; they can be expressed as follows:

$$a_0 = \frac{1}{12}\sum_{n=1}^{24} r_i,$$

$$a_n = \frac{1}{12}\sum_{n=1}^{24} r_i\cos nt,$$

$$b_n = \frac{1}{12}\sum_{n=1}^{24} r_i\sin nt.$$

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

$$r_n = (a_n^2 + b_n^2)^{1/2}$$

and

$$\varphi_n = \tan^{-1}[a_n/b_n].$$

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

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

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 $x = 2\pi$ (24^{th} hour), the trend correction value for any hour is given by the equation

$$\bar{y}_k = y_k \frac{(\pm\delta_y \times k)}{12},$$

where $k = 0, 1, 2, ..., 12$, y_k is uncorrected value, $\pm\delta_y$ denotes secular changes, i. e., $\pm\delta_y = y_{12} - y_0$.

Mode of Analysis. The pressure corrected data of the Deep River (vertical cutoff rigidity = 1.02 GV, geog. latitude = 46.1° N, geog. longitude = 282.5° E) and Inuvik (vertical cutoff rigidity = 0.18 GV, geog. latitude = 68.35° N, geog. longitude = 226.27° E) Neutron Monitor (NM) stations were subjected to the Fourier analysis for the period 1981—1993 after applying the trend correction. While performing the analysis of the data all the days having more than three continuous hourly data missing are discarded.

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 A_p and K_p. According to solar geophysical data (SGD) five quietest days in a month, i. e., 60 Q days in a year are selected. These days are called the International quiet-quiet-days or QQ days. Kumar et al. [33, 34] 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 for 60 QD are more regular and some of the variations are observed more clearly [31].

RESULTS AND DISCUSSION

The study of the anisotropy of galactic cosmic ray intensity is an essential tool as it is expected to carry important information on the origin and the propagation mechanism of the galactic cosmic rays. Numerous studies are concentrated on the diurnal variation of cosmic ray intensity [6, 7, 13, 30, 40].

Annual average values of the amplitude of the first three harmonics of daily variation in cosmic ray intensity along with statistical error bars on 60 quiet days are plotted for two different neutron monitoring stations, Deep River with middle cutoff rigidity (1.02 GV) and Inuvik with low cutoff rigidity (0.18 GV) in Fig. 1, *a—c*. One can clearly see from the plots that the amplitude of the first harmonic (A_1) remains high for Deep River as compared to the Inuvik neutron monitor having low cutoff rigidity throughout the period of investigation except for the year 1991. The amplitude is found to remain low (~ 0.2 %) showing dips during the years 1983, 1987, and 1991, whereas it remains high (~ 0.4 %) showing peaks during 1985 and 1989 at Deep River. The amplitude A_1 remains low (~ 0.2 %) showing dips during 1983, 1986, and 1992, whereas it remains high (~ 0.4 %) showing peaks during 1985 and 1992 at the Inuvik station. Thus the diurnal amplitude A_1 significantly decreases during 1986—1987, i. e., solar activity minimum years at both Deep River and Inuvik. It is also noticed from the shape of the plots that A_1 at both the stations is positively correlated during 1981—1990, whereas they are anti-correlated from 1990 onwards with each other.

The semi-diurnal amplitude A_2 as depicted in Fig. 1, *b* increases gradually from 1981 and reaches its maximum (0.1 %) during 1984 and

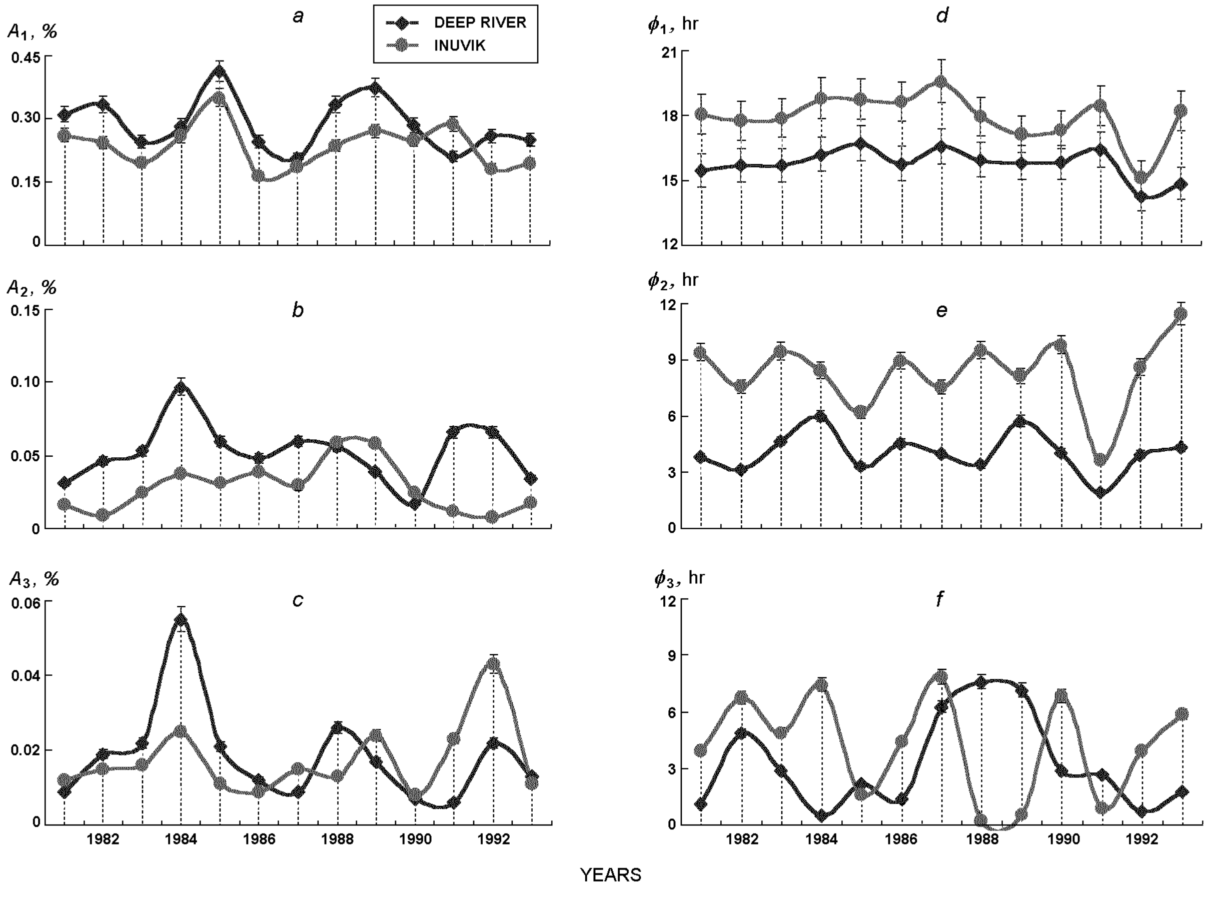

Fig. 1. Average values of the amplitude (*a, b, c*) and phase (*d, e, f*) of first three harmonics of daily variation in cosmic ray intensity along with statistical error bars on 60 QD for the Deep River and Inuvik NM stations

then decreases up to 1990 at Deep River. However A_2 increases gradually from 1982 with some fluctuations and reaches its maximum (0.06 %) during 1988 and then decreases sharply up to 1992 at Inuvik. The semi-diurnal amplitude A_2 significantly enhanced during 1984 (solar activity minimum) and 1991—1992 (solar activity maximum) at Deep River, whereas A_2 significantly remains low during 1991—1992 (solar activity maximum) at Inuvik. The semidiurnal amplitude A_2 is anti-correlated for the two stations during the years 1991—1992 as amplitude reaches its maximum for one station and minimum for the other during the same year.

The tri-diurnal amplitude A_3, as depicted in Fig. 1, *c* increases sharply from 1981 and reaches its first maximum during 1984 at both the stations having different cutoff rigidity. Then it decreases gradually and the second peak occurs in 1988 at Deep River and in 1989 at Inuvik. A_3 decreases sharply from 1988 to 1991 then increases and reaches its third maximum during 1992, whereas at Inuvik A_3 starts increasing from 1990 and reaches its third maximum in 1992. The amplitude A_3 significantly enhanced at Deep River during 1984 (solar activity minimum) and at Inuvik during 1992 (solar activity maximum). It is also noticed from the shape of the plots that the amplitude A_3 is positively correlated with each other for the two stations with different cutoff rigidity during the period of investigation.

Fig. 1, *d—f* gives annual average values of the time of maximum (hr) for the first three harmonics of daily variation in cosmic ray intensity on 60 quiet days along with statistical error bars for two different neutron monitoring stations Deep River and Inuvik. It is clear that the time of maximum (phase) φ_1 of diurnal anisotropy shifts towards an earlier time at Inuvik as compared to the phase at Deep River throughout the period of investigation. The phase φ_1 significantly shifts towards an earlier time during 1992 (solar activity maximum) at both the stations. The time of maximum at both the stations seems to be positively correlated with each other during the entire period. To confirm these trends further we also calculated the correlation coefficient between these two phases and found a significant positive correlation (r = 0.77 %). The phase φ_1 remains along the corotational direction (18 hr) at Inuvik and shifts towards earlier hours as compared to corotational direction at Deep River for the majority of the years.

The time of maximum of semi-diurnal anisotropy φ_2 significantly fluctuates during 1981—1990 and significantly shifts towards an earlier time during 1991 (solar activity maximum) and then shifts towards later hours from 1992 onwards at Inuvik. The phase φ_2 reaches its maximum (~ 06 hr) during 1980 and 1989 and its minimum (~ 02 hr) during 1991 at the Deep River station. It is also noteworthy that the time of maximum significantly shifts towards an earlier time at the Deep River station as compared to the time of maximum at the Inuvik 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 phase φ_2 significantly shifts towards an earlier time during 1991 (solar activity maximum) at both the stations with different cutoff rigidity. The time of maximum at both the stations seems to be positively correlated with each other during the entire period. To obtain a further confirmation these of trends we also calculated the correlation coefficient between these two phases and found a good positive correlation (r = 0.52 %).

The time of maximum φ_3 of tri-diurnal anisotropy reaches its maximum (~ 07 hr) in 1982, 1984, 1987, 1990 showing peaks during these years and its minimum during 1985, 1988—1989, 1991 showing dips during these years at the Inuvik station. Alternatively, the phase φ_3 reaches its maximum in 1982, 1987—1989 showing peaks during these years and it reaches its minimum (~ 0.50 hr) in 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 be positively correlated during 1981—1987 and anti-correlated for the period 1988—1993. To confirm these trends further, we have also calculated the correlation coefficient between these two phases and found a good positive correlation (r = 0.46) for 1981—1987 and a high anti-correlation (r = –0.69) during 1988—1993.

Solar wind and interplanetary magnetic field (IMF) play an important role in controlling the electrodynamics of the heliosphere [18]. Solar wind speed, V, and some 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 cosmic ray and generation of cosmic ray anisotropy in the interplanetary space. The solar wind velocity determines two components of the cosmic ray modulation mechanism: the convection and the adiabatic energy changes. The high velocity solar wind fluxes associated with coronal holes give rise to both isotropic and anisotropic variations in cosmic ray intensity [24, 26]. Changes of the solar wind velocity near the Earth may have not only local but also global character [53, 47]. Kondoh et al. [29] found that the peak solar wind velocity has good anti-correlation with the high-energy galactic cosmic ray intensity. The IMF magnitude and fluctuations are responsible for the depression of cosmic ray intensity during high-speed solar wind events [50]. The IMF magnitude reaches the highest value during declining phase of solar activity [48]. The correlation between cosmic ray intensity and solar wind velocity is statistically significant, especially in the period of the maximum solar activity. The regression coefficients obtained on yearly basis depend on sunspot number and are ~ −0.8 and ~ −0.2 per 100 km/s at the solar maximum and minimum, respectively [21]. The relation of cosmic ray intensity to solar wind velocity is, in general, dependent on physical conditions in the interplanetary space varying with the solar activity. The year-to-year variation of the effect of solar wind upon cosmic ray intensity is dependent on solar activity and the decrement of cosmic ray intensity due to the variation of solar wind velocity is proportional to sunspot number [21].

To find a 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 (B_z), the product ($V \times B_z$) for the two neutron monitoring stations.

Fig. 2, *a*—*c* shows 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) on quiet days and the regression line for Deep River during 1981—1993. The amplitude A_1 slightly decreases as the solar wind velocity increases and shows a very weak negative correlation ($r = -0.04$). The phase φ_1 significantly remains in a direction earlier than co-rotational/18-hr direction and slightly shifts to later time with the increase of solar wind velocity and shows a weak correlation ($r = 0.15$) as depicted in Fig. 2, *a*. The amplitude A_2 of semi-diurnal anisotropy increases with the increase of solar wind velocity and shows a good positive correlation ($r = 0.34$). The direction of the semi-

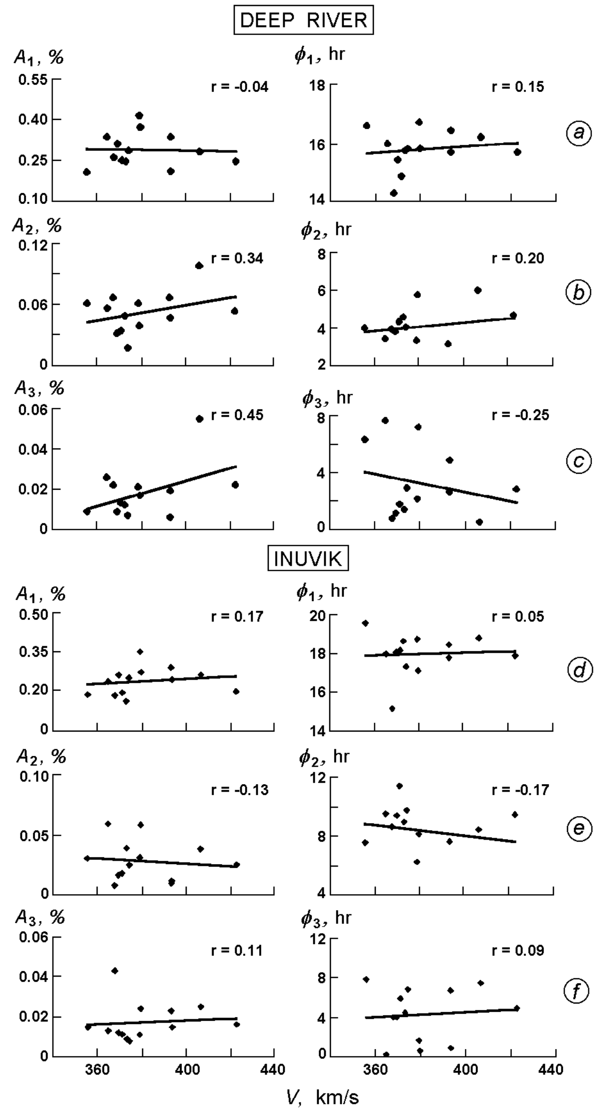

Fig. 2. Amplitude and phase of the diurnal, semi-diurnal and tri-diurnal anisotropy on quiet days along with solar wind velocity, regression line and correlation coefficient *r* during 1981—1993: *a*, *b*, *c* — at the Deep River station; *d*, *e*, *f* — at the Inuvik station

diurnal anisotropy φ_2 is observed to shift towards earlier hours with the decrease of solar wind velocity and shows some positive correlation (r = = 0.20) as depicted in Fig. 2, *b*. The amplitude A_3 of tri-diurnal anisotropy on quiet days is observed to increase with the increase of solar wind velocity and shows positive correlation (r = = 0.45). The phase φ_3 of the tri-diurnal anisotropy shifts towards an earlier time with increase of V and shows some anti-correlation ($r = -0.25$) with V as depicted in Fig 2, *c*. Thus, from the investigations described above we may infer that only the amplitude of semi/tri-diurnal anisotropy have a good positive correlation, while the others (amplitude and phase) have a very weak correlation with solar wind velocity on quiet days at the Deep River station during 1981—1993. It is also observed from these plots that the solar wind velocity significantly remains in the range from 350 to 425 km/s, i.e., being nearly average on quiet days.

Fig. 2, *d—f* gives 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) and the regression line for Inuvik on quiet days during 1981—1993. As depicted in Fig. 2, *d* the amplitude A_1 of the diurnal anisotropy is found to increase slightly as the solar wind velocity increases and shows some positive correlation ($r = 0.17$). The phase φ_1 is found to remain along the co-rotational/18-hr direction and slightly shifts to later time with the increase of solar wind velocity and shows a weak correlation ($r = 0.05$) as depicted in Fig. 2, *d*. The amplitude A_2 of semi-diurnal anisotropy slightly decreases with the increase of solar wind velocity and shows a weak correlation ($r = -0.13$). The direction of the semi-diurnal anisotropy φ_2 is observed to shifts towards earlier hours with the increase of solar wind velocity and shows a weak anti-correlation ($r = -0.17$) as depicted in the Fig. 2, *e*. The amplitude A_3 of tri-diurnal anisotropy on quiet days is observed to increase slightly with the increase of solar wind velocity and shows a weak correlation ($r = 0.11$). The phase φ_3 of the tri-diurnal anisotropy is found to shift slightly towards later hours with the increase of solar wind velocity and shows a weak correlation ($r = 0.09$) with V as depicted in Fig. 2, *f*. Thus from the investigations described above we may infer that neither the amplitude nor the direction of all the three harmonics have any significant trend associated with solar wind velocity on quiet days at the Inuvik station with low cutoff rigidity during 1981—1993. It is also observed from these plots that the solar wind velocity significantly remains in the range from 350 to 425 km/s, i.e., being nearly average on quiet days.

Usually, the velocity of high-speed solar wind streams (HSSWSs) is 700 km/s [41]. Therefore, it may be deduced from these plots that the amplitude as well as direction of the first three harmonics on quiet days do not depend on the HSSWS or by the sources on the Sun responsible for producing the HSSWS such as polar coronal holes (PCH) etc. Thus, we can infer that the amplitude and direction of the anisotropy on quiet days are weakly dependent on HSSWSs for the two neutron monitoring stations of mid and low cutoff rigidity threshold, which is in agreement with earlier findings [41] and significantly contradicts with the earlier results reported by Iucci et al. [23] and Dorman et al. [17] that the solar diurnal amplitude is enhanced during the HSSWSs coming from coronal holes. According to Ahluwalia and Riker [5], 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 [41].

We have also plotted the scattered diagram (plots are not shown here) 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 (B_z), the product ($V{\times}B_z$) and calculated the correlation coefficient between them on quiet days for the Deep River and Inuvik stations. We observed that the semi-diurnal amplitude A_2 have a good anti-correlation with B_z ($r = -0.40$) and the product $V{\times}B_z$ ($r = -0.35$) at Deep River. The time of maximum of the second harmonic φ_2 also shows a good anti-correlation with both B_z ($r = -0.48$) and $V{\times}B_z$ ($r = -0.45$) at Deep River. The other components (amplitude and phase) shows a very weak correlation with B_z and $V{\times}B_z$.

Alternatively, the amplitude of the first harmonic A_1 shows some positive correlation with the north — south component B_z (r = 0.36) and the product $V{\times}B_z$ (r = 0.36) at Inuvik. The time of maximum of the second and third harmonics (φ_2, φ_3) shows a good anti-correlation with the north — south component B_z (r = –0.62, –0.46) and the product $V{\times}B_z$ (r = –0.63, –0.44) at Inuvik, while the remaining parameters (i.e., amplitude and phase) do not show any significant characteristics associated with B_z and $V{\times}B_z$ on quiet days. Thus, from the above findings we may infer that the amplitude as well as direction of the second harmonic have a good anti-correlation with IMF B_z and the product $V{\times}B_z$ on quiet days at the Deep River station. However, the direction of the second and third harmonics has a good anti-correlation with IMF B_z and the product $V{\times}B_z$ on quiet days at the Inuvik station.

Sabbah [49] obtained an inverse correlation between cosmic ray intensity and the geomagnetic activity and observed the enhancement in upper cutoff rigidity, R_c and the geomagnetic activity resulting from variation in the solar plasma parameters. Upper cutoff rigidity correlates well with the product *VB* rather than with magnetic field *B* since *VB* reflects both diffusion by the IMF and convection with solar wind. The product *VB* is more important for cosmic rays and geomagnetic activity modulation rather than IMF alone. The amplitude of 27-day variation of GCR is also linearly correlated with the IMF strength *B*, the *z*-component B_z of the IMF vector and the product *VB* [51]. Burlaga and Ness [14] argued that it is ultimately the strong magnetic field and their associated fluctuations that produce the modulation of cosmic rays. Coupling between the IMF strength *B* and the CR transport parameters leads to a simple modulation model in which the modulation process is linked to global variations of *B*. Belov [11] suggested that the local value of the IMF played a significant role in controlling the GCR modulation at an observing site.

CONCLUSIONS

On the basis of the above investigations the following important conclusions may be drawn:

1. The amplitude of the first harmonic remains high for Deep River having mid cutoff rigidity as compared to the Inuvik neutron monitor having low cutoff rigidity on quiet days. The diurnal amplitude significantly decreases and phase shifts towards an earlier time during solar activity minimum years at both Deep River and Inuvik.

2. The amplitude of the second harmonic significantly enhanced during solar activity minimum as well as maximum at Deep River and remains low during solar activity maximum at Inuvik, whereas the phase shifts towards an earlier time during solar maximum for both the stations.

3. The amplitude of the third harmonic significantly enhanced during solar activity minimum at Deep River and during solar activity minimum at Inuvik, whereas the phase does not show any significant characteristics and fluctuates quite frequently.

4. The amplitude of semi/tri-diurnal anisotropy has a good positive correlation, while the others (i.e., amplitude and phase) have a very weak correlation with solar wind velocity on quiet days at Deep River.

5. The amplitude and direction of the anisotropy on quiet days are weakly dependent on high-speed solar wind streams for two neutron monitoring stations with mid and low cutoff rigidity threshold.

6. The amplitude as well as direction of the second harmonic has a good anti-correlation with IMF B_z and the product $V{\times}B_z$ on quiet days at the Deep River station. However, the direction of the second and third harmonic has a good anti-correlation with IMF B_z and the product $V{\times}B_z$ on quiet days at the Inuvik station.

Additional studies can make a contribution to understanding the results reported here and help to use this information for the elaboration of models of solar modulation. Studies of correlations between the CR intensity and IMF/SWP parameter(s) should be useful for identifying the parameter(s) controlling the amplitude of the intensity modulation. Besides, it is 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 producing long term effects.

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МОДУЛЯЦІЯ КОСМІЧНИХ ПРОМЕНІВ ПРИ ЕНЕРГІЯХ НЕЙТРОННОГО МОНІТОРА

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Розглянуто результати дослідження перших трьох гармонік інтенсивності космічних променів у геомагнетично спокійні дні за період 1981—1993 рр. для станцій нейтронного моніторингу Діп-Рівер та Інувік, котрі характеризуються середньою і низькою граничною жорсткістю. У спокійні дні амплітуда першої гармоніки залишається високою для нейтронного монітора в Діп-Рівер, котрий має середню граничну жорсткість, як порівняти з нейтронним монітором станції Інувік, що характеризується низькою граничною жорсткістю. Для обох нейтронних моніторів у роки мінімуму сонячної активності, добова амплітуда істотно зменшується, а фаза зміщується в бік більш ранніх годин. Амплітуда другої гармоніки значно збільшилася під час мінімуму сонячної активності, так як і під час її максимуму, у випадку станції Діп-Рівер і залишається низькою під час максимуму сонячної активності для монітора станції Інувік. Разом з тим, для обох станцій фаза зміщується в бік більш ранніх годин у період сонячного максимуму. Амплітуда третьої гармоніки суттєво зростає під час мінімуму сонячної активності на станціях Діп-Рівер та Інувік, тоді як фаза не показує ніяких істотних властивостей і коливається з досить високою частотою. Амплітуда півдобової і третинної анізотропії показує чітку позитивну кореляцію, у той час як амплітуда й фаза дуже слабо корелюють зі швидкістю сонячного вітру в спокійні дні на станції Діп-Рівер протягом 1981—1993 рр. Швидкість сонячного вітру головним чином залишається в межах 350—425 км/с, тобто в спокійні дні має приблизно середнє значення. Для обох станцій нейтронного моніторингу із середнім і низьким порогом граничної жорсткості амплітуда й напрям анізотропії в спокійні дні слабо залежать від високошвидкісних потоків сонячного вітру. Амплітуда, як і напрям, другої гармоніки показує чітку антикореляцію з міжпланетним магнітним полем B_z та з добутком $V\times B_z$ у спокійні дні на станції Діп-Рівер. Разом з тим на станції Інувік напрям другої й третьої гармоніки показує чітку антикореляцію з міжпланетним магнітним полем B_z та добутком $V\times B_z$ у спокійні дні.