Modulation of cosmic rays along with 10.7-cm solar radio flux
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Abstract. In this paper an attempt is made to study the occurrence of a large number high amplitude anisotropic wave train events in cosmic ray intensity and to identify a possible correlation with 10.7-cm solar radio flux (solar activity) using the hourly cosmic ray neutron monitor data. The diurnal time of maximum for both high amplitude events as well as for all days is found to significantly shift towards an earlier time as compared to the corotational/azimuthal direction since the year 1991 onward. It is found that diurnal amplitude and 10.7-cm solar radio flux significantly deviates and reaches to its maximum and phase remains in the corotational direction during the years close to solar activity maximum for high amplitude events. The occurrence of high amplitude anisotropic wave train events is dominant during solar activity minimum as well as maximum years. The amplitude as well as phase of the cosmic ray diurnal anisotropy during high amplitude events is well correlated with solar activity. The amplitude as well as phase of diurnal anisotropy shows very nominal correlation with 10.7-cm solar radio flux (r = 0.48, 0.47). However, the frequency of occurrence of high amplitude events shows a very weak correlation (r = -0.36) with 10.7-cm solar radio flux

Keywords: Solar radio flux, cosmic ray, anisotropy

1 Introduction
The ~11-year solar cycle variation in cosmic ray intensity observed at Earth is anti-correlated with solar activity with some time lag. It has been known for a long time that the intensity as well as the energy spectrum of the galactic cosmic rays is modulated by solar activity. It is now well-established fact that there is an inverse correlation between cosmic ray intensity and solar activity [1, 2]. The details of the cosmic ray modulation and variation of time-lag factor are still a matter of great interest. Many researchers have pointed out the anomalous phenomena in the solar modulation of cosmic rays in addition to variation in time lag for the odd and even cycles [3-6]. Earlier, correlative analysis between the cosmic ray intensity and solar activity parameters like sunspot number, grouped solar flares and geomagnetic activity index Ap have been performed for low and medium cut off rigidity stations [7-9].

A number of high amplitude
events have been observed with a significant shift in the diurnal time of maximum to co-rotational direction or later hours [10 and references therein]. Agrawal and Bercovitch [11] have shown that the direction of the 22-year component is perpendicular to the diurnal anisotropy vector and is along the line 162° east of the Sun-Earth line; they have attributed the 11-year component to the variation of cut-off rigidity.

2 Data and 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 1981-94 after applying the trend correction to have the amplitude (%) and phase (hr) of the diurnal anisotropy of cosmic ray intensity for unusually high amplitude events, as well as for all days. The amplitude of the diurnal anisotropy on an annual average basis is found to be □ 0.4%; hence 0.4% has been taken as the reference line in order to select high amplitude events.

3 Discussion

The long term variation of the amplitude (%) and time of maximum (Hr) of diurnal anisotropy for each HAE is plotted for the period 1981-1994 and shown in Fig 1 along with the corresponding 10.7-cm solar radio flux. It can be clearly seen from the figure that the amplitude of the diurnal anisotropy consistently remains constant (~ 0.6%) during 1981-86. The amplitude then increases sharply and reaches to its maximum (1.2%) during the year 1989. However, the 10.7-cm solar radio flux having its first maximum (274) on 1981 decreases sharply from 1981 to 1986 with some fluctuations during 1984. The 10.7-cm solar radio flux start increasing from 1986 (solar activity minimum) and reaches to its second maximum (225) during 1989. The diurnal amplitude and 10.7-cm solar radio flux both start decreasing from 1989 and the diurnal amplitude reaches to its minimum on 1990 and then found to remain statistically constant (~ 0.6%)
onwards. However, the 10.7-cm solar radio flux reaches to its minimum on 1990, then increases sharply and reaches to its third maximum during 1992. It is also evident from the figure that the amplitude distribution shows some peaks corresponding to 10.7-cm solar radio flux maximum during the year 1989-90 close to the solar activity maximum years. Further, we find from the figure that the observed diurnal time of maximum remains in the corotational/azimuthal direction (15.5 Hr) at Deep River station for majority of the events. The direction of the anisotropy observed to shift towards later hours as compared to the corotational/azimuthal (15.5 Hr) direction at Deep River during the year 1989-90 (close to solar activity maximum years) and for one of the event of 1992. Thus, from the above findings we can say that diurnal amplitude and 10.7-cm solar radio flux significantly deviates and reaches to its maximum for majority of the HAE, whereas the phase remains in the corotational direction (15.5 Hr) at Deep River station. This leads us to conclude that the amplitude as well as phase is well correlated with solar activity cycle during high amplitude days.

The frequency distribution of high amplitude anisotropic wave train events for each year is plotted in Fig 3. For comparison purpose, the annual variation in the 10.7-cm solar radio flux indicating the solar activity is also shown in the same figure. The figure clearly illustrates that the distribution of high amplitude days presents a very interesting picture. We observes that the occurrence of high amplitude days is dominant during 1984-85, close to solar activity minimum year and during 1992-93, close to solar activity maximum year showing two peaks during these years. It is noteworthy from the shape of the plot that the occurrence of HAEs is found to anti-correlated with 10-7-cm solar radio flux. These observations are in partial agreement with the results obtained by Kudo and Mori [27] on the 11-year enhancements of diurnal amplitudes. These observations clearly suggest that HAE events do contribute significantly to the long-term variation of amplitude as well as time of maximum of cosmic ray diurnal anisotropy.

To find out a possible dependence of the amplitude, phase and occurrence of HAEs with solar activity, we have plotted (not shown here) the graph of amplitude, phase and frequency of occurrence of HAE as
a function of annual average 10.7-cm solar radio flux along with regression line, R-squared value (The R-squared value, also known as the coefficient of determination, is an indicator that ranges in value from 0 to 1 and reveals how closely the estimated values for the trend line correspond to your actual data. It is clearly observe from the figure that the amplitude slightly increases and phase of diurnal anisotropy shifts towards later with the increase of 10.7-cm solar radio flux and shows very nominal correlation with amplitude (r = 0.48) and phase (r = 0.47). However, it is also noteworthy from the figure that the frequency of occurrence of HAEs seems to slightly decrease with the increase of 10.7-cm solar radio flux and shows a very weak correlation (r = -0.36). Thus, we can say the amplitude as well as phase of diurnal anisotropy shows some dependence on the annual average 10.7-cm solar radio flux during the periods of HAEs, whereas, the occurrence of HAEs do not show any significant correlation with 10.7-cm solar radio flux.

4 Conclusions

The diurnal amplitude as well as 10-7-cm solar radio flux significantly deviates and reaches to its maximum and phase remains in the corotational direction (□15.5 Hr) at Deep River station for majority of the HAE and shift towards later hours during solar activity maximum.

The amplitude of diurnal anisotropy and 10.7-cm solar radio flux significantly enhanced and the phase of the diurnal anisotropy remain in the corotational during solar activity maximum years for HAEs.

The amplitude as well as phase of diurnal anisotropy shows very nominal correlation with 10.7-cm solar radio flux (r = 0.48, 0.47). However, the frequency of occurrence of HAEs shows a very weak correlation (r = -0.36) with 10.7-cm solar radio flux.

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6 References