Modulation of cosmic rays at different cut off rigidity

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ABSTRACT

Propagation of cosmic rays to and inside the heliosphere, encounter an outward moving solar wind with cyclic magnetic field fluctuation and turbulence, causing convection and diffusion in the heliosphere. Cosmic ray counts from the ground ground-based neutron monitors at different cut of rigidity show intensity changes, which are anti-correlated with sunspot numbers. They also lose energy as they propagate towards the Earth and experience various types of modulations due to different solar activity indices. In this work, we study the first three harmonics of cosmic ray intensity on geo-magnetically quiet days over the period 1965-2012 for Beijing, Moscow and Tokyo neutron monitoring stations located at different cut off rigidity. The amplitude of first harmonic remains high for low cutoff rigidity as compared to high cutoff rigidity on quiet days. The diurnal amplitude significantly decreases during solar activity minimum years. The diurnal time of maximum significantly shifts to an earlier time as compared to the corotational direction having different cutoff rigidities. The time of maximum for first harmonic significantly shifts towards later hours and for second harmonic it shifts towards earlier hours at low cutoff rigidity station as compared to the high cut off rigidity station on quiet days. The amplitude of second/third harmonics shows a good positive correlation with solar wind velocity, while the others (i.e. amplitude and phase) have no significant correlation on quiet days. The amplitude and direction of the anisotropy on quiet days does not show any significant dependence on high-speed solar wind streams for these neutron monitoring stations of different cutoff rigidity threshold.
Keywords: cosmic ray, cut off rigidity, quiet days, harmonics, amplitude, phase.

Introduction

Earlier studies attempted to derive relationship between the mean daily variation and the level of solar and geomagnetic activity [1]. Annual 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 is changes with the solar activity cycles [2, 3, 4]. Lock-wood and Webber [5] 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 a dominant factor in the long-term intensity modulation. Forbush [6] showed that annual means of the CR diurnal anisotropy resulted from the addition of two distinct components. One, W has its maximum in the asymptotic direction of 128º 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 90º E of the Sun. Ahluwalia [7] has reported that diurnal anisotropy is unidirectional during 1957-70 with direction along 1800 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 1200 Hr LT. Sabbah [8] character-ized the diurnal anisotropy by two components. Only single anisotropy is dominant during each magnetic state of the solar cycle. The direction of the dominant anisotropy vector points towards the 1800 Hr LT corotational direction during the negative state of the solar cycle and toward earlier hours during the positive state. Ballif et al. [9] correlated Kp and Ap with the mean fluctuations in amplitude of 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 the convective component of convection-diffusion theory. Agrawal [10] and Bieber and Evenson [11] have preferred to in-vestigate the daily variation in cosmic ray intensity on long/short term basis performing the analysis for all days in a year; whereas, Kumar et al. [12, 13] have studied long/short term daily variation on geomagnetically 60 quiet days (QD).

Data Analysis

The pressure corrected data of Beijing, Moscow and Tokyo neutron monitoring stations located at different cut off rigidity has been subjected to Fourier analysis for the period 1965-2012 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.

Results and Discussion

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 the finger prints for identifying the modulation process and electromagnetic state of the interplanetary space in the neighbourhood of the Earth. Many workers have attempted to derive relationship between the main daily variation and the level of solar and geomagnetic activity. The spatial anisotropy of the galactic cosmic ray intensity in the interplanetary space manifests itself as daily variation with a period of 24 hours (and its higher harmonics) due to the rotation of the earth in course of a day. The power spectrum analysis as well as the Fourier analysis of the long term data of 24-hour values of cosmic ray intensity observed by Earth based detectors have provided confirmatory existence along with the characteristics of the first three harmonics of daily variation of extra terrestrial origin.

Annual average values of the amplitude and phase of first three harmonics of daily variation in cosmic ray intensity along with statistical error bars on 60 quiet days has been plotted for three different neutron monitoring stations, Beijing, Moscow and Tokyo neutron monitoring stations located at different cut off rigidity.

It is observed from the plots (shown elsewhere) that the amplitude of first harmonic (A1) remains high for Beijing and Moscow as compared to Tokyo neutron monitor having high cutoff rigidity throughout the period of investigation.

The diurnal amplitude A1 significantly decreases in 1987 at Beijing and Moscow and in 1986 at Tokyo close to solar activity minimum years. The semidiurnal amplitude A2 is anti-correlated for the three stations during the years 1981 and 1989 as amplitude reaches to its maxi-mum for one station and to minimum for the other during the same year. The amplitude A3 is found to be anti-correlated for these stations during 1984 and 1988 having the maximum for one and minimum for the other station in the same year. The diurnal time of maximum at these stations seems to be positively correlated with each other during the period 1980-88. The semi-diurnal phase shifts towards an earlier time at Beijing and Moscow stations as compared to the time of maximum at Tokyo station throughout the period.

We have also plotted the scattered diagram (plots shown elsewhere) for the amplitude (%) and phase (Hr) of cosmic ray diurnal/semi-diurnal/tri-diurnal anisotropy alongwith the variation in associated value of north south component of IMF (Bz), the product (V x Bz) and calculated the correlation coefficient between them on quiet days for Beijing, Moscow and Tokyo stations. We observed that the semi-diurnal amplitude A2 have a significant anti-correlation with Bz (r = - 0.79) and the product V x B (r = - 0.69) at Beijing and Moscow. The tri-diurnal amplitude A3 have a good anti-correlation with Bz (r = - 0.49) and the product V x Bz (r = - 0.39) at Beijing and Moscow. The time of maximum of first harmonic also shows a good anti-correlation with both Bz (r = - 0.46) and V x Bz (r = - 0.57) at Beijing and Moscow. The other components (amplitude and phase does not have a significant correlation with Bz and V X Bz.

Conclusion

1. The first harmonic is significantly shifts to an earlier time as compared to the corotational/1800 Hr direction at all these stations of different cutoff rigidity.
2. The amplitude of second harmonic 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 Beijing and Moscow station.
3. 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. The amplitude of second/third harmonics shows a good positive correlation with solar wind velocity, while the others (i.e. amplitude and phase) have no significant correlation on quiet days. The amplitude and direction of the anisotropy on quiet days does not show any significant dependence on high-speed solar wind streams for these neutron monitoring stations of different cutoff rigidity threshold.

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