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Effect of solar heliospheric parameters and geomagnetic activity on long-term cosmic ray anisotropy

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Deep River neutron monitor, solar and geomagnetic activities data have been used to study the first harmonic (during quiet days) of the variations of galactic cosmic rays connected with the rotation of the Sun. The period comprises the three solar cycles 20, 21 and 22. The evolution of the most significant periodicities and comparisons with solar activity indicators are presented. The amplitude remains significantly constant; whereas the direction of the diurnal anisotropy found to shifts towards earlier hours or towards corotational direction on quiet days. The compound approach to study the long-term modulation of cosmic ray diurnal anisotropy introduced here is found to be remarkably successful. It is noticed that the product of solar wind velocity (V_{QD}) and the z component (Bz_{QD}) of the IMF vector (V_{QD} x Bz_{QD}) found to remain low during solar activity minimum and high during solar activity maximum.

1. Introduction

It is known from a long time that cosmic ray intensity and their energy spectrum are modulated by solar activity cycle from one to another. Cosmic ray modulation is a complex phenomenon, which occurs all over the heliosphere and depends on several factors. Usoskin et al. [1] performed a correlative study of sunspot numbers and cosmic ray intensity for four solar cycles. Their analyses of the running cross correlation between the monthly series showed that the two cycles 21 and 22 coincided with each other. The amplitudes of the spherical harmonics of the source surface magnetic field were successfully used by Mikhajlutsa [2] and Nagashima et. al. [3] to simulate long-term modulation of cosmic rays.

Many authors have used the sunspot number or/and the flare activity in order to simulate the cosmic-ray intensity from the solar activity [4, 5]. An attempt was made to find out the most suitable index of the solar activity in order to reproduce to a certain degree the modulation of the cosmic ray intensity [6]. The contribution of more than one solar, interplanetary or geophysical parameter to the cosmic ray modulation process as solar flares, sunspot number, proton events, geomagnetic index etc. have also been reported [7]. Thus to examine the pattern of cosmic ray modulation with respect to the most suitable solar, interplanetary and geophysical parameters we can investigate the characteristic phenomena of the solar activity during a solar cycle.

2. Data and analysis

Pressure corrected data of Deep River neutron-monitoring (NM) station (cutoff rigidity 1.02 GV; latitude 46.1º N; longitude 282.5º E; altitude 145 M) has been Fourier analyzed after applying trend corrections to obtain the first harmonic at ground for the period 1964-95. According to solar geophysical data five quietest days are selected in a month; thus 60 quietest days in a year. These are called International Quiet Quiet days or QQ days. The study of diurnal variation has been performed on 60 QQ for the period

1964-95. The days with extraordinarily large amplitude, if any, have not been taken into consideration. Also all those days are discarded having more than three continuous hourly data missing. The data related with interplanetary magnetic field (IMF) and solar wind plasma (SWP) parameters for each corresponding quiet days have also studied in the present analysis.

3. Experimental Results and Discussion

To investigate the cosmic ray diurnal variation during 1964-95 the following parameters were studied: the cosmic ray intensity registered by Deep River neutron monitor, sunspot number (Rz_{QD}), geomagnetic activity index (Ap_{QD}), and the heliospheric and interplanetary medium parameters: solar wind velocity (V_{QD}), z component (Bz_{QD}) of the IMF vector and product of solar wind velocity (V_{QD}) and the z component (Bz_{QD}) of the IMF vector (V_{QD} x Bz_{QD}) during quite days. The amplitude (%) and time of maximum (Hr) along with the interplanetary and solar wind parameters during quiet days has been plotted in Figure 1.

We see from the top panels (a & b) of Figure 1 that the amplitude of the diurnal anisotropy on quiet days remaining almost statistically constant during the entire period of investigation i.e. 1964-1995. The time of maximum of quiet day diurnal anisotropy gradually shifts towards earlier hours till 1976 and then towards corotational/1800 Hr direction till 1991. Again it started shifting towards earlier hours. The time of maximum remains to its minimum (1200 Hr direction) during 1976 and 1995; whereas the sunspot numbers are found to be minimum during 1964, 1976, 1985 and 1995. Thus the sunspot shows the ~11-year periodicity; whereas the diurnal cycle shows the ~22-year periodicity. As depicted in the Figure 1 the solar wind velocity does not seems to affect either the amplitude or the time of maximum of the diurnal anisotropy on quiet days.

In general there is a correlation between the long-term variations of Ap and the observed GCR modulation [8, 9 and references therein]. In an earlier analysis [10] it was noted that a subsidiary maximum appears in the annual mean solar diurnal anisotropy data, "when (the solar wind bulk velocity) V>470 km/s or when B has large values. It is shown that Ap is most responsive to the changes in the fine structure of B [11]; this point has been emphasized also by Lockwood et al. [12]. The geomagnetic activity index (Ap) has found to its lowest during 1964 and has its highest during 1982-1984. The amplitude and time of maximum doesn't seem to be affected in context with the Ap-index. However, the solar wind velocity seems to have good correlation with Ap-index. The geomagnetic activity index (Ap) found to remain low during the years when solar wind velocity also remains low; whereas Ap-index found to remain high during the years when solar wind velocity also remains high.

The product (V x Bz) has significantly remains low during the year 1964-65 and also has the minimum during 1971, 1976, which are the periods of minimum solar activity. The product (V x Bz) has its maximum during 1991, which is the period of maximum solar activity. Sabbah [13] analyze the cosmic ray data as well as interplanetary magnetic field data. They observed that the IMF magnitude B and the product of the solar wind speed (V) times B (VB) display separate solar cycle variation during cycles 21 and 22. The values of B and VB are enhanced right after solar activity maximum in 1979 and1989. The cosmic ray amplitudes are also enhanced during the same time as well. The Bz component of the IMF is also related to the variation in cosmic ray amplitude, it reaches the highest value right after solar activity maximum in 1989.

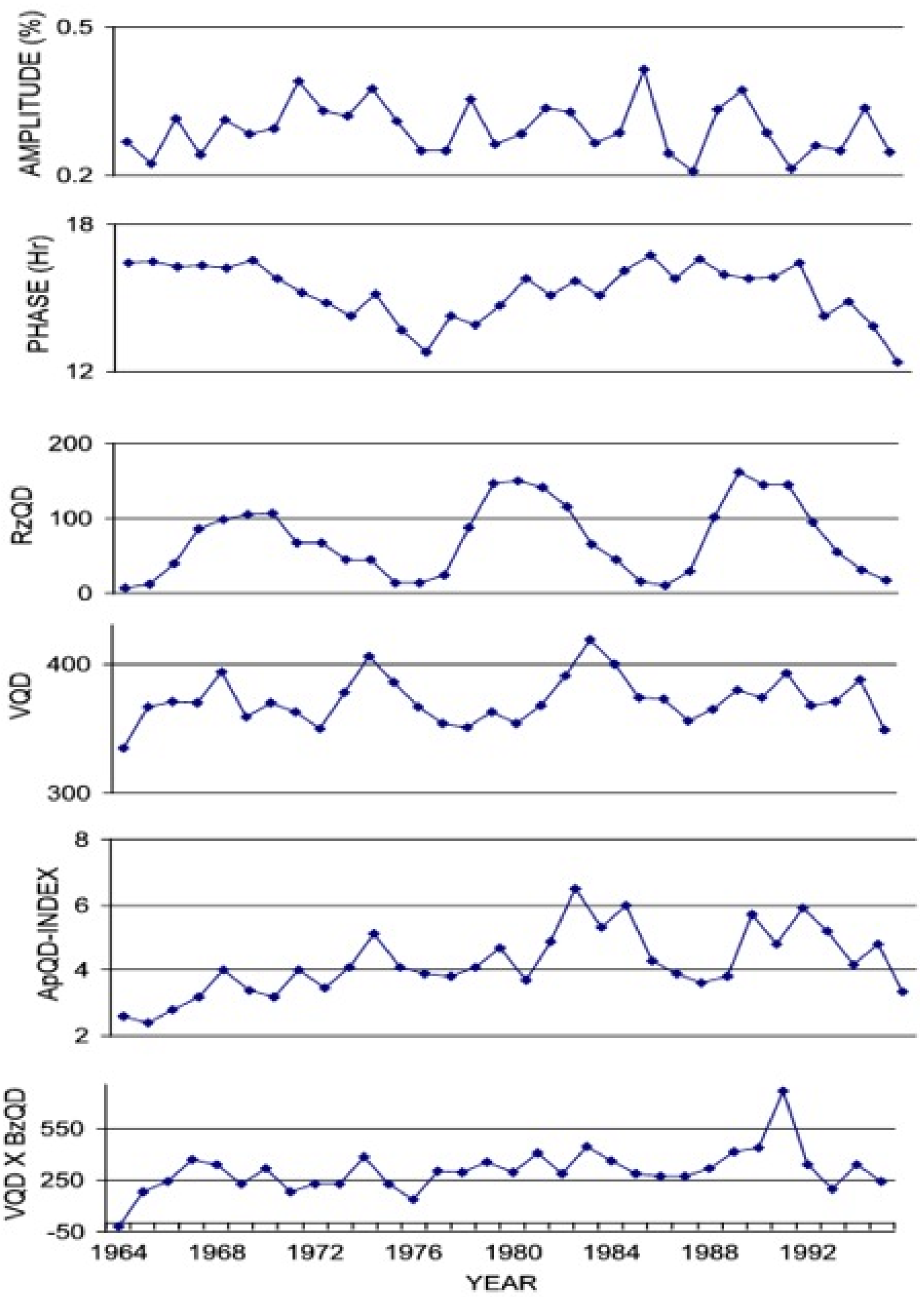

Figure 1: The long-term variation of cosmic-ray diurnal anisotropy amplitude (%) and the time of maximum (hr) during quiet days is shown as a function of solar cycle represented by sunspot number (Rz_{QD}), solar wind velocity (V_{QD}), geomagnetic activity index (Ap_{QD}) and the product of solar wind velocity (V_{QD}) and the z component (Bz_{QD}) of the IMF vector (V_{QD} x Bz_{QD}) for the period 1964-1995.

4. Conclusion

- ❋ The amplitude of the diurnal anisotropy significantly remains constant on quiet days during all the three solar cycle 20, 21 and 22.
- ❋ The direction of the diurnal anisotropy found to shifts towards earlier hours or towards corotational direction on quiet days.
- ❋ The solar wind velocity has a positive correlation with geomagnetic activity index (Ap_{QD}).
- ❋ The product of solar wind velocity and the southwards component of interplanetary magnetic field (V_{QD} x Bz_{QD}) found to remain low during solar activity minimum and high during solar activity maximum.

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