

# Cosmic Ray Daily Variation on Anomalous Days

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**Abstract-** The Characteristics of the daily variation of cosmic ray intensity on different types of anomalous days have been studied by using data of Neutron Monitors. It is observed that Cosmic Ray intensity remains statistically low during the period of 1996-1998 on both Beijing and Moscow Neutron Monitor stations. These data are subjected to Harmonic Analysis and Fourier Techniques for entire period of consideration that is 1996-2006. The amplitude and phase of diurnal and semidiurnal anisotropies on these stations particularly on Anomalous days have been discussed. The occurrence of these events are dominated during solar activity minimum years. The number of days of occurrence is more anti-correlated with solar cycle.

**Keywords:** anomalous cosmic rays, solar poloidal magnetic field, daily variation.

## 1. Introduction

Cosmic ray daily variation (diurnal, semi-diurnal and tri-diurnal) arise from spatial anisotropies in interplanetary space. Ground-based detectors record these once every day as their asymptotic cone of acceptance sweeps through the direction containing the spatial anisotropy, co-rotational direction. The asymptotic cone of acceptance of a detector is the solid angle that contains all the asymptotic direction of approach of particles of various energies, which make a significant contribution to the counting rate of the detector. In addition to the diurnal component, the daily variation is composed of at least two more contribution of lesser amplitudes, i.e., semi-diurnal and tri-diurnal components.

The solar diurnal variation of the cosmic ray intensity is interpreted initially on the basis of an outward radial convection and an inward diffusion along the IMF. The balance between the convection and diffusion generates an energy independent anisotropic flow of cosmic ray particles from the 18-hour co-rotational direction.

The continuous outward flow of solar wind and frozen-in magnetic field produces time variations in cosmic ray intensity of different periodicities, viz. 22 years, 11 years, 27 days and 24 hours. The systematic study of the time variation of relativistic cosmic rays started some 60 years ago by using the ground based detectors. The ground based observations, its anisotropies and their relationship with other geomagnetic and interplanetary parameters, provide the basis to understand the time variation characteristics of cosmic ray intensity.



[1]. In their study of diurnal anisotropy on day to day concluded that on an average basis the diurnal anisotropy of cosmic radiation is completely understood as a superposition of simple convection and field aligned diffusion. Cosmic ray intensity observed on the ground is subject to the solar semi-diurnal variation of extraterrestrial origin. The variation is due to the second order anisotropy produced by the diffusion-convection of cosmic rays in interplanetary space. [2, 3] Studies of the solar semi-diurnal variation have been made by [4, 5] to obtain information about solar modulation in various conditions of the heliosphere. [6, 7] have investigated the existence of the tri-diurnal variation i.e., the third harmonic of the daily variation in the recorded cosmic ray intensity. The results of power spectrum and harmonic analysis for different worldwide cosmic ray station have showed that the observed tri-diurnal variations are of extraterrestrial origin and arises from an ecliptic plane anisotropy in free space.

Solar diurnal variation of cosmic ray intensity shows a large day-to-day variability. This variability is a reflection of the continually changing conditions in interplanetary space [8]. The average diurnal anisotropy of cosmic radiation being explained in terms of azimuthal corotation [9]. The systematic and significant deviations of amplitude as well as phase for diurnal/semi-diurnal anisotropies from the average values are known to occur in association with strong geomagnetic activity [10]. The distinguishing features of these systematic deviations are the unusually low or high amplitude and usually, through not always, a shift in the phase towards earlier hours [11].

The average characteristics of cosmic ray diurnal anisotropy are adequately explained by co-rotational concept. [12, 13]. This concept supports means diurnal amplitude in space of 0.4% along the 1800 Hr direction using the worldwide neutron monitor data. Though, the day-to-day deviation both in amplitudes and phase and the abnormally large amplitudes or abnormally low amplitudes of consecutive days cannot be explained in co-rotational terms. Many scientists [14] and [16] used a new concept for the interpretation of the diurnal variation. [17] first suggested the extension of this new concept from the solar cosmic events to the observed diurnal variation and the theoretical formulation is provided by [18]. On the basis of this mechanism, the diurnal variation can be explained in terms of radial convection together with diffusion, which is mainly along the magnetic field line. The co-rotational concept is a special case of the convective-diffusive model with which we can explain the characteristics of the diurnal variation even on a day-to-day basis. The phase shift of the diurnal anisotropy to earlier hours is well understood in terms of the convective-diffusive mechanism [15, 16] have noted that the non-field-aligned diffusion on the days of nominal diurnal amplitude which are influenced by magnetic sector passages.

## 2. Data Sources and analysis

The anisotropic events are identified using the hourly plots of cosmic ray intensity recorded at ground based Deep River neutron monitoring station (data from <http://spidr.ngdc.noaa.gov/NeutronMonitor>).

In earlier studies on cosmic rays variation, it has been reported that the tri-diurnal amplitude generally decreases by a factor of 4 to 5 from the semi-diurnal amplitude. The signal-to-noise ratio is generally found to be poor even on annual average basis. [19, 20] have reported the detailed characteristics of tri-diurnal anisotropy of cosmic ray intensity for the period 1973-1975 and 1976-1980, respectively. They have reported a positive correlation between semi-diurnal and tri-diurnal amplitudes. Their results suggest that solar polar coronal holes may influence both the solar tri-diurnal and semi-diurnal variation of galactic cosmic ray intensity. [21] have reported a significant relationship of first two harmonics of cosmic ray daily variation with solar activity. They found a significant and positive correlation of diurnal amplitude and phase with sunspot numbers is also reported for semi-diurnal phase. Recently, [22] have reported the long-term trend of the first three harmonics of the daily variation of cosmic ray intensity for the period 1991-2004, using the Haleakala neutron monitor data. They have reported the 11-year cycle trend in diurnal and semi-diurnal component but did not find any long-term variational trend in tri-diurnal component. [23] reported the long-term behaviour of the diurnal wave of cosmic ray anisotropy in relation with interplanetary magnetic field. Long-term characteristics of cosmic ray diurnal variation are also reported in recent

publications. In the present analysis, the amplitude and phase have been derived first on daily basis and then on average basis, for the Beijing and Moscow neutron monitors covering different cutoff rigidities.

The 11-year (1996-2006) harmonic analysis alongwith the geographic co-ordinates of the two stations are given in Table-1.

The first station Beijing and second Moscow station are at some different latitude. These two stations consist of high and low cutoff rigidities, which respond to different energy range of cosmic ray particles.

### 3. Result

In recent years a new component in low energy cosmic rays (1-30 MeV/amu) is discovered in the vicinity of Earth and at distances upto 18 B.U. [24, 25]. The component has anomalous He, N, O, Ne abundances, that are quite different from solar and galactic cosmic rays. The IMP 7 and 8, Pioneer 10 and 11 and Voyager 1 and 2 Spacecrafts have provided new and interesting information on the competition, time variation, radial and perpendicular gradient of this component. Pioneer 10 was at 20 A.U. in mid 1979 and travelling at the rate of 3 A.U. per year is likely to reach close to the hemisphere boundary at 50 A.U. by about this new component.

The origin of these particles is not definitely known at present. Several attempts have been made to explain its origin [26]. The model of [27] have some attractive features which could partly account for the composition of the anomalous component. However, recent result show very large time variation of this component and the intensity reached very low value in early 1979 as discussed in details the long-term modulation of the anomalous component and they pointed

out that hemispheric model of [27] cannot account for the long-term variation observed recently and these variation can be easily understood from the stellar model of [25] they interpret the modulation as occurring due to the polarity reversal of the polar magnetic field of the Sun, one such reversal having occurred in the period of 1969-71. This interpretation is based on the hypothesis that when polar magnetic field of the Sun is nearly parallel to galactic magnetic field, they both could easily connect with each other are hence the low energy galactic rays could penetrate more easily into the hemispheric along the magnetic lines of force, as compared with those in the antiparallel state of the magnetic field. This leads to a 22 year variation in cosmic ray intensity because polarity reversal occurs around every solar maximum. These authors point out the sudden appearance of the anomalous component in 1972 and its absence in 1975 could be easily understood by the hypothesis of [25] as a polarity reversal. Further, these authors point out the observation presented by the Chicago group that the anomalous component have abnormally large density gradient perpendicular to the solar equatorial plane can also be understood by the stellar origin model of [25].

The model by Fisk, Koslovsky and Ramaty (hereinafter FK and R) Predicts that there should be ACR contributions to species that are mainly or partially neutral in the interstellar medium. The observed abundance of He, C, O, Ne and Ar generally consistent with this picture and provide a means of measuring the composition of the natural interstellar medium For example, that low abundance of carbon in ACRs implies that only ~1% of the carbon in the interstellar medium is in a neutral state. The model of FK and R also predicts that ACRs should be singly charged, in contrast to galactic cosmic ray, which are essentially fully stripped and there is now abundant evidence that the bulk of ARCs with ~10 MeV/nuc are singly charged [28].

As pioneer 10 and 11 and later voyager 1 and 2, begin to explore that outer solar system they

Table 1: 11- year cosmic ray daily variation

Stations	Geographic Latitude (Deg.)	Geographic Longitude (Deg.)	Cutoff rigidity, (GV)
Beijing	40	116	9.56
Moscow	55	37	2.42

found that the intensity of ACRs increased with distance from the Sun, and the distribution of ACRs in the hemisphere has now been measured out of 60 AU, and to latitudes as high as  $80^{\circ}$ . Ulysses has recently measured the abundances of the “pick-up” ions that are the seed population for ACR acceleration. It is now believed that the bulk of ACR acceleration takes place at the solar wind termination shock estimate to be at a distance of ~80 to 100 AU from the Sun. Because the access of low energy cosmic rays to inner solar system is strongly affected by interplanetary condition (“Solar modulation”), ACRs are detectable at 1AU only near solar minimum.

Figure.1 Shows plot of annual mean diurnal amplitude and phase of Beijing and Moscow neutron for the period 1996-2006. Most of the values are statistical as shown in Figure. The amplitude of cosmic ray daily variation are invariant in different time scale. The values of amplitude are found much larger during 2002-2006. **RDVV, Jabalpur.**

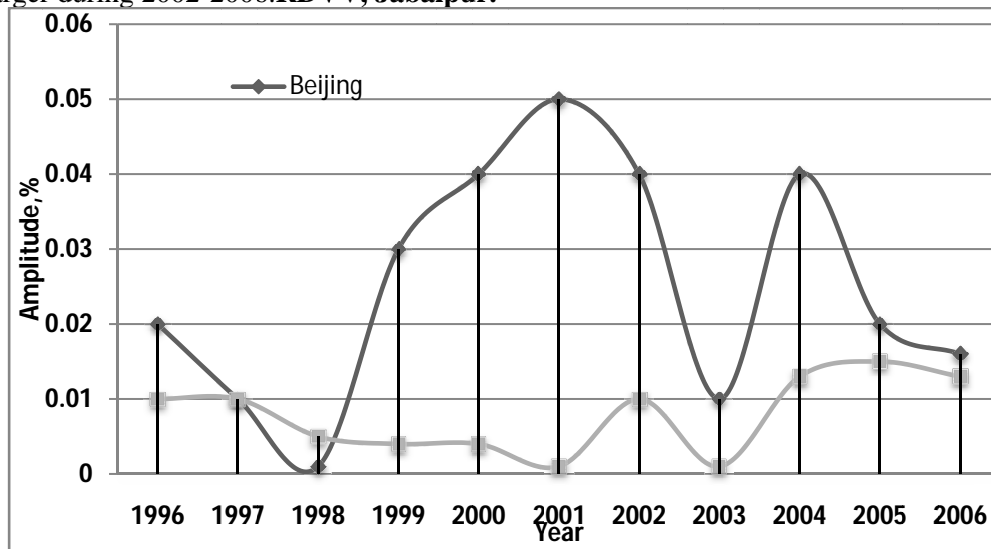


Figure. 1 — Amplitudes (%) for the annual average diurnal variation for Moscow and Beijing neutron monitors.

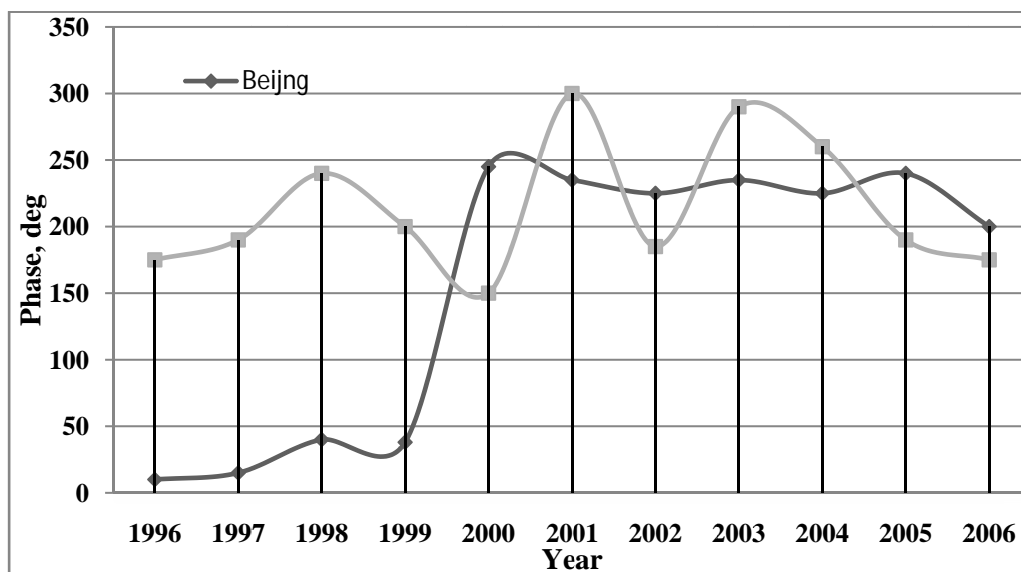


Figure 2 – Phases (degree) for the annual average diurnal variation for Moscow and Beijing neutron monitors

Change in phases is larger from year to year. Linear plots for Moscow and Beijing station for phases(in degree)are shown in Figure. 2. **RDVV, Jabalpur.**

The station Beijing and Moscow are situated in different latitudes. These station consist of low and high cutoff rigidities which respond to different energy ranges of cosmic ray particles.

#### 4. Conclusion

On the basis of the present investigation the following conclusions have emerged.

- The amplitude significantly deviates from the annual average value of diurnal anisotropy. The time of maximum of the diurnal anisotropy has shifted toward earlier hours for the low amplitude anisotropic wave events.
- The long-term behaviour of the amplitude of the diurnal anisotropy can be explained in term of the occurrence of low amplitude events.
- The occurrence of low amplitude anisotropy wave train events is dominant during solar activity minimum years.
- The amplitude of the diurnal anisotropy is correlated with the solar cycle but the direction of the anisotropy is not correlated with the solar cycle and shows a systemic shift to earlier hours.
- The long-term behaviour of the time of maximum of the diurnal anisotropy vectors could be explained in term of co-rotational (1800 Hr) component and 1200 Hr component.
- The anisotropy does not show any long-term variation.

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