ICRC'07 Mérida, México

Semi-diurnal variation of cosmic ray intensity and solar activity on low amplitude days

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Abstract: A detailed study has been conducted on the long-term changes in the semi-diurnal anisotropy of cosmic rays using the ground based Deep River neutron monitor data during significantly low amplitude anisotropic wave train events (LAEs) in cosmic ray intensity for the period 1981-94. It has been observed that the phase of the semi-diurnal anisotropy for majority of the LAE events significantly shifts towards later hours as compared to the annual average anisotropy direction. The long-term behaviour of the amplitude of the semi-diurnal anisotropy can be explained in terms of the occurrence of LAE events. The occurrence of LAE is dominant during solar activity minimum years. The amplitude of the semi-diurnal anisotropy is correlated with the solar cycle but the direction of the anisotropy is not correlated with the solar cycle and shows a systematic shift to later hours.

Introduction

The diurnal variation of the cosmic ray intensity was interpreted initially on the basis of an outward radial convection and an inward diffusion along the interplanetary magnetic field (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. Ananth et al. [1] on 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 many authors [4, 5] to obtain information about solar modulation in various conditions of the heliosphere. Mori et al. [6] and Nagashima et al. [7] have investigated the existence of the tri-diurnal variation i.e., the third harmonic of daily variation in the recorded cosmic ray intensity. The results of power spectrum and harmonic analysis for different worldwide cosmic ray stations showed that the observed tri-diurnal variations are of extraterrestrial origin and arises from ecliptic plane anisotropy in free space.

Solar diurnal variation of cosmic ray (CR) intensity shows a large day-to-day variability[1]. This variability is a reflection of the continually changing conditions in the interplanetary space [8]. The average diurnal anisotropy of cosmic radiation is being explained in terms of azimuthal co-rotation [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, though not always, a shift in the phase towards earlier hours [11].

The average characteristics of cosmic ray diurnal anisotropy are adequately explained by the co-rotational concept [12, 13]. This concept supports mean 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 amplitude and phase and the abnormally large amplitudes or abnormally low amplitudes of consecutive days cannot be explained in co-rotational terms. Many scientists [14 - 16] used a new concept for the interpretation of the diurnal variation. McCraken et al. [17] first suggested the extension of this new concept from the solar cosmic events to the observed diurnal variation and the theoretical formulation was provided by Forman and Gleeson [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]. Owens and Kash [16] have noted that the non-field-aligned diffusion on the days of nominal diurnal amplitude which are influenced by magnetic sector passages.

Ananth et al. [19] examined the occurrence of a large number of high and low amplitude cosmic ray diurnal wave trains during the two solar cycles (20 and 21) over the years 1965-1990 as a function of solar activity. They concluded that the low amplitude days show an inverse correlation with solar activity and have a time of maximum along the ~ 1500 Hr direction.

Jadhav et al. [20] have studied the behaviour of semi-diurnal anisotropy for LAE by comparing the average semi-diurnal amplitude for each event with 27-day or annual average semi-diurnal amplitude. They found that there is no significant difference between the two wave trains. For these LAE cases the semi-diurnal amplitude is found to be normal, which shows that the diurnal and semi-diurnal anisotropies are not related with each other for these LAEs.

The study of diurnal anisotropy during 1981-94 for LAE has been presented in this paper to investigate the basic reason causing the occurrence of these types of unusual events.

Data and Analysis

The anisotropic events are identified using the hourly plots of cosmic ray intensity recorded at ground based Deep River neutron monitoring station and selected 13 unusually low amplitude anisotropic wave train events (LAEs) during the period 1991-94. The amplitude of the diurnal anisotropy on an annual average basis is found to be 0.4%, which has been taken as a reference line to select LAEs. Low amplitude wave train events of continuous days have been selected when the amplitude of diurnal anisotropy remains lower than 0.3% on each day of the event for at least five or more days. The pressure corrected hourly neutron monitor data after applying trend correction is harmonically analysed to have amplitude (%) and phase (Hr) of the diurnal anisotropy of cosmic ray intensity for LAE.

Results and Discussion

The amplitude (%) and phase (Hr) of the semi-

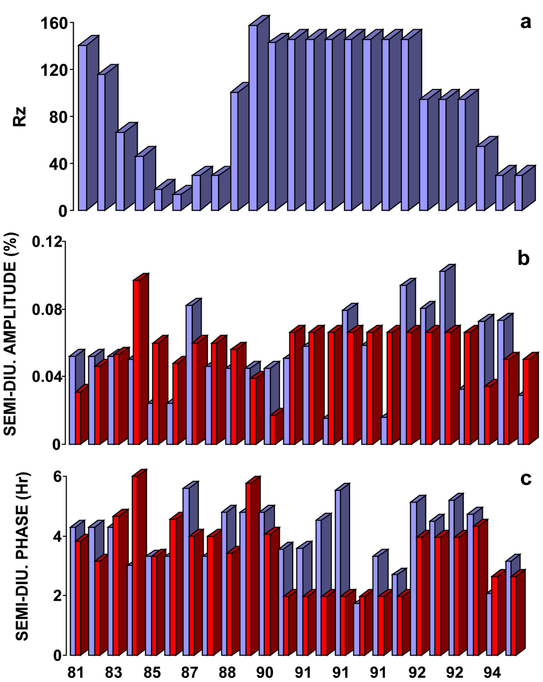

Fig 1: The long-term variation of cosmic-ray semi-diurnal anisotropy amplitude (%) and the time of maximum (Hr) for each LAE event is shown as a function of solar cycle represented by sunspot number (Rz) for the period 1981-1994.

diurnal anisotropy for the LAE events along with annual average values (red mark) and the corresponding sunspot numbers have been plotted in Figs 1 (a, b, c). As depicted in Fig 1 (a, b, c), it is quite apparent that the time of maximum (phase) of the semi-diurnal anisotropy seems to shifts towards later hours for majority of the LAE events as compared to the annual average anisotropy direction, whereas the amplitude significantly deviates from lower to higher values as compared to the annual average amplitude. This is in partial agreement with the earlier findings [21, 22], where they reported that the phase of the semi-diurnal anisotropy shifted to later hours and the amplitude remains statistically constant for majority of the LAEs. Similar results have also reported by Jadhav et al. [20].

It can be clearly seen from the figure that the amplitude of the semi-diurnal anisotropy consistently remains constant (~0.05%) during the period 1981-83. The distribution of amplitude shows peak during 1986. There is a sharp decrease in the semi-diurnal amplitude during the year 1983 and remains low during the solar activity minimum year 1984, which is in accordance with the findings of Ahluwalia et al. [23] for Deep River neutron monitor for the period 1980-87. It remains almost constant for the period 1987-90. It shows four peaks and three dips during 1991, 1992, 1993 close to solar activity maximum maximum years. However it does not indicate a one-to-one correlation with the sunspot numbers. It is also evident from the figure that the semi-diurnal amplitude remains low during solar activity minimum (1985) as well as solar activity maximum (1991-92). Further we find from the figure that the semi-diurnal time of maximum does not show any correlation with the sunspot numbers but indicates a shift towards later hours from the annual average anisotropy direction for the majority of events. These trends are found to be consistent with that of Kumar et al. [24] and Ananth et al. [25] and suggest that the amplitude of the semi-diurnal anisotropy is correlated with the solar cycle but the direction of the anisotropy is not correlated with the solar cycle and shows a systematic shift to later hours.

It is clearly seen from the figure that frequency of days with semi-diurnal phase in the 0400 hr direction statistically remains constant and the frequency of days with semi-diurnal phase in the 0600 hr direction show an increase during 1985 and 1991-92. This clearly indicates that during 1981-1994, the change in the direction of the semi-diurnal anisotropy vector has been caused by two kinds of flow of cosmic ray particles; one having a maximum in the 0400 hr direction and another in the 0600 hr direction. During 1985 and 1991-92 the phase shift of semi-diurnal anisotropy has been caused by the streaming of particles in the 0600 hr direction and during the rest of the period, in addition to the 0400 hr component, the presence of excess streaming in the 06 hr direction caused a shifting of the diurnal phase to later hours. Thus the anisotropy seems to be completely dominated by the two components one in the 0400 hr and the other in the 0600 hr direction.

The frequency distribution of low amplitude anisotropy days for the two solar cycles is shown in Fig 2. In the same figure we have also shown

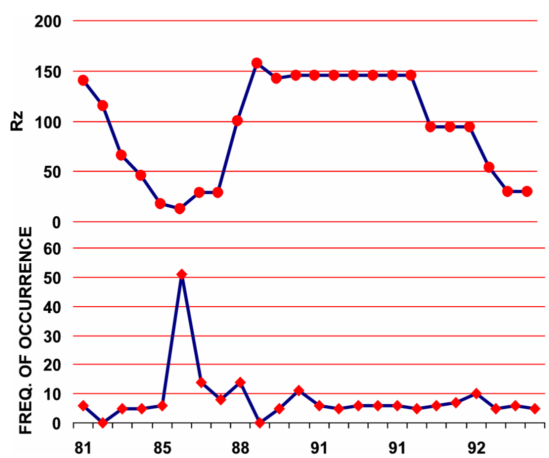

Fig 2: The solar cycle dependence of days with semi-diurnal anisotropy for each LAE event for the period 1981-1994

the variation of sunspot numbers indicating the solar cycle. The figure clearly illustrates that the distribution of low amplitude days presents a very interesting picture. We observed that the occurrence of low amplitude days is dominant during 1985-86 close to solar activity minimum years showing peak during these years. The occurrence of LAE events is practically remains constant for rest of the period of solar activity. These observations clearly suggest that LAE events do contribute significantly to the long-term variation of time of maximum of diurnal anisotropy. We have calculated the correlation coefficient between sunspot numbers (Rz) and occurrence of LAEs, which is found to be –0.35. Thus one may conclude that LAEs are seems to be weakly correlated sunspot numbers.

Conclusions

The amplitude significantly deviates from the annual average values for semi-diurnal anisotropy. The time of maximum of the semi-diurnal anisotropy has shifted towards later hours for majority the LAEs. The long-term behaviour of the amplitude of the diurnal anisotropy can be explained in terms of the occurrence of LAE events. The occurrence of LAE is dominant during solar activity minimum years. The amplitude of the semi-diurnal anisotropy is correlated with the solar cycle but the direction of the anisotropy is not correlated with the solar cycle and shows a systematic shift to later hours. The long-term behaviour of the time of maximum of the semi-diurnal anisotropy vectors could be explained in terms of 0400 Hr component and 0600 Hr component during low amplitude days.

Acknowledgements

The authors are indebted to various experimental groups, in particular, Prof. Margret D. Wilson, Prof. K. Nagashima, Miss. Aoi Inoue and Prof. J. H. King for providing the data.

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