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Interplanetary Magnetic Field Sector Structure & Its Effect on Cosmic Ray Diurnal Variation*

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The influence of interplanetary magnetic field sector structure and its boundary crossing on daily variation of cosmic ray intensity has been investigated for the years 1970-76, a period of declining solar activity and occurrence of unusually large high velocity solar wind streams. Its relationship with other correlated variables such as solar wind velocity (V), ΣK_p and mean intensity of the cosmic rays (I), shows a consistent behaviour throughout the period. It is found that, in general, the amplitude of the diurnal variation on the day of sector boundary crossing is lowest, whereas the time of maximum seems to be unperturbed. These results along with its effect on V, ΣK_p and I are reported and discussed.

1. Introduction

Based on the long term study of the average characteristics of diural anisotropy of cosmic rays, it has been demonstrated that in general a balance exists between outward radial convection due to solar wind and inward field-aligned diffusion of cosmic ray particles, producing diurnal anistropy from 18-hr direction.[1,2] However, such a balance is not evident in recent measurements even on yearly average basis,[3] which has been discussed in terms of 22-year wave superimposed on corotational anisotropy.[4] Further, large variability in both amplitude and phase of the anisotropy, on a day-to-day basis, has been observed all along; and based on the theoretical considerations, it is related to solar wind velocity and low frequency field fluctuations. Even though, attempts have been made to understand the day-to-day variability in terms of convection-diffusion model,[5,6] large percentage of days ($\approx 20\%$) remains where the anisotropy is not field aligned. During 1966-67 some of them are found to occur near sector boundary crossing of the interplanetary magnetic field (IMF); during which the field may be fluctuating for a considerable period of the day. In general, it is therefore instructive to investigate the effect of boundary crossing on diurnal anisotropy.

The effect of sector structure and its boundary crossing particularly on geomagnetic field variations,[7,8] and on solar wind velocity[9,10] has been well observed and documented. However, these studies are mainly confined to periods prior to 1972, when large high velocity solar wind streams of long duration were not common. An attempt has therefore been made in this paper to study the statistical behaviour of the sector structure and its boundary crossing on cosmic ray intensity and the diurnal variation and on the geomagnetic field variations as well as its association with the solar wind velocity for recent period which includes the period of high velocity solar wind streams. Since this investigation is being further extended to include earlier period with more complete data,[11] the implications of the results presented will not be discussed here in terms of those obtainted earlier, as it has been emphasized by many workers that the period in question may be unique and the phenomenon could be restricted only to this solar cycle.[12] Nevertheless their implications with regard to period under study will be reported.

2. Observations and Results

It has been demonstrated that the sector boundary crossing and the polarity of the field (IMF) can be determined with a very high degree of accuracy using traces of polar magnetograms[13] and this method is well suited for our study with time scales of 1 day, because during the period of 24 hr it is implied in the derivation of diurnal amplitude and phase that the anisotropy is constant. Sector field polarities are now published in a routine manner in *Solar Geophysical Data* by WDC-A. To avoid ambiguity due to multiple sector crossings, only those sector boundaries have been considered where

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the field polarity does not change both before and after for at least 4 days. However, sector boundaries associated with Forbush decrease type of cosmic ray intensity changes have been rejected, to exclude the possibility of universal time effects in diurnal anisotropy.

The pressure corrected hourly counts ftom Kiel and Deep River neutron monitoring stations have been used to derive the daily mean intensity as well as the diurnal variation for the period under study to investigate the boundary effects. The superposed epoch analysis has been performed separately for the two types of sector boundaries; one in which field change from away polarity (+) to towards polarity (−), whereas in the other case field changes from (−) to (+) polarity. Since the total number of days available in each category are limited to 80 and 86, respectively, for the period 1970-76, the results are reported for the total period, but are generally true even for shorter periods. Further, to avoid the dominance of a few of the isolated and large events, the complete data of all the parameters used in this analysis have been physically examined before the selection of sector boundary days in our analysis, which seems to be very essential.

The results of the superposed epoch analysis for the period 1970-76 for the two neutron monitors are presented in Fig. 1. The zero day corresponds to the day of sector boundary passage and the average diurnal amplitude shown for each day has been derived from the daily vector, whereas all error-bars show scatter representative of individual values on zero day. Despite large variability, which could be due to universal time variation effects still present on individual days and which will have different local time effects at Kiel and Deep River (being separated in longitude by more than 8 hr), a significant decrease in amplitude associated with the day of sector boundary passage can be inferred. This is true for both types of boundary passage, and could be expected either due to a significant random nonstationary anisotropy in space or due to the effects of universal time intensity variations. A similar analysis for diurnal time of maximum indicates no significant change during boundary passage as compared to other days. This implies that the anisotropy could be varying randomly in space during boundary passage, whose time within a day as derived for limited period, has uniform distribution.

To investigate the other conjecture of the universal time effects, the analysis has been performed on cosmic ray daily mean intensity for Deep River neutron monitoring station, and is depicted in Fig. 2 for ± 5 days for the same period. It is noticed that

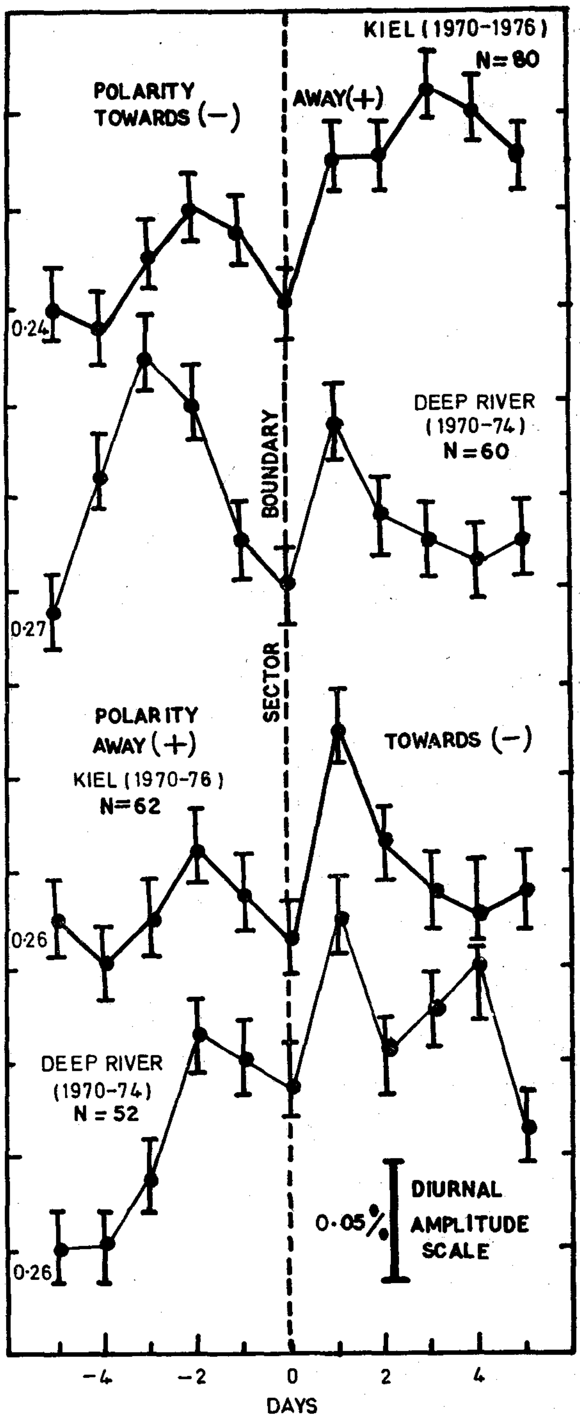

Fig. 1 — Results of the superposed epoch analysis of the diurnal amplitude of Kiel and Deep River neutron monitoring stations for ± 5 days (Zero day corresponds to IMF sector boundary passage, and error bars at each point pertain to 1 standard error of mean for this day. The numeral indicated on − 5 day gives numerical value of average amplitude in per cent)

for both sets of boundary crossing, the intensity is maximum on zero day with significant decrease on either side, particularly after the boundary passage. Such a peak and steep gradient in cosmic ray inten-

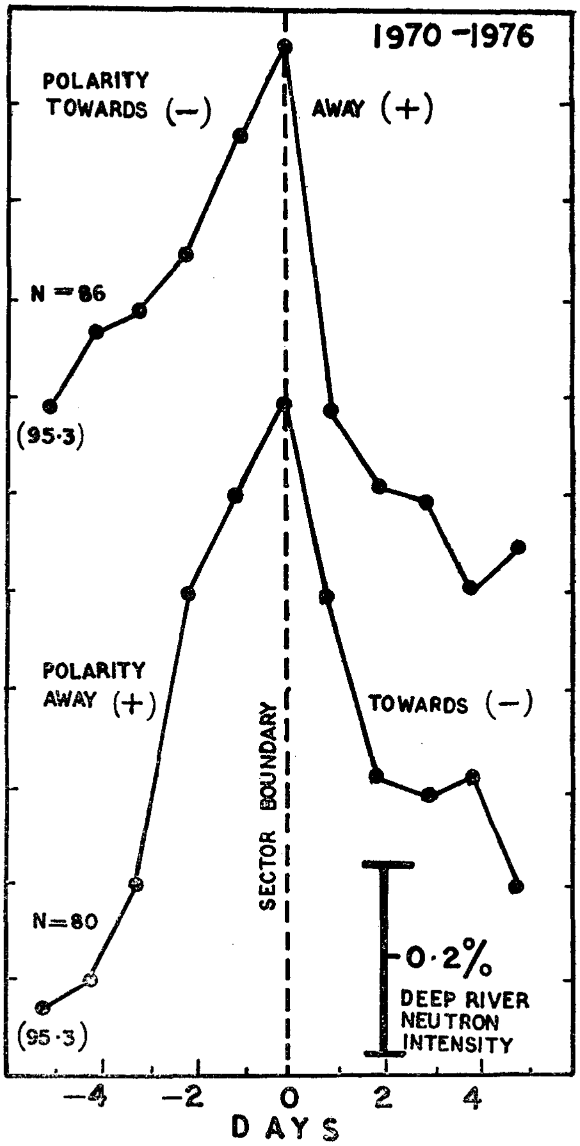

Fig. 2 — Results of superposed epoch analysis of the daily mean value of cosmic ray intensity for Deep River neutron monitor stations for $\pm$ 5 days (The size of the points are bigger than the statistical error, and the standard error of mean derived from the scatter of individual data point is also $\lesssim$0·1% near zero day of IMF sector boundary passage)

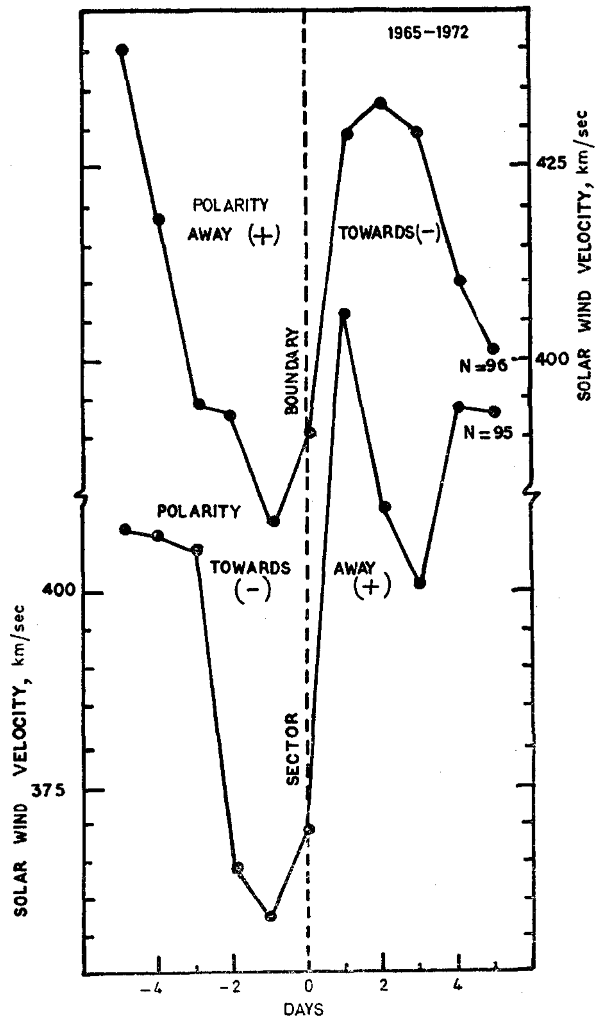

Fig. 3 — Results of superposed epoch analysis (zero day being IMF sector boundary crossing) of the daily mean value of the solar wind velocity for $\pm$ 5 days for the available period of 1965-72

sity can easily introduce a significant component in diurnal vector particularly on zero day, and have great implications which are discussed later.

Further, to investigate sector boundary effect on solar wind velocity which is an integral part of the theories explaining both the isotropic and anisotropic cosmic ray variations, the average behaviour of solar wind velocity is depicted in Fig. 3. A steep positive gradient in solar wind velocity associated with both types of sector boundary with increase in the velocity by 50 km/sec in one day is evident. These two parameters coupled with the southward component of IMF produce geomagnetic fluctuations, which are being investigated further and will be reported separately. Nevertheless, the epoch analysis for daily mean value of ΣK_p index, shown in Fig. 4, depicts very similar behaviour for 1970-76 as was reported for earlier period.[14] Fig. 4 implies that both positive gradient associated with sector boundary and the high solar wind velocity, in general, influence the geomagnetic field fluctuations.

3. Discussion

The investigation reported here is mainly concerned with the IMF sector boundary passage near the earth. The neutral sheet between the oppositely directed fields is extremely thin[15] and many times associated with large fluctuations (ΔB and ΔB_z) in both total IMF (B) as well as its southward component (B_z), and extends to large distances in the ecliptic plane. Earlier investigations have revealed a

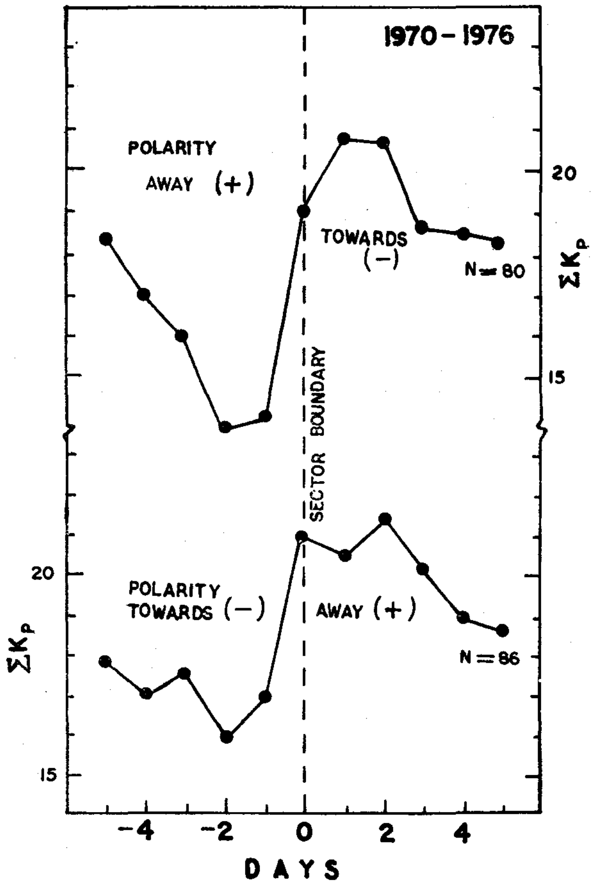

Fig. 4 — Results of superposed epoch analysis (zero day being IMF sector boundary crossing) of the daily mean value of the ΣK_p index for $\pm$ 5 days for the period 1970-76

significant but consistent variation in the diurnal time of maximum in positive and negative polarity sectors and sometimes significant trend in amplitude also,[16] which is not seen during the period 1970-76 reported here. This is not surprising if one considers the large shift in diurnal time of maximum to earlier hours since 1971 and the fact that the anisotropy cannot be defined simply in terms of variational rigidity spectral exponent ≈ 0 (Ref. 3) as was the case earlier.[1] However, a decrease in diurnal amplitude on the day of sector boundary suggests a mechanism similar to that of Iucci and Storini,[17] involving the mixed polarity days, associated with the steep gradient in solar wind velocity. The analysis is being extended further restricting to boundaries with very great length sectors on either side seen in 1973-74 to determine, if possible, the associated mechanism and also to see if the effect proposed by Levy[18] is observed in short time scale. The use of high latitude grid of well distributed low cutoff rigidity monitors might provide the method to separate the universal and local time variations[19] to study the effects more precisely. This is essential due to the peak observed in cosmic ray intensity and large decrease associated with it (Fig. 2), which can easily introduce large spurious anisotropy. Decrease associated with a sector boundary has also been observed earlier,[20] and can be understood in terms of steep positive gradient in solar wind velocity to be confirmed for a further period of 1973-76. Duggal and Pomerantz[21] have reported recently similar decrease using the data base from 1964-75 and have calculated the radial gradient for 10 GV cosmic rays using the north and south polar stations data.

4. Conclusions

(i) The diurnal amplitude of cosmic ray intensity decreases significantly on the day of sector boundary passage, with no definite trend on either side; however, the diurnal time of maximum is not affected due to the sector structure or boundary passage of IMF during 1970-76.

(ii) Associated with the boundary crossing and decrease in diurnal amplitude, the daily mean cosmic ray intensity as observed by high latitude neutron monitors peaks at zero day with large decrease thereafter.

(iii) The solar wind velocity steepens on zero day reaching the highest value next day with definite association with the high values of ΣK_p index, similar to what was reported for an earlier period on a statistical basis.

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