Helio-latitudinal cosmic ray intensity distribution at IAU during recent sunspot cycle*

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The yearly excursion in the heliographic latitudinal position of the earth, which is generally used for the investigation of cosmic ray density distribution, has been used in the study for the two recent intervals 1985-87 and 1988-90. The correction is estimated and is applied to obtain the cosmic ray density distribution free from the effect of solar activity variation during the period 1988-90. The cosmic ray intensity in the southern hemisphere is observed to be significantly greater than that in the northern hemisphere. Results based on observations during different phases of the solar cycle indicate, in general, larger cosmic ray density distribution in southern hemisphere at times of higher solar activity, whereas insignificant differences are observed during the period of low solar activity.

1 Introduction

The presence or absence of latitudinal density gradients (bidirectional or unidirectional) in cosmic ray intensity, particularly at neutron monitor energies, has direct relationship with diurnal variation of cosmic ray intensity and its higher harmonics as predicted by theories. The plane of rotation of the earth around the sun is inclined to the solar equatorial plane by 7.25°. So the earth changes its maximum position of excursion in helio-latitude by ± 7.25° with respect to the solar equatorial plane during September-March each year. Therefore, any cosmic ray density gradient perpendicular to solar equatorial plane will be observed as an annual wave in cosmic ray intensity. Theories have predicted that the linear gradients in cosmic ray intensity perpendicular to solar equatorial plane, if present, are expected to produce changes in the amplitude and phase of the diurnal variation of cosmic ray intensity from its average (normal) corotational directions. The theories also predict larger semi-diurnal amplitudes in the daily variation of cosmic ray intensity for larger values of symmetrically rising cosmic ray density gradients with respect to solar equatorial plane. However, in an earlier study for the period 1973-75, no evidence was found for the presence of any significant cosmic ray density gradients in the helio-latitude range of ± 7.25°, as was expected because of very large increase observed in the amplitude of the semi-diurnal variation of cosmic ray intensity. The period 1973-75 was the period of minimum solar activity. However, the unidirectional linear cosmic ray gradients with increasing intensity in southern helio-latitudes have been reported by Shrivastava et al. for the high solar activity period 1978-83. The study has now been extended to cover the recent period 1985-90 for studying the nature of the perpendicular cosmic ray gradients as observed over a long period of time.

2 Data analysis

The pressure-corrected monthly-average cosmic ray intensity values obtained from the data of the high latitude neutron monitor station, Deep River, have been used to derive the density distributions. As was done earlier, the period 1985-1990 has been divided into two slots of three years each, namely, 1985-87 and 1988-90. The average monthly values of sunspot numbers have been used to compensate the long-term effect of the solar activity changes on cosmic ray intensity. The annual mean deviations for each month for each 3-year period have been used to derive the distribution and are then plotted against the helio-latitudinal position of the earth to obtain the cosmic ray density distributions.
3 Results and discussion
As discussed earlier, the average cosmic ray intensity values for each month have been cross-correlated with the sunspot number for the corresponding period in both the slots, i.e. 1985-87 and 1988-90, and are shown in Figs 1 and 2, respectively. The scatter of points for the low solar activity period 1985-87 is quite large, which is indicative of poor correlation. However, significant correlation is observed during 1988-90, a period of rising and peak solar activity. The value of correlation coefficient \( r = -0.43 \) has been found to be significant. The best-fit line can be represented by a straight line \( x = -0.057 y \).

Therefore, the cosmic ray intensity values for 1988-90 have been suitably corrected for each month for the effect of variation of solar activity. Such a modified cosmic ray intensity has been cross-plotted with the helio-latitude of the earth for the 12 month period for 1988-90 (Fig. 3) and for the observed cosmic ray intensity for 1985-87 (Fig. 4). The heliographic excursion of the earth is maximum (\( \pm 7.25^\circ \)) during the month of September and March. In Fig. 3, both the uncorrected and corrected values of cosmic ray intensities are depicted for the interval 1988-90, whereas only uncorrected values of cosmic ray intensities are plotted for the period 1985-87 because of their poor correlation with sunspot numbers.

Figure 4 shows very little increase in cosmic ray intensity (\( \approx 0.8\% \)) during 1985-87 from north to south of helio-equator, whereas we observe that the total percentage change in cosmic ray intensity is \( \approx 2.0\% \) for the period 1988-90 (Fig. 3). However, the increase is seen only in the southern hemisphere without any significant change from \( +7.25^\circ \) to about \( 2^\circ \) south helio-latitude. The significance of the results presented here can be better visualized by comparing the observations over a long period of time. Figure 5 shows the observed changes in cosmic ray density, covering almost two solar cycles from 1973 to 1990. From the plots in Fig. 5, we observe that the results for 1988-90 presented here are in agreement with that observed one cycle earlier, i.e., for the interval 1978-80. From Fig. 5 we also note that during
Fig. 4—Cross-plot between the (observed) percent deviation of average cosmic ray intensity for 1985-87 and the helio-latitudinal position of the earth.

Fig. 5—Yearly average values of the sunspot number ($R_s$) along with the cosmic ray density distribution perpendicular to solar equatorial plane for different phases of the solar cycle 21 and 22 (upper part). The displacement of each vertical line above and below the heliographic equator indicates lower (left displacement) or higher (right displacement) density gradients predicted from the results obtained for different intervals at neutron monitor energies.

1981-83, the cosmic ray intensity increases continuously from $+7.25^\circ$ to $-7.25^\circ$. In contrast, we find that the cosmic ray intensity is almost constant from $+7.25^\circ$ to $-7.25^\circ$ for the quiet period 1985-87, which is again in agreement with the results reported for 1973-75 of previous solar cycle (Fig. 5). Thus, it is found that the distribution of the density of cosmic ray particles perpendicular to solar equatorial plane varies with the solar cycle, and higher cosmic ray densities are always observed in the southern hemisphere during the high solar activity period since 1973, whereas they are of equal values during the period of minimum solar activity.

Swinson et al. have used yet another method to estimate the cosmic ray density gradients perpendicular to solar equatorial plane, considering the drift effect on cosmic ray solar diurnal variation. Latitudinal cosmic ray gradients can also be estimated by sorting the daily cosmic ray data according to the direction of the interplanetary magnetic field and then obtaining the annual average solar diurnal variation for the ‘towards’ (T) and ‘away’ (A) field days separately. The vector difference between the observed solar diurnal variation for the T and A subsets is an indication of the presence of perpendicular gradient relative to the earth. Based on such theoretical considerations and using the cosmic ray daily variations derived from the cosmic ray detectors responding to high energies (Embudo underground), the cosmic ray density gradients perpendicular to solar equatorial plane have been reported by Swinson.

The results indicate the predominance of southward perpendicular gradient prior to 1971, whereas the situation is found to be reversed (northward gradient) only for very short periods during 1973-74 and 1976-77. For other periods, the difference is insignificant. Such changes in the cosmic ray density is not observed in the present work in which neutron monitor intensity data have been used. However, it is pertinent to note that the response of two sets of detectors is quite different, e.g. the neutron monitor used in this analysis responds to the mean energy of $\approx 10$ GeV, whereas the underground detectors used by Swinson et al. respond to much higher energies $\approx 50$ GeV. Because of large energy difference in the response of the two detectors, the gyroradius of the particles will be similarly different.

Therefore, the high energy underground detectors will scan much larger volume of the interplanetary space in comparison to particles detected by neutron monitors, and hence they are expected to monitor the particle densities corresponding to the different regions of interplanetary space.

The $in situ$ observation by Voyagers 1 and 2 have monitored galactic cosmic ray ions ($E > 70$ MeV) up to $\approx 38$ AU helio-radius and over $30^\circ$ heliographic latitude. The cosmic ray intensity as recorded by Voyager 2 reached a sharp maximum in mid 1987 and, by mid 1989 has decreased by $\approx 33\%$. In contrast, Voyager 1 observed almost constant intensity during all this period. The latitudinal gradient calculated from the Voyagers data has decreased from a maximum of $\approx -1.2%/deg$ ($\approx -2.6%/AU$) in mid 1987 (indicating lower densities in northern heliosphere) to essentially zero by April 1989. The cosmic ray density values derived by us for northern
hemisphere are essentially zero continuously since 1984-85, which partly agrees with the above result (from mid 1987). The differences for earlier periods up to mid 1987 could be due to the difference in the energy response of the two detectors and their vast difference in heliocentric position. The Voyager (1 and 2) observations correspond to large heliocentric distance up to 38 AU and to energies > 70 MeV which is an order of magnitude different from those for ground-based neutron monitors (for which the results have been presented in Fig. 5). However, because of differences in the spatial position as well as in the energy responses of different detectors, it would not be proper to give much credence to the stated agreement (or otherwise) in the cosmic ray density variations. Therefore, more systematic data analysis, using Swinson method for the neutron monitor data, would be quite useful to compare their results of cosmic ray density distribution perpendicular to the solar equatorial plane.

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References