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Study of Cosmic-Ray Depressions due to Corotating High-Speed Solar-Wind Streams and their Dependence on Solar Polarity

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We studied the solar magnetic cycle dependence of cosmic ray depressions due to corotating high speed solar wind streams (CSWS) during different polarity states of the heliosphere. Cosmic ray intensity data together with solar wind plasma and field data were subjected to superposed epoch analysis with respect to CSWS start time. These analysis were carried out separately for different polarity states of the heliosphere, A $<$ 0 and A $>$ 0. Although the average variations in the solar wind velocity, IMF strength and its variance are almost similar, the amplitudes of CSWS associated cosmic ray depressions are quit different during different polarity epochs; it is larger during A $>$ 0 than A $<$ 0 periods. Further, a correlation analysis between cosmic ray intensity and solar wind velocity during CSWS shows differences in their relationship during A $>$ 0 and A $<$ 0; it is much better during A $>$ 0 than A $<$ 0. Although IMF strength and its variance is enhanced at the onset of depression, correlation between cosmic ray intensity and the variations in these parameters are not good during CSWS.

1. Introduction

Recurrent cosmic ray modulation due to CIRs and high speed streams have been studied using ground-based and spacecraft data [2]-[7], also see reviews, [1], [8] and [9]. However, the relative contribution/role of corotating barrier, local structures within CIR, enhanced solar wind speed and the direction of solar magnetic field, in the modulation of galactic cosmic rays during the passage of a CIR and high-speed stream is still not fully understood. Such depressions in cosmic ray intensity have been associated with enhanced convection by high speed solar wind [2], [10], diffusion in enhanced/compressed field region [3], [11] and/or particle drifts in large scale heliospheric magnetic field [11]-[13]. Further studies of recurrent modulation can therefore provide new insight into global modulation phenomena.

In this paper, we have investigated GCR intensity depressions due to corotating high speed streams (CSWS), using daily as well as hourly averaged data during four periods of different solar magnetic conditions (two A $>$ 0 and two A $<$ 0 epochs).

2. Discussion

We have selected CSWS detected during 1964-96 and divided them into fours groups; (a) those observed during 1964-69 (A $<$ 0), (b) 1971-79 (A $>$ 0), (c) 1981-89 (A $<$ 0) and (d) 1991-96 (A $>$ 0). We applied the method of superposed epoch analysis and analysed the neutron monitor and solar wind data with respect to CSWS detected in these four periods. The results of analysis for two periods, 1964-69 (A $<$ 0) and 1971-79 (A $>$ 0) are shown in Fig. 1 and 2. These Figures show the results of hourly cosmic ray intensity I together with solar wind plasma and field parameters V, B, σ_B, T, N and the products VB and Vσ_B; zero hour is the arrival time of CSWS. In both the figure shown here (as well as those for 1981-89 and 1991-1996; not shown in this paper) the onset of decrease is associated with increase in solar wind velocity and enhanced field variance, indicating that both convection and diffusion play a role in the onset of the decrease. Decrease amplitude together with peak values of V, B, σ_B, T and N are given in Table-1. Tabulated values do not show any systematic difference between the values of the respective parameters during A $>$ 0 and A $<$ 0. Correlation analysis of intensity

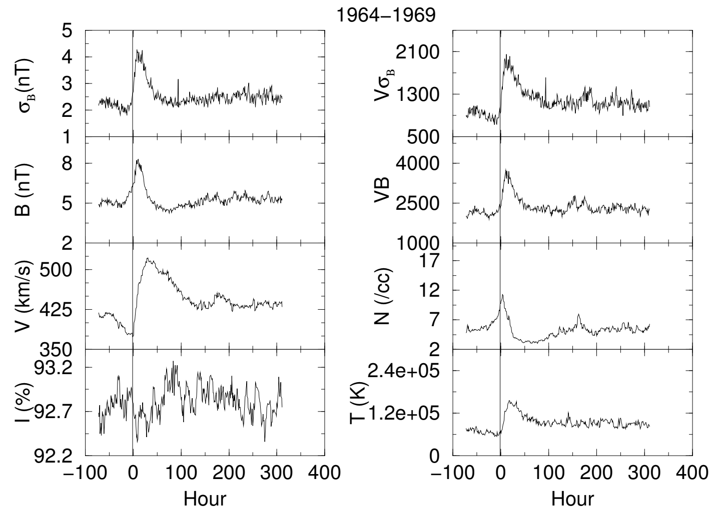

Figure 1. Variation of cosmic ray intensity and solar wind plasma and field parameters (V, B, Bz, σ_B, N, T) due to CSWS detected in 1964-1969 (zero hour denotes the arrival time of the high speed streams).

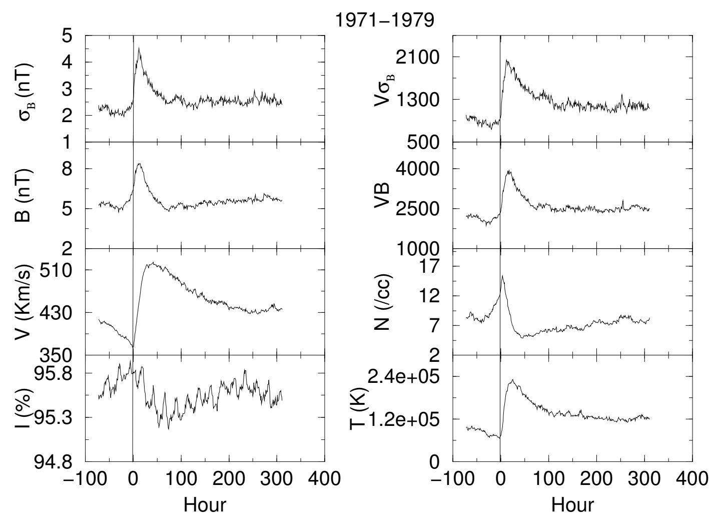

Figure 2. Same as Fig. 1 for the period 1971-1979.

depression during A $>$ 0 and A $<$ 0 periods with parameters V, B, σ_B, VB and Vσ_B shows a good correlation with the solar wind velocity only during A $>$ 0 epochs. Scatter plot of the variation in intensity and solar wind velocity in different periods (epochs) shows much better correlation during A $>$ 0 epochs (Fig. 3). From these figures it can be inferred that the response of the GCR to solar wind enhancements is apparently reduced in A $<$ 0 epochs [4]. However the exact cause of this apparent reduction in the response of GCR to solar wind enhancements is not clear; it may be due to epoch dependent transport coefficients [4]. The epoch dependent

Table 1. GCR depression (in %) and peak values of various plasma/field parameters due to CSWS

Periods	ΔI (%)	V (Km/s)	B (nT)	σ_B (nT)	N (/cc)	T (K)	VB	σ_BV
1964-1969 (A < 0)	0.09	522	7.8	4.2	11.9	156383	3489	1991
1971-1979 (A > 0)	0.55	524	8.4	4.5	15.4	232027	3938	2036
1981-1989 (A < 0)	0.28	511	9.1	4.6	14.6	191605	4167	2117
1991-1996 (A > 0)	0.39	531	9.6	4.7	17.6	221697	4554	2266

corotating modulation in GCR (weaker in A $<$ 0) may be explained by models proposed in recent years [4], [12] and [13]; however a critical examination of relative merits/limitations of these models is required vis-a vis the observed features of corotating decreases.

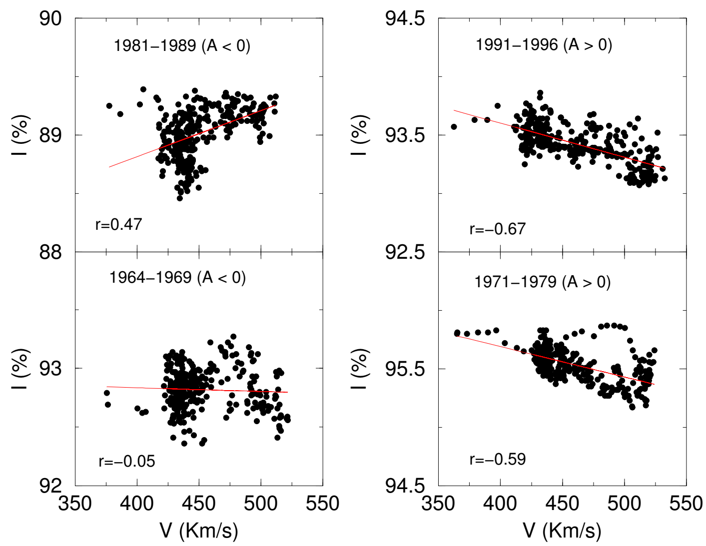

Figure 3. Dependence of cosmic ray intensity on solar wind velocity in different solar magnetic periods.

Corotating depressions in GCR have also been studied by the method of superposed epoch analysis using daily averaged neutron monitor data. These results were then tested for their statistical significance adopting the procedure illustrated by Badruddin and Singh [14]. It is found that the corotating depressions in GCR intensity are statistically significant during A $>$ 0 epochs only (Fig. 4). Burger and Hitge ([13]) have recently developed a steady state 3-D modulation model using a divergence-free Fisk-Parker hybrid heliospheric magnetic field and investigated the 26-day recurrent variation using this model. Their model calculations show that the hybrid field reduces intensities compared to Parker field when A $>$ 0. However, when A $<$ 0, the global effect of the hybrid field are almost negligible.

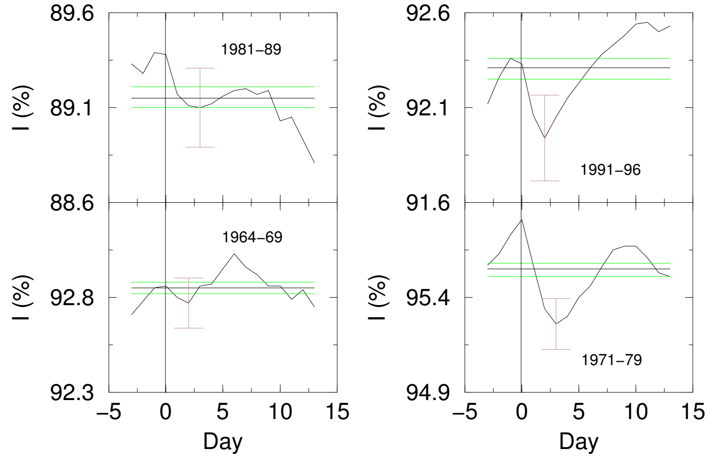

Figure 4. Mean superposed intensity alongwith the 95% confidence interval for minimum intensity (vertical bar) and for mean intensity (upper and lower horizontal bars) alongwith the mean counts (middle horizontal bar) in different solar epochs.

3. Conclusions

GCR depressions due to CSWS are significantly larger during $A > 0$. Correlation analysis between cosmic ray variation and solar wind velocity during high speed streams shows much better correlation during $A > 0$ as compared to $A < 0$ epochs. This reduced response of cosmic rays to solar wind enhancement is due to different paths of cosmic rays entering in the heliosphere during $A < 0$ and $A > 0$ (through equatorial region and polar regions respectively) or due to polarity dependent transport coefficients, is not clear yet.

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