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Interplanetary coronal mass ejections, their associated features, related plasma/field variations and transient modulation of cosmic rays

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Abstract. Interplanetary structures such as shock, sheath, coronal mass ejections (CMEs) and their interplanetary counterpart (ICMEs), magnetic clouds and corotating interaction regions (CIRs) are of special interest for the study of the transient modulation of galactic cosmic rays (GCRs). These structures modulate the GCR intensity with varying amplitude and recovery time. It is known that ICMEs are mainly responsible for Forbush decreases in GCR intensity. However, all the ICMEs do not produce such decreases in GCR intensity. We utilize GCR intensity data as recorded by neutron monitors and solar wind plasma/field data during the passage of ICMEs with different features and structures. We perform superposed epoch analysis of the data and study their relative GCR-effectiveness. We also adopt the best fit approach to search for interplanetary parameter that relates to transient decreases in GCR intensity.

Keywords : solar modulation – galactic cosmic rays – Forbush decrease – coronal mass ejection

1. Introduction

Galactic cosmic ray (GCR) intensity is modulated by short-term effects such as passage of corotating flows (high speed streams) and transient disturbances (e.g. interplanetary coronal mass ejections). Short-term transient depressions caused generally by ICMEs, and particularly by Magnetic Clouds (see e.g. Rao 1972; Badruddin, Yadav & Yadav 1986; Venkatesan & Badruddin 1990; Badruddin, Venkatesan & Zhu 1991; Cane 2000; Kudela & Brenkus 2004; Singh & Badruddin 2007; Oh, Yi & Kim 2008; Subramanian et al. 2009; Yu et al. 2010; Richardson & Cane 2011; Dumbovic

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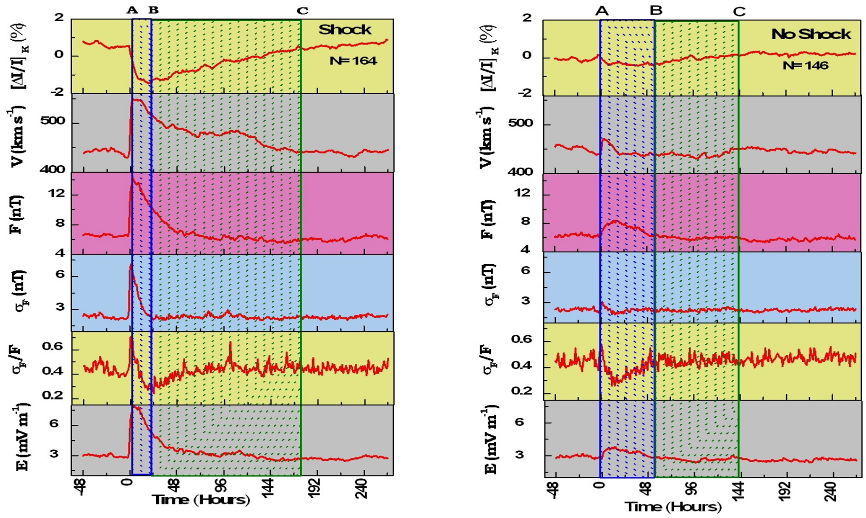

Figure 1. Superposed epoch analysis results of GCR-intensity and interplanetary plasma and field parameters; velocity (V), magnetic field vector (F), standard deviation of field vector (σ_F), ratio (σ_F/F) and electric field (E), with respect to passage of ICMEs associated with, (a) shock/sheath and (b) ICMEs not associated with shock/sheath region.

et al. 2012) have been studied extensively and many properties of these structures and resulting depressions in GCR intensity, have been clarified. However, important features of fields and flows, their magnetic structure and the physical processes playing dominant role are yet to be clearly identified (e.g. see Richardson & Cane 2011; Dumbovic et al. 2012; Kumar & Badruddin 2013).

2. Analysis and results

The ICMEs and their associated features/structures have been identified in near earth-space with better accuracy specially after 1995 (e.g. Gopalswamy et al. 2007, Richardson & Cane 2010). In addition to neutron monitor data as a measure of GCR intensity, we have also considered interplanetary plasma/field parameters, solar wind velocity V (km s^{-1}), interplanetary magnetic field F (nT), standard deviation in field vector σ_F (nT), ratio σ_F/F, and interplanetary electric field E (mV m^{-1}).

It is important to study in detail the relative GCR-effectiveness of different structures/features associated/not-associated with ICMEs. It will help us not only in identifying the structures/features of importance but also to understand the physical mechanism playing important role in transient modulation of galactic cosmic rays. We have performed the superposed epoch (SPE) analysis of GCR intensity and interplanetary plasma/field parameters with respect to ICMEs observed during solar cycle 23 (1996-2009). One of the results of this analysis with respect to ICMEs associated with (a)

Table 1. Average GCR intensity depression ΔI (%) at Kiel neutron monitor, peak values of interplanetary plasma/field parameters (V_{max}, F_{max}, $(\sigma_F)_{max}$, $(\sigma_F/F)_{max}$ and E_{max}) due to ICMEs associated with/without shocks, BDEs, Magnetic Cloud, Halo structures. The calculated ratios of the values of different parameters due to ICME with/without particular structure are also given.

ICME Structure	ΔI %	V_{max} km s^{-1}	F_{max} nT	$(\sigma_F)_{max}$ nT	$(\sigma_F/F)_{max}$	E_{max} mV m^{-1}
Shock	−1.92	546	13.95	7.31	0.70	7.95
No Shock	−0.56	471	8.42	2.97	0.59	3.78
Ratio	3.43	1.16	1.66	2.46	1.19	2.10
BDE	−1.63	533	12.27	6.30	0.70	6.90
No BDE	−0.48	472	8.55	3.33	0.58	3.98
Ratio	3.40	1.13	1.43	1.89	1.21	1.73
MC	−1.84	512	13.96	6.40	0.84	7.67
No MC	−1.16	526	10.39	4.85	0.68	5.59
Ratio	1.59	0.97	1.34	1.32	1.23	1.37
Halo	−2.31	568	15.60	7.69	0.84	9.07
No Halo	−1.34	535	11.03	5.19	0.68	6.03
Ratio	1.72	1.06	1.41	1.48	1.23	1.50

shock and (b) ICMEs not associated with shock are shown in Fig. 1. Differences in amplitudes and time profile can be seen from this figure.

The SPE analysis have also been performed with respect to ICMEs with bidirectional superthermal electron (BDE) flows and ICMEs not associated with BDEs; ICMEs with magnetic cloud (MC) structure and those not having such special structures; ICMEs due to halo CMEs and those due to non-Halo CMEs. The results so obtained are tabulated in Table 1. Differences in GCR-effectiveness of various parameters are evident, from the table.

Using these averaged values, we attempted to find a relation between GCR-intensity depression and various parameters. Scatter plot with best-fit linear curve between GCR-intensity and electric field is plotted in Fig. 2. On the basis of this fit, the GCR-intensity is found to decrease at a rate of 0.38±0.03% per unit increase in electric field (mV m^{-1}) during the passage of ICMEs.

3. Conclusions

We found that the GCR-effectiveness of shock-associated ICMEs, on an average, is 3.43 times more than those not associated with shock/sheath region. Similar analyses also reveal that the ICMEs with BDE are 3.40 times more GCR-effective than ICMEs not associated with BDEs. Further, ICMEs with magnetic cloud structure are 1.59 times more GCR-effectives as compared to ICMEs observed to have non-magnetic cloud structures. The ICMEs due to Halo-CMEs are found to about 1.72

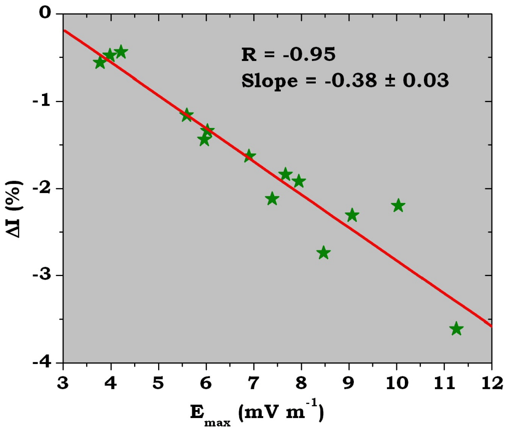

Figure 2. Best fit linear curve between averaged GCR-intensity depression and electric field amplitude E_{max} (mV m^{-1}) due to ICMEs with different GCR-effectiveness and ICMEs associated/not associated with different structures/features.

times more GCR-effective than those due to non-Halo CMEs. Enhancements in various plasma and field parameters are also found to be more due to ICMEs associated with shocks/BDEs/MCs/Halo-CMEs as compared to those not associated with these structures/features.

From the best fit linear relation between GCR-intensity depressions and enhancement in the electric fileds (E_{max}), we found that GCR-intensity decreases at the rate of 0.38±0.03% per unit increase in electric field (mV m^{-1}).

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