ISSN 1845–8319

SOLAR INFLUENCES ON THE SHORT-TERM COSMIC RAY MODULATION

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Abstract. This study aims to provide a quantitative basis for physical interpretations of Forbush decreases (FDs) caused by disturbances in the interplanetary magnetic field. A superposed epoch analysis is applied to the magnetic field strength and fluctuations data obtained from the Advanced Composition Explorer, and to the cosmic ray data obtained from ground level neutron monitors. We found that the morphology, as well as the amplitude and duration of FDs, are dependent on the type of the disturbance that caused the FD.

Key words: coronal mass ejections (CMEs) - solar-terrestrial relations - cosmic rays

1. Introduction

The cosmic ray (CR) flux is modulated by compressions of the interplanetary magnetic field (IMF) associated with interplanetary coronal mass ejections (ICMEs) and corotating interaction regions (CIRs). Sometimes the two interact, producing a mixed ICME-CIR event, which also modulate the CR flux. These modulations, manifesting as decreases in cosmic ray count, often are referred to as Forbush decreases (FDs) after S.E. Forbush, who first reported them (Forbush, 1937).

Most of the short-term depressions of CR flux have amplitudes distinctly larger than the daily CR flux variation and last for about a week. They differ in amplitudes, durations and shapes, which is presumably a consequence of the variety of solar wind disturbances (SWDs) causing them. For example, a typical FD caused by a shock-associated ICME is asymmetric, but if SWD is not associated with a shock it will cause a shallower and more symmetric depression like the one caused by CIR (for a comprehensive overview see, e.g. Lockwood, 1971; Cane, 2000; Richardson, 2004).

The mechanism by which SWDs cause FDs is widely analysed via the Parker transport equation (Parker, 1965), attributing changes of the CR distribution function to a reduced drift and diffusion, convection by solar wind, and energy loss. The first two mechanisms are the basis for most models regarding short-term CR modulation (see, e.g. Le Roux and Potgieter, 1991; Kota and Jokipii, 1991; Wibberenz *et al.*, 1998; Wawrzynczak and Alania, 2010), thus giving a motivation to confirm the relevance of magnetic field enhancement and fluctuations by inspecting the empirical data. Hereinafter we present the superposed epoch analysis of the GCR flux and IMF strength B and fluctuation δB, whereas a detailed statistical study is presented in (Dumbović *et al.*, 2011, 2012).

2. Data and Method

A total of 26 periods of 20-day intervals was selected around the events from the list of identified CME-ICME pairs prepared by Schwenn *et al.* (2005) and the case-study list of the European FP7-project SOTERIA (http://soteria-space.eu/). Cosmic ray data was taken from SPIDR website (http://spidr.ngdc.noaa.gov/spidr/). The hourly averaged count rates from 7 neutron monitor (NM) stations, corrected for atmospheric pressure, were used. To eliminate daily variations, an average of 3-4 NM stations located at different longitudes and of similar rigidity was calculated (mean rigidity: 2.56 GV) and in each interval the CR count was set relative to the average value in the first four days, before the arrival of a particular SWD. The magnetic field data was taken from the magnetometer instrument (MAG; Smith *et al.*, 1998) on board the Advanced Composition Explorer (ACE; Stone *et al.*, 1998). We used level-2 data of 1-hour magnetic field strength averages (http://www.srl.caltech.edu/ACE/). A more detailed description of data preparation and a list of all events are given in Dumbović *et al.* (2011). In 26 selected periods a total of 66 solar wind disturbances (SWDs) were identified as increases in magnetic field strength. Then corresponding depressions in cosmic ray (CR) count were found.

The data set was sorted by the type of SWD, i.e., a distinction was made between interplanetary coronal mass ejections (ICME), corotating interaction regions (CIR), and mixed ICME-CIR disturbances (mixed). For more details on the identification of SWDs see Dumbović *et al.* (2011) and Dumbović *et al.* (2012). A superposed epoch analysis (SEA) was used to analyse the influence of the magnetic field enhancement and fluctuations on the CR count for different types of SWD. The onset of the magnetic field enhancement was taken as the point of reference for superposition. Time scales of CR count and magnetic field strength were normalized to the duration of the analysed SWD and the values of the CR count and the magnetic field strength and fluctuations were normalized to FD magnitude $|FD|$, magnetic field strength amplitude B, and fluctuations amplitude δB, respectively. The SEA samples used contain 33 ICMEs, 7 CIRs, and 9 mixed events. A detailed description of the normalized SEA that was applied is given by Dumbović *et al.* (2012). Here we focus on the results obtained for magnetic field fluctuations.

3. Results

Differences between CIRs, ICMEs, and mixed events can be seen in the SEA curves in B, δB, and FD in Figure 1. The shape of the depression is related to the shape of the magnetic field enhancement, as concluded in Dumbović *et al.* (2012). The same conclusion can be drawn for magnetic field fluctuations.

In ICMEs the fluctuations of magnetic field δB increase sharply and return to the pre-increase level fairly gradually, showing a very asymmetric shape, which results also in asymmetric shape of the corresponding FD. CIRs show a more gradual increase in the fluctuations, and unlike ICMEs, the increased δB in CIRs last longer. Furthermore, they are characterized by a second, smaller peak, two and a half days after the event onset. The corresponding FD is almost symmetric. The structure for mixed events shows characteristics of both CIRs and ICMEs. The increase of δB has an onset similar to CIRs, and are increased for a longer period, but there is no clear second maximum. The corresponding depression is asymmetric in shape, though to a smaller degree than in ICMEs and the CR count does not return to the pre-decrease value. As with the magnetic field enhancement, for ICMEs and mixed events the maximum of fluctuations corresponds to the steepest part of the depression, between the FD onset and minimum. In the case of CIRs this is unclear, because of the noise.

4. Discussion and Conclusion

The SEA results showed that for different shapes of magnetic field enhancement and fluctuations, associated with different solar wind disturbances

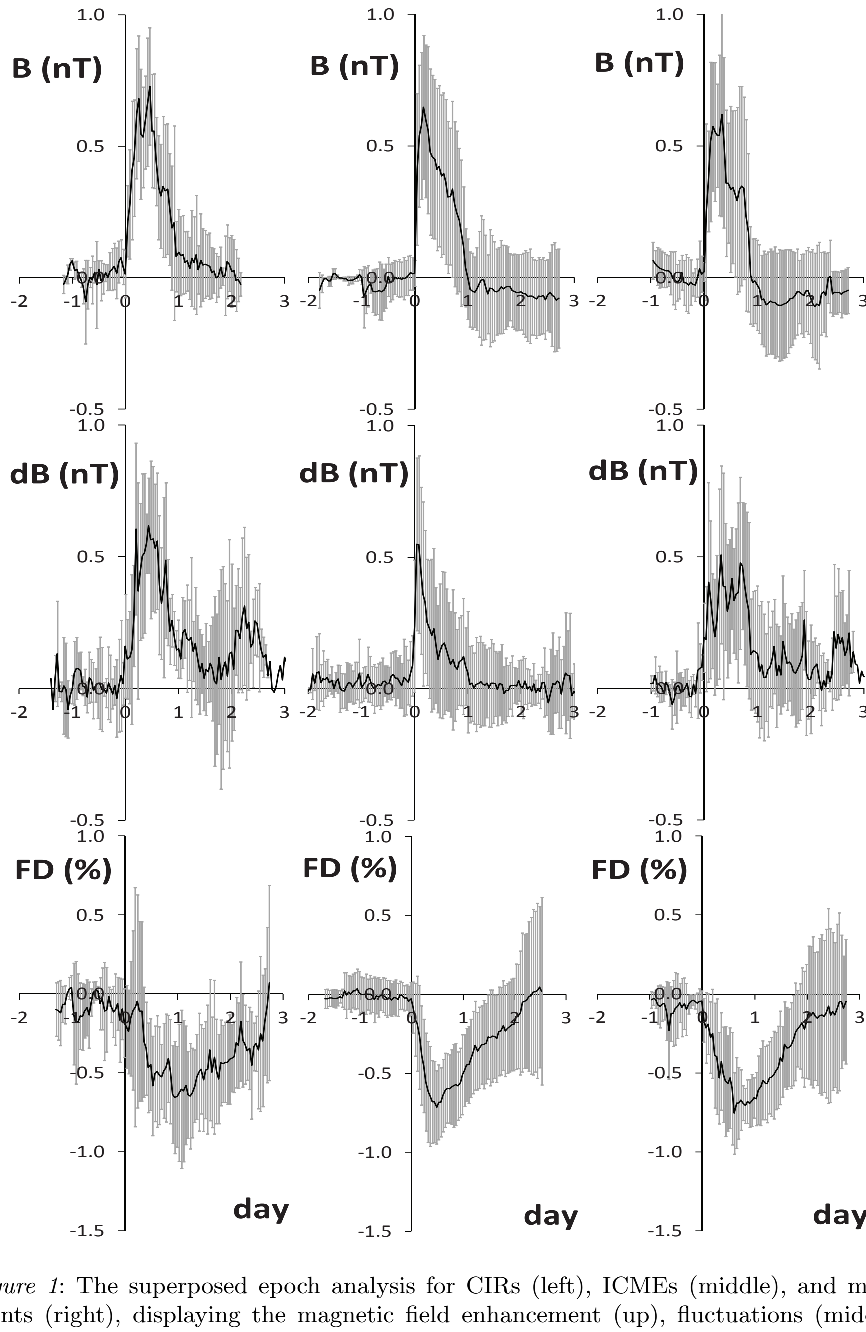

Figure 1: The superposed epoch analysis for CIRs (left), ICMEs (middle), and mixed events (right), displaying the magnetic field enhancement (up), fluctuations (middle), and Forbush decrease (down).

(CIR, ICME, mixed), different shapes of depressions in cosmic ray count are to be expected. This is in agreement with other SEA studies (e.g. Badruddin *et al.*, 1986; Badruddin, 1996; Singh and Badruddin, 2007). In Dumbović *et al.* (2012) we related the shape of the depression to the shape of the magnetic field enhancement and here we see a similar connection with the shape of the fluctuations curve. For CIRs and mixed events the fluctuations are increased also during the recovery phase of the FD, which is not the case with ICMEs. Furthermore, for the same amplitude of the magnetic field enhancement and fluctuations, shallower depressions are expected for CIRs, as compared to ICMEs and mixed events (see Dumbović *et al.*, 2012). This might be indicating different mechanisms involved in the CR modulation by ICMEs and CIRs.

Acknowledgements

The research leading to the results presented in this paper has received funding from the European Commission's Seventh Framework Programme (FP7/2007-2013) under the grant agreement no. 218816 (SOTERIA project, www.soteria-space.eu).

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