Interplanetary magnetic field disturbances with particularly high cosmic ray modulation efficiency

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Abstract

Forbush effects (FEs) are usually observed simultaneously with an increase in the Interplanetary Magnetic Field (IMF) strength. As a rule, large Forbush decreases correspond to big increases in the IMF. We studied the exceptions to this rule: events where weak disturbances of the IMF are associated with big FEs. The apparently high modulation efficiency of interplanetary disturbances is most often evidence of the large power of the IMF disturbance in these cases, much greater than it might be concluded from the solar wind measurements near Earth.

1. Introduction

Usually, a Forbush effect is observed simultaneously with an IMF increase. A cosmic ray (CR) decrease is created in a region of interplanetary space where particle access from outside is difficult. This special area is characterized by a stronger IMF. Thereby a wide rigidity range of the CR is affected, and a strong CR modulation results. As a rule, large Forbush decreases are caused by big increases in the IMF strength [1,2,6]. The goal of this report is to study the exceptions to this rule. We extracted events in which small disturbances of the IMF were followed by a big Forbush decrease and tried to analyze how these events differ from others, and what the reasons of their distinction are. We used the Forbush-effect database [3] for this study.

2. Analysis, Results and Conclusions

We selected events with duration >18 hours during which IMF measurements are available. In Fig. 1 the relation between the magnitude of the Forbush decreases, A_F, and the IMF maximum intensity, B_{max}, of these 2204 events is presented. The plotted regression line obtained from this large number of FEs corresponds to: $A_F(\%) = (-0.47 \pm 0.03)\% + (0.156 \pm 0.005)\%/\mathrm{nT} \cdot B_{max}$ (nT). It shows the well-known relation between A_F and B_{max} [4,5,7]. The majority of the points are concentrated close to the regression line, but one group, containing all

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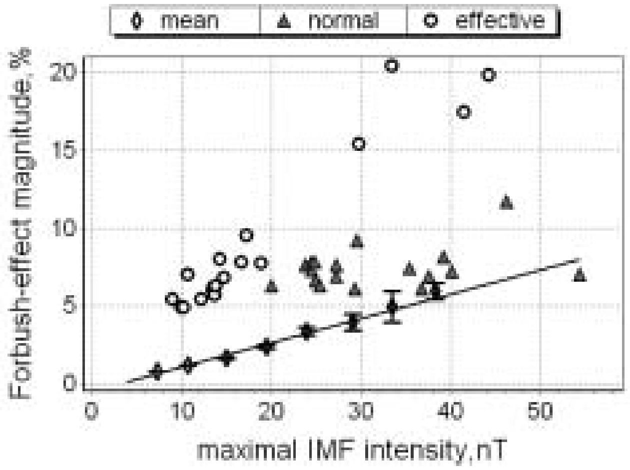

Fig. 1. Dependence of the FE magnitude on the maximal IMF intensity in the associated disturbance. Circles and triangles mark events in the "effective" and "normal" control groups. The straight line corresponds to the linear regression derived from all events.

giant Forbush effects, are placed significantly above the regression line. The correlation coefficient of 0.59, obtained for the 2204 events, indicates the existence of a FE magnitude - B_{max} relation and the statistical character of this relation by also considering the significant deviations in separate cases. The average FE is ~1.1 % for disturbances in the IMF near Earth of 10 nT, and ~2.6 % for 20 nT. However, sometimes small interplanetary disturbances with maximum IMF strength of 10–20 nT create large FEs of about 7–10 %. In other words, the observed IMF exhibits different efficiencies from event to event. We can therefore introduce a measure of the efficiency: $K_{FB} = A_F/B_{max}(\%/\text{nT})$. The magnitude of K_{FB} varies within the wide range 0.01–0.65, however, about half of the all events fall into 0.06–0.12 %/nT interval, and >85 % events are within 0.04–0.20 %/nT. The mean value of K_{FB} is 0.115±0.002 %/nT and most often K_{FB} is ~0.08 %/nT.

The most effective 18 events with $K_{FB} > 0.40$ %/nT selected for this analysis are marked by circles ("effective") in Fig.1. An example of these "effective" events is presented in Fig. 2. The minimum CR intensity in this FE was reached surprisingly late, only on the fourth day after the Sudden Storm Commencement (SSC). The maximum IMF intensity during this event was only 10.7 nT. The solar wind speed and the geomagnetic activity were enhanced before the shock arrival. This event seems to be caused by at least two solar sources: a large coronal hole and a Coronal Mass Ejection (CME), associated with the eastern X1.1/2B solar flare on 17 July 1991 (onset 6:18 UT, S25E46) and a powerful type II radio burst. All "effective" FEs were associated with two or more solar sources. Thereby one or all of the solar sources were located to the East from the Sun-Earth line.

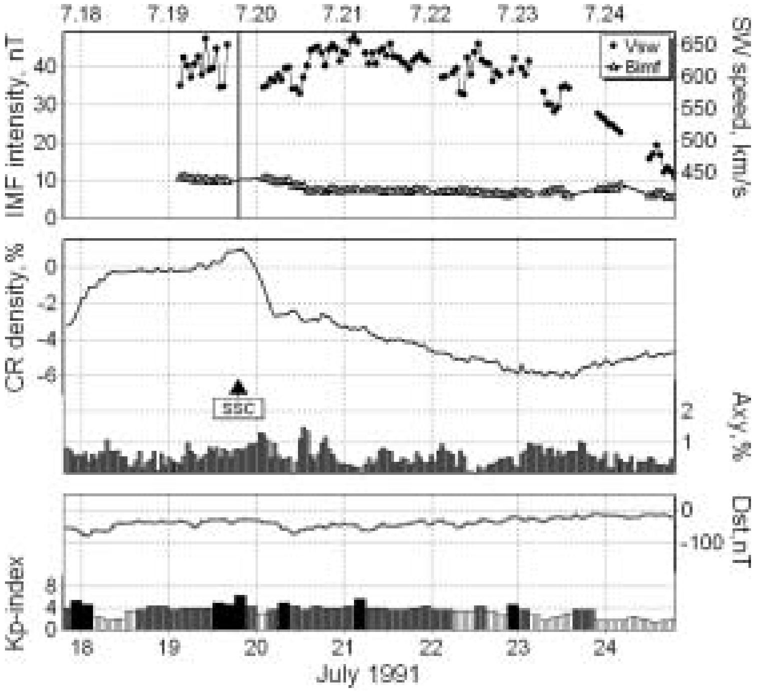

Fig. 2. Example of an event with a small interplanetary disturbance followed by a big Forbush effect. Solar wind velocity, IMF strength, 10 GV CR density, equatorial component of the vector anisotropy Axy, Dst- and Kp-indices of geomagnetic activity are plotted from top to bottom.

We compared the "effective" events with a group of events with maximal amplitude of Forbush decrease $> 6\,\%$ and $K_{FB} < 0.32\,\%/\mathrm{nT}$, named "normal" hereafter. The mean characteristics of these two groups are presented in the Table. It is worth noting that the main decrease phase for the FEs from the "effective" group is more than twice as long as for the events of the "normal" group. The solar wind speed is almost the same in both groups, whereas geomagnetic activity is lower and CR anisotropy higher in the "effective" group. CMEs play the dominant role in all selected events. The event-associated flares were found more powerful, prolonged, and farther easternly located in the "effective" group than in the "normal" group. The number of eastern flares is twice as high as western ones in the events analysed here. The CMEs and interplanetary disturbances that caused the "effective" events appear to have a larger size and a more complicated structure. The interplanetary and geomagnetic situation as a rule was already disturbed before these events occured, and they were associated with more than one solar source. In a large fraction of the "effective" events the Earth traverses only a peripheral part of the interplanetary disturbance. The main part of the disturbance passes apart from the Earth (as a rule to the East), but has a profound and prolonged modulating effect on CRs near the Earth. The specific

Table 1. Mean parameters of disturbance in the solar wind, cosmic rays, and geomagnetic field for the "effective" ($A_F/B_{max} > 0.4\,\%/\mathrm{nT}$) and "normal" ($A_F/B_{max} < 0.32\,\%/\mathrm{nT}$) Forbush event groups.

Parameter	Symbol	"effective"	"normal"
Forbush effect magnitude	A_F	$9.1 \pm 1.2\,\%$	$7.4 \pm 0.3\,\%$
Maximal IMF intensity	B_{max}	18.7 ± 2.6 nT	31.7 ± 2.1 nT
Maximal solar wind velocity	V_{max}	713 ± 46 km/s	682 ± 24 km/s
Maximal Kp-index	Kp_{max}	6.1 ± 0.3	7.3 ± 0.2
Minimal Dst-index	Dst_{min}	-100 ± 21 nT	-133 ± 16 nT
Maximal equatorial component of the CR anisotropy	Axy_{max}	$3.4 \pm 0.3\,\%$	$2.7 \pm 0.2\,\%$
Onset to minimum FE time	t_{min}	41.6 ± 7.3 hours	18.6 ± 1.5 hours

properties of FEs related to eastern sources were discussed in [4,7].

As a rule, Forbush decreases are created by an expanding region of the strengthened IMF. However, this does not mean that FEs are limited by this region, or that spatial Forbush decrease regions coincide with the region of strengthened IMF. At any fixed moment the FE region is significantly larger than the space of the IMF disturbance. At any fixed point of the FE observation, the duration of the CR effect exceeds the duration of the IMF effect. The high modulation efficiency of the interplanetary disturbances found in the cosmic ray observations at Earth for the "effective" events is most often evidence for an increased power of the disturbance which is much greater than might be concluded from the near-Earth solar wind measurements. The region of high CR modulation is essentially wider than the region of high IMF intensity and shifted in space. Therefore cosmic ray observations can be an important tool for the remote diagnostic of solar wind disturbances and heliospheric processes.

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