

Anomalous Forbush effects from remote by longitude solar sources

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Abstract. The Forbush effects associated with far western and eastern powerful sources on the Sun and occurred on the background of unsettled and moderate interplanetary and geomagnetic disturbance have been studied by the data from neutron monitor network and relevant measurements of the solar wind parameters. These Forbush effects may be referred to a special sub-class of events, with the characteristics closed to the event in July 2005, and incorporated by the common conditions: absence of a significant disturbance in the Earth vicinity; absence of the strong geomagnetic storm; slow decrease of cosmic ray intensity during the main phase of the Forbush effect. General features and separate properties in behavior of density and anisotropy of 10 GV cosmic rays for this subclass are investigated.

Keywords. elementary particles, Sun: activity, interplanetary medium, solar-terrestrial relations, coronal mass ejections (CMEs), shock waves.

1. Introduction

We consider Forbush effect (FE) as a result of influence of interplanetary disturbance on the galactic cosmic rays (CR): it is the response of cosmic rays to the propagating disturbance including precursors (pre-increase and pre-decrease in CR variations), CR intensity decrease as the main phase (FD), and the recovery phase while the Earth exits a disturbance area (Belov et al. 2003a, Belov et al. 2007). Usually FE is observed simultaneously with the interplanetary magnetic field (IMF) increase. Cosmic ray intensity decrease (FD) during the FE is created in a separate region of interplanetary space where the particle access from outside is difficult. The stronger IMF created this special area, the wider rigidity diapason of CR is exposed to this effect, the stronger CR modulation. As a rule, the deep Forbush decreases correspond to the big increases of the IMF intensity. In (Belov et al. 2005) we studied the exceptions to this rule where FEs with a magnitude more than 6 % were created on the background of weak disturbances of the IMF. It was found that in a large fraction of the efficient events the Earth is struck only by a peripheral area of the interplanetary disturbance and the main part passes apart from the Earth, as a rule to the east. However, the event in July 2005 caused by the far western source on the Sun indicated analogous features of higher efficiency of a disturbance modulating influence on the CR (Papaioannou et al. 2008). In the present work we continue our study of such anomalous effects. Among all FEs we distinguished a subclass of events characterized by relatively unsettled interplanetary and geomagnetic conditions (IMF < 15 nT, Kp < 6), gradual decrease of the CR intensity on the main phase of FE and slow recovery phase. It turned out that all these events were caused by far

eastern or western solar sources and have very characteristic features in a behavior of CR variations. The goal of our work is to analyze the subclasses of such anomalous FEs associated with far eastern and western solar flares, to study the variations of CR density and anisotropy during these effects and to compare and contrast the CR behavior for these two groups with the aim to use these results for diagnostics of the interplanetary space and near Earth vicinity.

2. Data and methods

Database on the Forbush effects and interplanetary disturbances, created in IZMIRAN, has been used for the mentioned above study. This database includes as parameters of CR density (A_0) and anisotropy (equatorial component of the first harmonic, A_{xy}) so data on the solar wind, interplanetary magnetic field, solar data and geomagnetic activity indices K_p and Dst (Archive SPIDR Data Base, available from <http://spidr.ngdc.noaa.gov>. The updating measurements on GOES, and OMNI data base have been utilized from the web sites: <http://www.ngdc.noaa.gov>, <http://omniweb.gsfc.nasa.gov>, <http://sec.ts.astro.it>) and CME data from <http://lasco-www.nrl.navy.mil>. The list of sudden storm commencements (SSC) has been also used (<ftp://ftp.ngdc.noaa.gov>) as a proxy for interplanetary shocks; the time of SSC generally defines the onset of FE. Density and anisotropy for 10 GV CR was derived by the global survey method (Belov et al. 2005, Belov et al. 2007) over the period 1965-2006 by the hourly data from neutron monitor network (<http://cr0.izmiran.rssi.ru/common/links.htm>) and included into the IZMIRAN database (Asipenka et al. 2008). Normally, the stronger interplanetary disturbance the bigger of the FE amplitude (A_F) which has in total a linear dependence on B_m (Belov et al. 2001). Only the events separated by at least 24 hours have been taken for the analysis and only those where the IMF data were provided not less than on 80 %.

3. Discussion of the results

Well known relation between IMF intensity and FE magnitude (Belov et al., 2001) is obtained in the present work on the extremely large statistical material (2000 events).

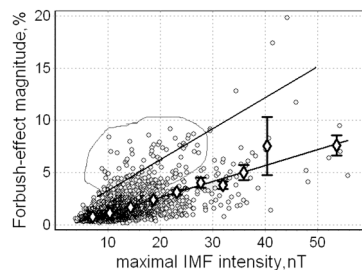


Figure 1. FE magnitude (A_m) vs the maximal IMF intensity B_m . Diamonds are the A_F values averaged by the equal B_m intervals

In Fig.1 one can see a dependence of FE magnitude (A_F) on the maximum IMF intensity B_m . The majority of points are concentrated near the regression line, but there is a group placed significantly higher this line. A correlation coefficient of 0.67 obtained by the 1987 events shows as the existing of a relation between FE magnitudes and B_m , so the statistical character of this relation and possibility to be essentially violated in some cases: an experience shows the large FEs observed under relatively low values of

the IMF intensity, and on the contrary, relatively small FEs corresponded sometimes to the large IMF intensity. We were interested in the events (circled group) where small and moderate values of IMF corresponded to the large A_F . It looks as a result of more effective influence of a disturbance on the CR. A degree of such the efficiency might be estimated as $K_F = A_F/B_m$, %/nT.

This coefficient may be considered as a characteristic of modulating ability of the associated IMF disturbance and it was one of the main parameters by which a selection of events for analysis was carried out. As our experience shows the events with $K_F > 0.36$ belong to a group of anomalous when near Earth measured IMF parameters could not provide the observable Forbush effect. Selection of the FEs by this parameter among events identified with associated solar sources gives the following distribution by the source longitudes within 60° range.

type	East (E90-E30)	Centre (E30-W30)	West (W30-W90)
$K_F > 0.36$ anomalous	14	10	9
$K_F < 0.36$ normal	24	62	13

One can see that in normal events the central sources dominate whereas anomalous FEs are mainly caused by the extreme eastern or western sources. All anomalous FEs turned out to be of >3 % magnitude and occurred in relatively weakly disturbed interplanetary and geomagnetic conditions (IMF < 15 nT, $K_p < 6$), with gradual fall of CR intensity in the main phase of Forbush-effect. We compared the characteristics of CR variations during the FEs from western and eastern sources.

In Fig. 2 the examples of FEs in July 2005 (western source at the longitude W79°) and in April 1981 (longitude W52°) are presented. In both cases on the background of relatively quiescent interplanetary and geomagnetic conditions we observe FEs with the magnitude of FD > 4 % and appreciate increase of A_{xy} , up to 4.6 % in the main phase (whereas in usual events it doesn't exceed 2 %). The A_{xy} increase started at once with the FE onset herewith the direction of A_{xy} vector varied very little and remained of the usual westward during the recovery phase.

In Fig. 3 we give the same presentation of different parameters for the FEs associated with far eastern solar sources. The difference in a behavior of vector A_{xy} in these cases and in western events during the FEs is evident.

The magnitude of FEs caused by the eastern sources turned out to be a little less as for the western ones, but vector of the equatorial component of CR anisotropy A_{xy} shows quite different behavior by a direction (see Fig. 4). For 9 western events the FE averaged magnitude A_0 was found as 4.5 %, maximum value of the equatorial component of anisotropy $A_{xy} = 3.5$ %, solar wind velocity did not exceed 600 km/s. For 10 eastern events the mean value of $A_0 = 4.2$ %, maximum $A_{xy} = 2.1$ %.

In Fig. 4 vector diagrams of the anisotropy A_{xy} are presented by the eastern and western events for comparing. We can note very specific behavior of the CR anisotropy before and during the FEs which is different for eastern and western effects. By a magnitude the increase of A_{xy} is essentially larger for western FEs, however for 'east' events we observe sharp change of a direction of A_{xy} during the main phase of Forbush-effect. The properties of A_{xy} behavior may help with the identification of a disturbance source caused the FE when there is no sufficient information to make it surely (e.g. Fig. 5). In these plots one can see the characteristic behavior of A_{xy} vector which evidences the FE as those caused by western source.

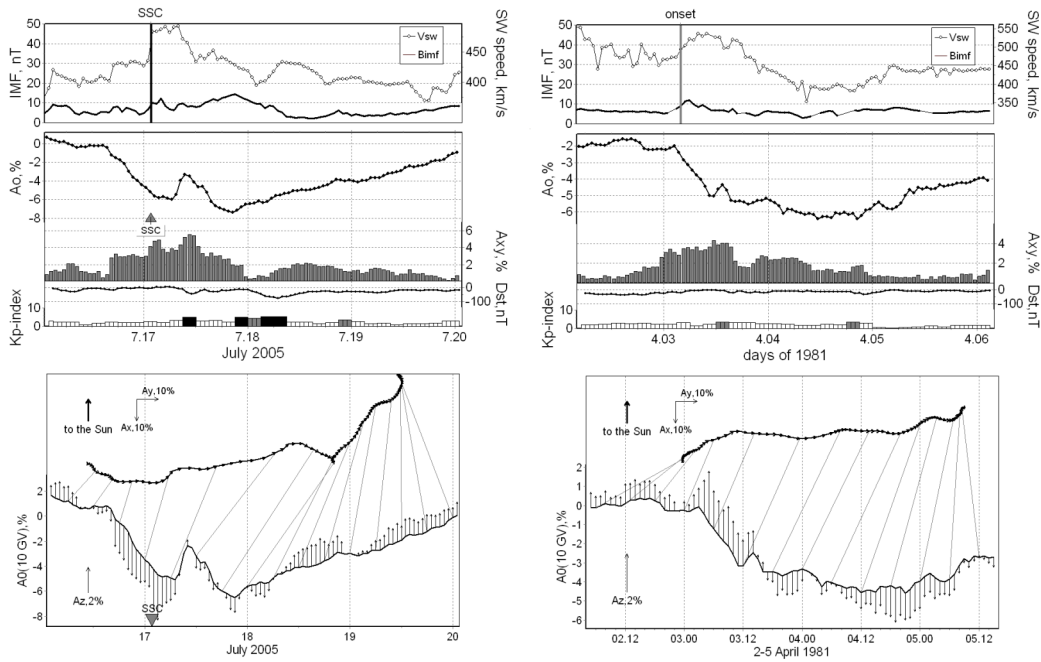


Figure 2. Examples of the FEs in July 2005 and April 1981 caused by the far western solar sources: IMF, solar wind, geomagnetic data (Kp-index and Dst variations), cosmic ray density and anisotropy (A0 and Axy) during the FEs associated with the western power solar flares W79 and W52. In the low panel vector diagram of CR anisotropy (equatorial component Axy) and density (A0) are presented. Vertical vectors mean north-south component of the CR anisotropy. Thin lines connect equal time points in each 6 hours in vector diagram and density curve.

All the above considered FEs are associated with power disturbances originated from far solar sources, and every time the Earth was localized in a periphery of propagating disturbance, so the near Earth measurements did not show a high perturbation in the Earth vicinity. The high magnitude of FEs from such remote sources on this quiet background assumes great power of a disturbance and tells about modulating area wider than the size of disturbance. How it may occur in the case of western source may be, in particular, illustrated by Fig. 6 where the picture of propagating disturbance (adopted from Lugaz et al. 2008) and behavior of CR anisotropy are presented together.

FE started on August 26 2002 after weak shock arrival on the background of moderate interplanetary and geomagnetic activity ($B_m = 15$ nT, $K_p=5-$, minimum $Dst=-47$ nT). The FE magnitude was not big (about 2 %), but CR anisotropy was rather large for such small effect - 3.3 %. It was caused by a CME originated from the western limb (W81) and associated with X3.1/1F solar flare. Fig. 6 demonstrates that western flank of CME came to open magnetic field lines connected to the Earth. This effect is one of the reasons why this CME originated from the western limb caused a noticeable FE with large CR anisotropy on the unsettled background.

4. Conclusions

- In the majority of effective events the Earth enters only a periphery of the interplanetary disturbance, the main part of which passes apart of Earth (to the East or to the West).

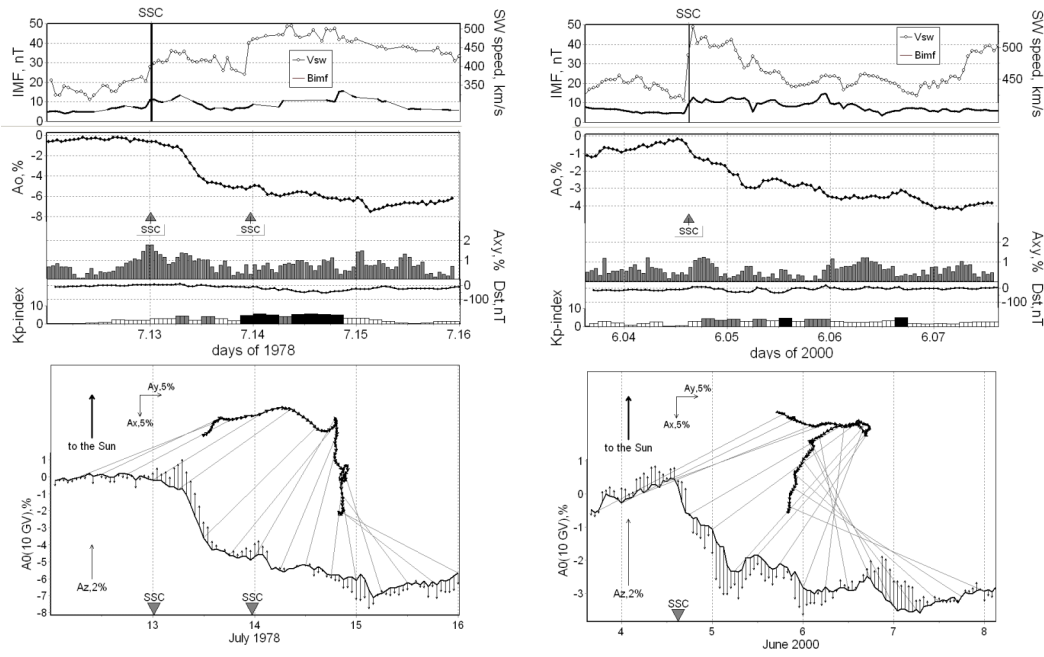


Figure 3. Parameters of the cosmic ray, interplanetary and geomagnetic activity during the FEs associated with far eastern solar flare: in July 1978 (E58) and June 2000 (E60). There are the same designations as in Fig 2.

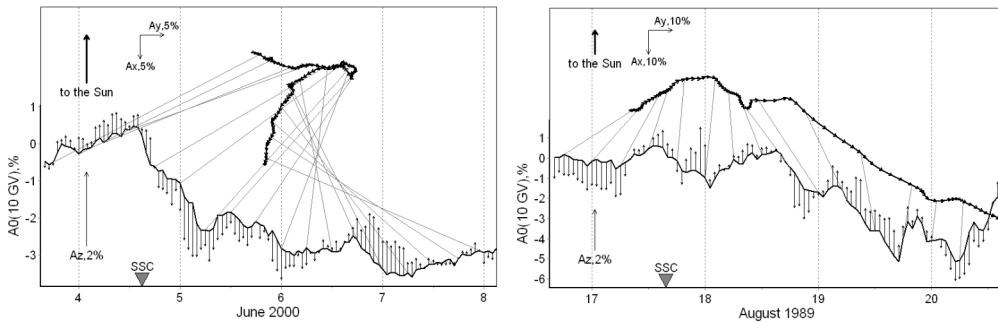


Figure 4. Vector diagrams for equatorial component of CR anisotropy A_{xy} during the FEs associated with eastern (June, 2000, E60) and western (August 1989, W60) solar sources. The notifications are the same as in Fig 2.

- Those events are preceded by powerful flares on the Sun, which are generally located far from the center of solar disk. The CMEs and interplanetary disturbances, originated from the near the limb longitudes, appear to be of larger size and more complicated structure than it is visible near Earth.

- It was possible to separate small but very definite groups of large FEs which were not followed nor by strong interplanetary disturbances near Earth, neither by high geomagnetic activity but seem to be associated with great solar wind disturbances passed apart of Earth.

- The anomalous eastern FEs have prolonged descent phase with a later minimum but

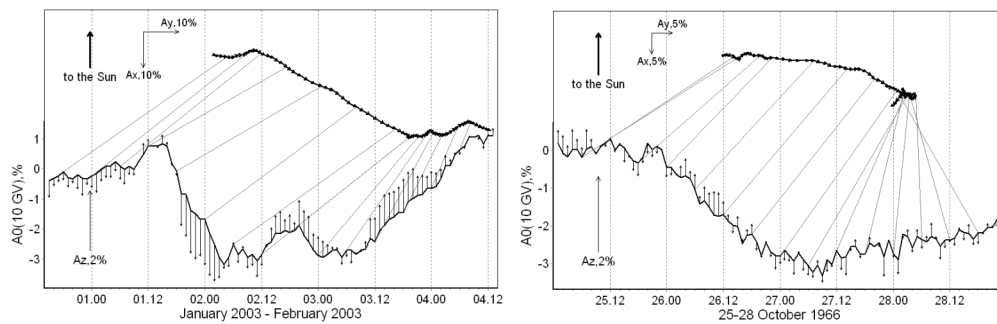


Figure 5. Two examples of events from non-identified sources (February 2003 and October 1966).

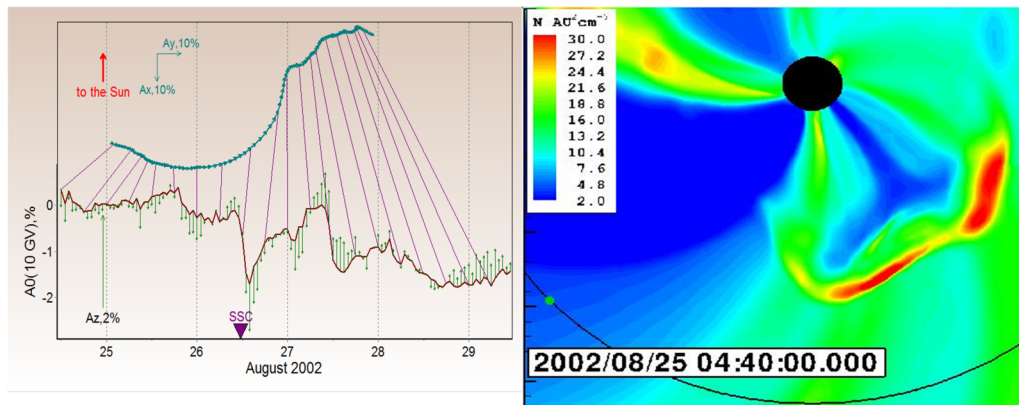


Figure 6. Vector diagram of CR anisotropy behavior and CME model calculations (Lugaz et al. 2008) during the August 2002 event.

larger magnitude in CR density than western events. They emphasize a sharp change of the anisotropy direction in the minimum of FE

- The anomalous western FEs strongly differ from typical FEs caused by western sources which are usually not big and very short. They also differ from the anomalous eastern FEs by bigger size of CR anisotropy and less variability of its direction.

- These properties may be used for the inner heliosphere diagnostics and Space Weather predictions

- In the cases of far sources the CR observations give better information about real power and size of a disturbance than near Earth measurements of the solar wind. Moreover, it may be a useful tool in the cases of events where there is no sufficient data for their identification.

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Discussion