Dependence of Forbush-decrease characteristics on parameters of solar eruptions

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Abstract. We analyze relations between characteristics of an extended ensemble of Forbush decreases (FDs) caused by CMEs from the central zone of the solar disk during the 23rd solar cycle, on the one hand, and such solar eruption parameter as a summarized unsigned magnetic flux of CME-associated EUV dimmings and arcades, on the other hand. This eruption parameter is shown to have a pronounced direct correlation with the FD magnitude and a conspicuous reverse correlation with the ICME transit time from the Sun to the Earth. The revealed correlations indicate that main quantitative characteristics of major non-recurrent FDs (and geomagnetic storms as well) are largely determined by parameters of solar eruptions, in particular such as the summarized magnetic flux of dimmings and arcades.

1. Introduction

Non-recurrent Forbush decreases (FDs) and geomagnetic storms (GMSs) are caused by coronal mass ejections (CMEs) and their interplanetary counterparts ICMEs [1,2]. One of the most important tasks of the solar-terrestrial physics and space weather predictions is diagnostics of geoeffectiveness of CMEs, i.e., an advance quantitative evaluation of a possible GMS and FD from observed characteristics of an eruption, which just occurred. Existing algorithms of such diagnostics are based anyhow on measurements of the CME speed and shape in the plane of the sky near the Sun [1,3].

We develop a new approach to the early diagnostics of solar eruptions in which quantitative characteristics of such large-scale CME manifestations as dimmings and post-eruption (PE) arcades observed in the extreme ultraviolet (EUV) range are used as key parameters instead of the projected CME speed and shape [4,5]. Dimmings are CME-associated regions in which the EUV (and soft X-ray as well) brightness of coronal structures is temporarily reduced during an ejection and persists over many hours. Deep core dimmings formed near the center of an eruption are identified with CME footpoints. Large-scale PE arcades of bright loops enlarging in sizes over time arise at the place of the main body of pre-eruption magnetic flux ropes ejected as CMEs. First of all, we address correlations of the eruption parameters with FD characteristics because the latter, unlike GMSs, do not depend on the interplanetary Bz component being determined by the magnetic field strength in a global ICME as well as by its speed and sizes [6]. Such an analysis is worth itself. In addition, it allows us to estimate relevance of the eruption parameter and its suitability for comparison with GMSs.

In [4,5] we analyzed FDs of the 23rd solar cycle accompanied by major GMSs of Dst < -100 nT and caused by eruptions in the central zone of the visible solar hemisphere within 45° from the disk

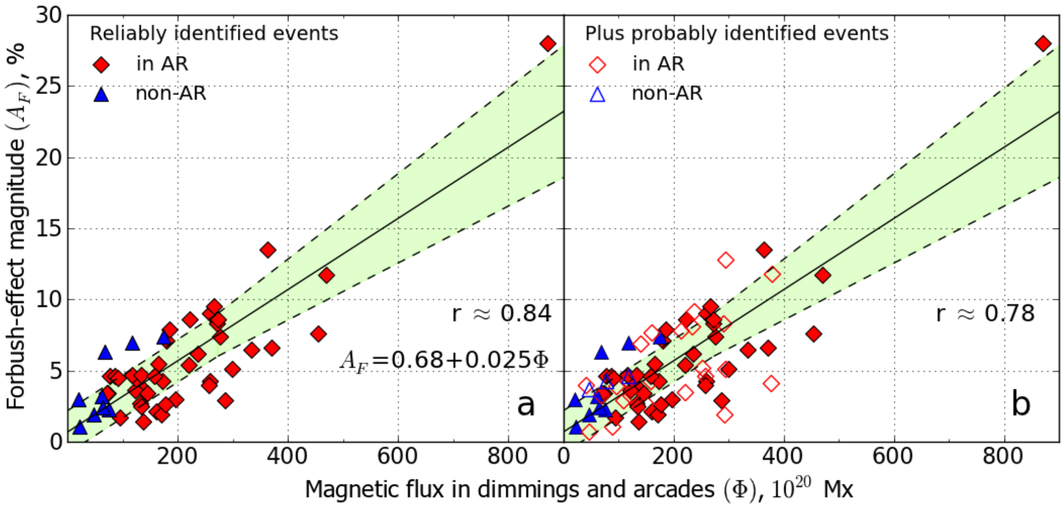

Figure 1. Dependence of the FD magnitude on the summarized unsigned magnetic flux in dimmings and arcades: (a) for FDs unambiguously identified with concrete solar eruptions (filled symbols); b) for all considered events including events with a probable source identification (open symbols). Here and afterwards the diamonds denote eruptions in ARs, and triangles denote filament eruptions outside ARs. The dashed lines delimit the accepted deviation band.

center. Now we extend the ensemble of events and include FDs which, according to [6] and the IZMIRAN Data Base, were not accompanied by GMSs of Dst<-100 nT but had magnitude ≥3% and reliable identification with central solar eruptions.

2. Analyzed parameters

To evaluate parameters of dimmings and arcades, we used EIT solar images in the 195 Å channel and MDI magnetograms gathered with SOHO (see [4]). For each event, the solar rotation in the analyzed images was compensated, and then the same image before an eruption was subtracted from each subsequent ones to obtain fixed-base difference images. Significant dimming and arcade areas were selected with chosen criteria of relative (not absolute) changes of brightness. The analysis showed that the brightness depression of more than 40% was an optimal criterion for selection of relevant dimmings. For PE arcades, a criterion turned out to be appropriate which selected an area around an eruption center where the brightness exceeded 5% from a maximum one. To avoid ambiguity, selection of a PE arcade was performed in an image temporally close to the maximum of the EUV flux from the selected area. Usually this time is close to the peak time of a corresponding GOES soft X-ray flare or somewhat later.

As for a FD characteristic, its maximum magnitude is accepted which corresponds to a cosmic ray rigidity of 10 GV and is determined from data of the world network of neutron monitors using the global survey method. In considering the temporal parameters of an FD, the peak time of the corresponding soft X-ray flare was taken as an eruption time at the Sun. In this study, we analyze two transit times, which adequately characterize FDs and are important for their forecasting. The onset transit time (Δ*T*o) is defined as an interval between the eruption time and the arrival time of the corresponding interplanetary disturbance (shock wave) to the Earth which is indicated particularly by the GMS sudden commencement (SSC). The peak transit time (Δ*T*p) is calculated as an interval between the same eruption time and the moment of the FD maximum for the given event.

We discriminate events initiated by eruptions occurring in ARs and events associated with filament eruptions outside ARs (the latter are referred below as non-AR ones). The reasons are that these two categories of eruptions differ significantly in characteristics of accompanying dimmings and PE arcades, properties of CMEs/ICMEs, and intensities of FDs which they cause. The whole list of the

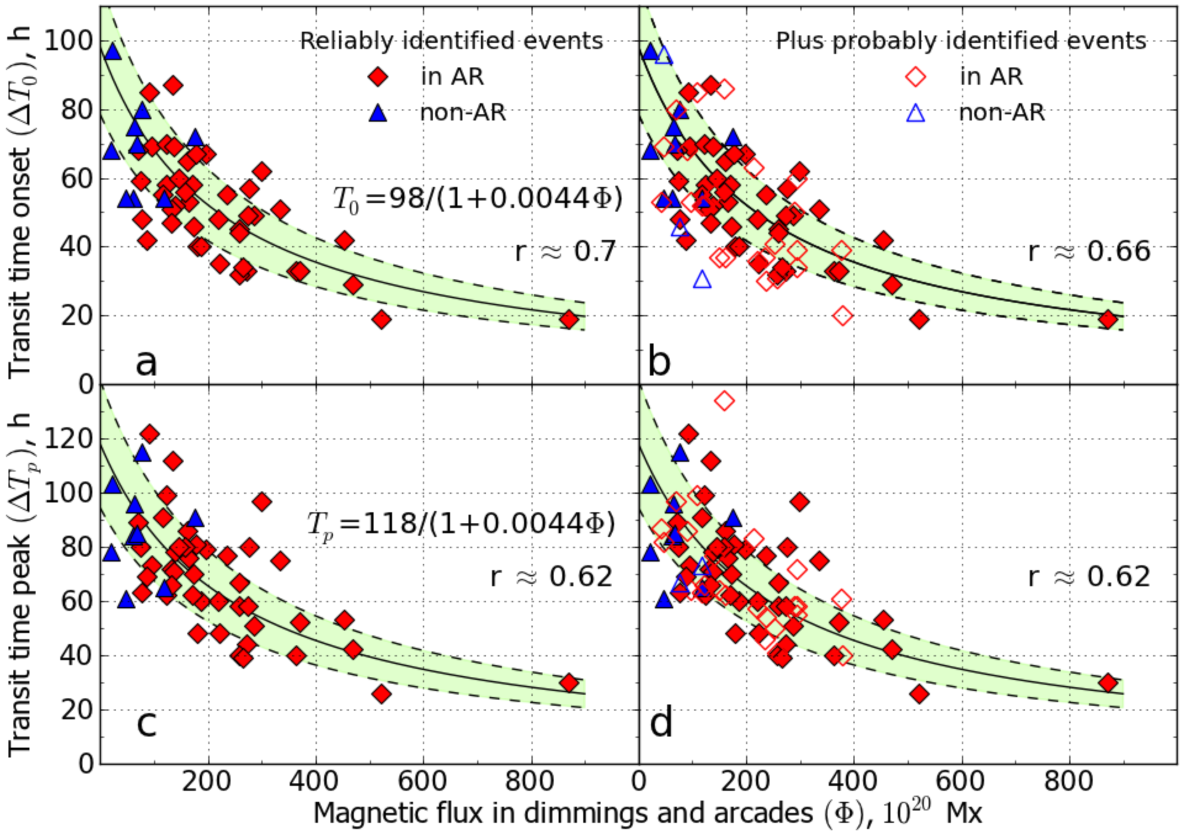

Figure 2. The same as in figure 1 but for dependence of the FD onset (ΔTo, panels a,b) and peak (ΔTp, panels c,d) transit times on the eruptive magnetic flux Φ.

events under consideration and their relevant parameters is presented in Table accessible at http://helios.izmiran.rssi.ru/lars/Chertok/Forbush/ together with some additional illustrations.

3. FD magnitude

Figure 1a shows the relationship between the magnetic flux Φ and the FD magnitude AF for events unambiguously identified with concrete solar eruption. Here and afterwards the filled diamonds and triangles correspond to the AR and non-AR eruptions, respectively. One can see that a conspicuous dependence of the FD magnitude on the magnetic parameter of eruptions does exist. The correlation coefficient between Φ and AF reaches $r \approx 0.84$. Note that this high correlation is only marginally due to a great contribution from the event with the largest values of Φ and AF caused by the famous Halloween solar eruption on 2003/10/28. The high correlation ($r \approx 0.68$) persists even without this event. For additional evaluation of the point scatter, we accept a deviation band bounded by ±0.2 of the regression line's slope but not less than ±1.5% of AF. The latter condition applies at relatively small eruptions, which correspond to magnetic fluxes $\Phi \leq 273\times10^{20}$ Mx and FD magnitudes AF ≤ 7.5%. Calculations show that 26 of 51 events (i.e., 51%) fall into this deviation band.

The dependence of the FD magnitude on the eruption magnetic flux appears to be basically the same when events with probable source identification (open symbols in figure 1b) are added to unambiguously identified events. Here, as expected, the scatter of points increases, and the correlation coefficient somewhat reduces ($r \approx 0.78$). In this case, 37 points of 78 (*i.e.*, 47%) fall into the same deviation band. Events associated with filament eruptions outside ARs (triangles) are characterized by relatively low values of magnetic fluxes. Nevertheless, some of them were accompanied by relatively strong FDs. A probable reason for this might be that the adopted criteria of extraction of the dimming and arcade areas are not fully appropriate for these non-AR eruptions.

4. Transit times

In figure 2, the relationships between the eruptive magnetic flux Φ and the onset (ΔTo) and peak (ΔTp) transit times are presented. For unambiguously identified events (figure 2a,c) the dependencies between Φ and ΔTo, ΔTp are evident. The greater eruptive magnetic flux (*i.e.*, the more powerful eruption), the shorter the transit times of the ICME-driven shock and ICME body from the Sun to the Earth are, and the faster a FD starts and peaks. For the strongest eruptions with $\Phi \approx (500–900)\times 10^{20}$ Mx, the onset and peak transit times come to a level of about 20–30 h, which corresponds to the average 1 AU ICME transit speed of about 1400–2100 km s^{-1}. The correlation coefficient between the observed transit times and those calculated from the curves shown in figure 2a,c is sufficiently high: $r \approx$ 0.7 and 0.62 for ΔTo and ΔTp, respectively. The ±0.2 deviation band between the dotted lines contains 29 of 52 (*i.e.*, 56%) and 30 of 52 (*i.e.*, 58%) of the events for the onset and peak times.

The dependencies between Φ and both transit times are almost not impaired, when less reliably identified events (open symbols) are taken into account and plotted in figure 2b,d. Here the correlation coefficients between the observed times and those calculated from the curves only slightly reduce to $r \approx$ 0.66 for ΔTo and 0.62 for ΔTp. The scatter somewhat increases, and the number of points within the same ±0.2 deviation bands decrease to 40 of 79 (*i.e.*, 51%) and to 47 of 79 (*i.e.*, 60%) .

5. Conclusion

We have studied relationships between magnitudes and time characteristics of non-recurrent FDs, on the one hand, and quantitative parameters of such their solar source manifestations as EUV dimmings and PE arcades accompanying the corresponding CMEs, on the other hand, for the extended ensemble events of the 23rd cycle. In particular, the summarized unsigned magnetic flux of the line-of-sight magnetic field at the photospheric level within the dimming and arcade areas is used as a main parameter of eruptions. The results confirm conclusions of [4,5] and reveal that parameters of FDs caused by CMEs/ICMEs are largely determined by energetics and spatial extent of solar eruptions in spite of many other factors affecting the propagation of interplanetary disturbances from the Sun to the Earth. This is true especially for sufficiently powerful eruptions. Just thanks to this fact we were able to establish the close statistical relationships of the magnetic flux in dimmings and arcades with the main parameters of FDs. Positive results obtained for FDs show high relevance of the eruptive magnetic flux as a diagnostic parameter and allow us to use it for comparison with intensity of GMSs even without taking into account the factors determining the Bz component near the Earth [5].

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