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# Dependence of Forbush-Decrease Magnitudes on Parameters of Solar Eruptions[1]

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**Abstract**—By data of the 23rd solar cycle, it is shown that close statistical relations exist between quantitative parameters of dimmings and arcades caused by solar coronal mass ejections (CMEs), on the one hand, and magnitudes of non-recurrent Forbush-decreases of the galactic cosmic ray flux, as well as the propagation time of disturbances from the Sun to the Earth, on the other hand. Parameters of dimmings and arcades, in particular their summarized magnetic flux of the prolonged field at the photospheric level, were calculated by data of the EUV SOHO/EIT telescope in the 195 Å channel and the SOHO/MDI magnetograms. Received results mean that the scale, characteristics, and propagation time of interplanetary disturbances to the Earth are determined to a large degree by measurable parameters of solar eruptions and may be estimated in advance by observations of dimmings and arcades in the EUV range.

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## INTRODUCTION

Non-recurrent space weather disturbances in the form of geomagnetic storms, as well as Forbush-decreases (FDs) of the galactic cosmic ray flux are caused by solar coronal mass ejections (CMEs) which under their propagation from the Sun transform into interplanetary transients (ICMEs) (see, e.g., [1, 2]). An eruption of large CMEs at the Sun is accompanied by formation of post-eruptive (PE) arcades and dimmings (Fig. 1). Arcades of bright loops enlarging in sizes form at the place of pre-eruptive magnetic flux ropes ejected as CMEs. Dimmings (or transient, i.e. temporal, coronal holes) are large-scale regions of reduced brightness of the extreme ultra-violet (EUV) and soft X-ray emission which arise in the corona as a result of CMEs and are identified with footpoints of erupting magnetic structures. As a main background it is accepted that dimmings and PE arcades visualize control structures involved in CMEs. So far, in the space weather aspect, only qualitative information about dimmings and arcades was used as a tool for separation of CMEs originating in result of eruptions on the visible solar disk. Meanwhile, basing on the dimming and arcade nature, one can expect statistical relations of their quantitative parameters with intensity of geomagnetic storms and FDs [3]. It is logical to begin the analysis of such relations just with FDs, because the intensity of geomagnetic storm depends on value and sign of the $B_z$ magnetic field component in ICMEs while the FD depth does not depend on the $B_z$ sign and is determined by the magnetic field strength in ejecta as well as by their speed and sizes [4]. In this paper, preliminary results of correlation of FD depths, causing by CMEs/ICMEs, with quantitative parameters of the corresponding dimmings and arcades, as well as results of the analysis of relations between these parameters and the propagation time of interplanetary ejecta from the Sun to the Earth (so called transit time) are presented.

[1] The article was translated by the authors.

## DATA AND METHOD

For estimation of the dimming and arcade parameters, we analyzed solar images in the 195 Å channel (predominated line is Fe XII, characteristic temperature of 1.3 MK) gathered with the space EUV telescope on SOHO/EIT [5]. Data processing was carried out with an IDL program elaborated for this object

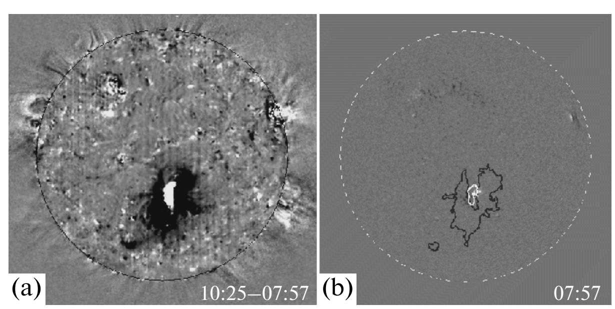


**Fig. 1.** Eruption of 3 April 2010: (a) solar difference images in the 195 Å channel with dimmings (dark areas) and PE-arcade (bright structure); (b) dimmings and arcade contours against the background of the MDI magnetogram.

which performs: calibrations of initial EIT FITS files; compensation of solar rotation and making difference images [6]; extraction of the dimmings and PE arcade forming in the region of an analyzing CME; measurements by chosen criteria of areas and emission fluxes (summarized brightness) in the dimming and arcade regions; overlapping of the received images of the dimmings and arcade with the SOHO/MDI magnetograms [7] and calculation of the photospheric magnetic fluxes corresponding to these structures. In the course of the analysis, the thresholds of relative changes of brightness, which are optimal for estimations of the dimming and arcade parameters, were determined. Brightness reductions of more than 40% were considered as a criterion for extraction of significant dimmings. For PE arcades an optimal criterion extracted an area above the eruptive center in which the EUV emission brightness exceeded 5% from maximum one at the peak time.

At the first stage, about 70 large events of the 23rd cycle (1997–2008) have been analyzed, in which by data of the Coordinated Data Analysis Workshop (CDAW; see [8]), besides FDs, geomagnetic storms with the index |Dst| > 100 nT occurred and which at a great probability level were identified with an eruption of concrete CMEs from the central zone of the visible solar hemisphere within ±45° from the central meridian. The majority of these eruptions occurred in active regions but some part of events was associated with filament eruptions outside active regions. As a FD characteristic, its maximum magnitude was accepted which corresponded to a rigidity of 10 GV and was determined by data of the world station network using the global survey method [9, 10].

## MAGNITUDE OF FORBUSH-DECREASES AND TRANSIT TIME

A summarized magnetic flux of the prolonged field at the photospheric level within dimmings and arcades (Φ) is the most informative parameter for the given analysis. Results of its correlation with the FD magnitude ($A_F$) are presented in Fig. 2a. One can see that a quite explicit dependence of the FD magnitude on the dimming and arcade magnetic flux takes place for reliably identified events. When Φ increases from $3 \times 10^{21}$ to $10^{23}$ μs, the expected FD amplitude $A_F$ rises from 0.8 to 30%. The correlation coefficient between Φ and $A_F$ makes up 0.94. The dependence between the dimming and arcade summarized magnetic flux and the FD magnitude is described by the following linear regression relation $A_F\,(\%) = -0.08 + 0.03\Phi\ (10^{20}\ \mu s)$.

As the present analysis showed, the dimming and arcade parameters, including the summarized magnetic flux of the prolonged field at the photospheric level Φ, contains also information on speed of erupted CMEs and consequently on the transit time of interplanetary disturbance propagation from the Sun to the Earth. In the given case, the transit time ($T_t$) was calculated as an interval between the maximum moment of the soft X-ray burst associated with the eruption under consideration and the arrival time of the corresponding shock wave to the Earth which was determined particularly by the geomagnetic storm sudden commencement (SC). Figure 2b demonstrates a clear relationship between the summarized magnetic flux Φ and transit time $T_t$ which takes place for single reliably identified events. When Φ increases in the (30–300) × $10^{20}$ μs interval, $T_t$ decreases sharply on the average from 75 to 40 h. With furter increase of the magnetic flux, the transit time continues to decrease gradually and under the largest expected values of the magnetic flux $\Phi \approx 10^{23}$ Mx it amounts $T_t \approx 18$–20 h. As a whole, the dependence between Φ and $T_t$ can be described by the following relations (dashed line in Fig. 2b) $T_t\,(\text{h}) = 85/(1 + 0.004\Phi)$, here Φ is in $10^{20}$ μs. In this case, the correlation coefficient between the calculated and observed values of $T_t$ constitutes 0.73. The fact that the quite explicit dependence between $T_t$ and Φ takes place allows us to conclude that in comparison of the FD magnitude with the dimming and arcade magnetic flux it is not necessary to involve any additional information about CME/ICME speed. Note that the events associated with a filament eruption outside of active regions (triangles in Fig. 2) are characterized by not great magnetic flux values and concentrate mainly in the region of small FD magnitudes and large transit times.

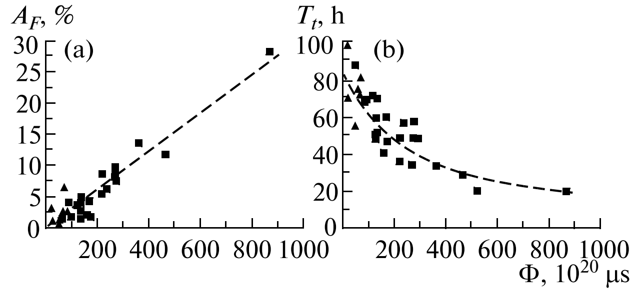


**Fig. 2.** Dependence of the Forbush-decrease magnitude ($A_F$) (a) and transit time ($T_t$) (b) on the summarized magnetic flux of the dimmings and arcade at the photospheric level (Φ) for single events identified reliably with a concrete solar eruption from the central sector of the solar disk. Squares refer to eruptions in active regions, triangles—to eruptions outside active regions.

## CONCLUSIONS

The presented results show that the value of non-recurrent FDs and the transit time of interplanetary disturbance propagation from the Sun to the Earth are determined to a considerable degree by character and parameters the solar eruptions. It turns out that both the magnitude of non-recurrent FDs and the transit time are closely associated with such a complex parameter of dimmings and PE arcades as their magnetic flux at the photospheric level. These results are important for understanding of the solar eruption nature. The eruptive magnetic flux turned out to be an informative parameter for estimations not only of the FD magnitude and transit time but also of such important space weather disturbances as non-recurrent geomagnetic storms. This is confirmed by a preliminary analysis already carried out whose results will be published separately.

Results of the present analysis provide an instrument for diagnostics of the geoefficiency of solar eruptions and for short term forecasting of non-recurrent space weather disturbances. By EUV images and magnetograms of the solar disk one can determine the quantitative parameters of dimmings and PE arcades, including their summarized magnetic flux at the photospheric level, and by it estimate the expected magnitude and onset time of FDs and geomagnetic storms with advancing from 1 to 4 days. It should be kept in mind only that the dependences presented here are obtained by large eruptions with which geomagnetic storms of the index $|Dst| > 100$ nT were associated.

As an experiment, such a short term forecasting of the space weather disturbances by results of the solar eruption diagnostics was carried out during 2010 in the IZMIRAN Center of Space Weather Forecasting. Eruptions of the incipient 24th cycle from the central zone of the solar disk were considered. By the dimming and arcade parameters, the majority of them was relatively small and according to estimations should resulted in rather faint space weather disturbances, that was confirmed. One of the most significant eruptions of 2010 took place on 3 April. The dimmings and arcade observed just in this eruption is shown in Fig. 1. The summarized magnetic flux in this case was of $\Phi \approx 1.1 \times 10^{22}$ μs. The expected transit time $T_t \approx 59$ h, FD magnitude $A_F \approx 3\%$ and geomagnetic storm intensity Dst $\approx -90$ nT correspond to such a flux. The really observed values turned out close to the forecasted ones: $T_t \approx 47$ h, $A_F \approx 2.9\%$, Dst $\approx -73$ nT. Approximately the same coincidence of the expected and observed values of $T_t$, $A_F$ and Dst was obtained in diagnostics of another large eruption from the central sector of the disk occurred on 1 August 2010.

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