
2. Five-Phase Dynamics of the Substorm of October 28–30

K. G. Ivanov and A. F. Kharshiladze

Pushkov Institute of Terrestrial Magnetism, Ionosphere, and Radiowave Propagation, Russian Academy of Sciences (IZMIRAN), Troitsk, Moscow oblast, 142190 Russia

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Abstract—The assumption that a solar–heliospheric storm has five phases is formulated based on the storm that occurred in October 2003. The first phase: slow (between solar rotations) convergent motions of photospheric sources of large-scale open solar fields (LOFs) with generation of active regions (ARs) between these fields. The second phase: magnetic energy pumping with adjustment of zero lines of the photospheric magnetic field in AR to the configuration of the LOF sector (subsector) boundaries. The third phase: AR destabilization with ordering of the complex of sporadic phenomena near ARs parallel to the zero line and fragments of the nearest LOF boundary. The fourth phase: propagation of disturbances in the near-Sun space with ordering relative to the LOF boundaries. The fifth phase: propagation of a coronal mass ejection (CME) in the inner heliosphere in the case when the axial axis of a magnetic cloud in CME is parallel to the LOF boundary and to the zero line in AR. Original results of LOF modeling and a number of substantial results of the known advanced studies of individual aspects of this storm are used to justify this dynamics as applied to the storm of October 28–30. Specific contents and features of each storm phases are presented. The specific feature of the first phase, responsible for the storm space–time scales and intensity, consisted in the displacement of the entire LOF negative magnetic flux (~5 × 10^{22} µs) from the north pole to the south with flowing around a midlatitude obstacle and with zonal convergent motions of LOF. The assumption of the AR configuration adjustment (the second phase) and ordering of disturbances (the third–five phases) during this storm near the subsector boundary between LOFs of identical polarity has been confirmed. It is noted that the pulse phase of the AR 0486 flare, coronal waves, and dimmings along the subsector boundary and the southwestern LOF “dam” joining ARs 0486 and 0484 (superposition of the third and fourth phases) originated almost simultaneously. The two-component disturbance structure is confirmed: halo-type CME with the axis along the LOF subsector boundary and a bright local ejection of magnetic plasma from the region above the southwestern LOF dam.

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1. INTRODUCTION

It becomes more actual to study the Sun, interplanetary medium, and near-Earth space as an integrated physical system. Within the scope of the known programs Living with a Star and International Heliospheric Year, such studies are considered as priority works favoring the solution of the strategic problems of creating the detailed and exact pattern of the solar–interplanetary–magnetospheric coupling and applied problems [Guhathakurta, 2006].

These objects are naturally achieved by developing phenomenological and semi-phenomenological models of prominent solar–terrestrial storms, which order the entire complex of experimental data from the solar convective zone to the Earth and take into account a substantial peculiarity of each individual storm. Such an approach was realized as applied to the storms of January 10, 1997 [Ivanov et al., 2003], May 15, 1997 [Ivanov et al., 2003a], and July 15, 2000 [Ivanov and Kharshiladze, 2004; Ivanov, 2004, 2004a; Ivanov et al., 2005]. Similar approaches to studying the storms of October–November 2003 [Ivanov et al., 2005a, 2006] and August 2005 [Ivanov and Kharshiladze, 2007] were initiated.

The development of the phenomenological model of a solar–terrestrial storm [Ivanov et al., 2005; Ivanov, 2006] was one of the results of these studies. The solar–interplanetary part of this storm includes the following five phases: (1) Convergent motions (collisions) of photospheric sources of solar LOFs and generation activity complexes in the space between these fields. (2) Magnetic energy pumping with generation of active regions (ARs) between these fields. The second phase: magnetic energy pumping with adjustment of zero lines of the photospheric magnetic field in AR to the configuration of the LOF sector (subsector) boundaries. The third phase: AR destabilization with ordering of the complex of sporadic phenomena near ARs parallel to the zero line and fragments of the nearest LOF boundary. The fourth phase: propagation of disturbances in the near-Sun space with ordering relative to the LOF boundaries. The fifth phase: propagation of a coronal mass ejection (CME) in the inner heliosphere in the case when the axial axis of a magnetic cloud in CME is parallel to the LOF boundary and to the zero line in AR. Original results of LOF modeling and a number of substantial results of the known advanced studies of individual aspects of this storm are used to justify this dynamics as applied to the storm of October 28–30. Specific contents and features of each storm phases are presented. The specific feature of the first phase, responsible for the storm space–time scales and intensity, consisted in the displacement of the entire LOF negative magnetic flux (~5 × 10^{22} µs) from the north pole to the south with flowing around a midlatitude obstacle and with zonal convergent motions of LOF. The assumption of the AR configuration adjustment (the second phase) and ordering of disturbances (the third–five phases) during this storm near the subsector boundary between LOFs of identical polarity has been confirmed. It is noted that the pulse phase of the AR 0486 flare, coronal waves, and dimmings along the subsector boundary and the southwestern LOF “dam” joining ARs 0486 and 0484 (superposition of the third and fourth phases) originated almost simultaneously. The two-component disturbance structure is confirmed: halo-type CME with the axis along the LOF subsector boundary and a bright local ejection of magnetic plasma from the region above the southwestern LOF dam.

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the conservation of the initial geometry, propagation of an MHD disturbance from the Sun to the Earth’s orbit.

In the initial form, this model (with the last three phases distinguished) originated when the results of the solar-terrestrial extrastorm of July 15, 2000, were systematized [Ivanov et al., 2005] and, subsequently (without formal introduction of the first two phases), in the report [Ivanov, 2006]. The aim of this paper is to study the possibility of applying this model to the solar–terrestrial extrastorm of October 28–30, 2003.

As was indicated above, we began to systematize the studies of this storm in [Ivanov et al., 2005]. Specifically, we indicated that (1) the storm started with the convergent motions of LOFs of identical polarity accompanied by the generation of extremely powerful sunspot groups in NOAA AR 100486 and 100488 (point 1 of the above model); (2) the axis of the near-Earth cloud was quasi-parallel to the subsector boundary near which AR 0486 and 0488 originated and became stable (point 5 of the model).

In this paper we will continue the systematization within the scope of the above model, using recently obtained results of advanced studies of this storm on the Sun [Borisevich et al., 2004; Dvornikov et al., 2004; Eselevich and Eselevich, 2004; Chertok and Grechnev, 2005; Gopalswamy et al., 2005; Grechnev et al., 2005; Wang, 2005; Wang et al., 2005; Yurchyshyn et al., 2005] and in the near-Earth interplanetary medium [Dmitriev et al., 2005; Farrugia et al., 2005; Hu et al., 2005; Jackson et al., 2005; Terasawa et al., 2005]. Moreover, the reviews of the main results of this storm observation [Veselovsky et al., 2004; Gopalswamy et al., 2005a] and MHD modeling of disturbance propagation from the Sun to the Earth [Wu et al., 2005].

In Section 2 we successively consider the above five phases of this storm.


2.1. The First Phase: Convergent LOF Motions and Origination of NOAA AR 100486 and 100488

This phase was rather comprehensively described in the previous paper [Ivanov et al., 2005a]. It was indicated that LOFs accomplished convergent motions between October 1 and 28, 2003. By the end of this period, the area and number of sunspots in one of the groups, AR 0470(0486), reached unusually large values, and the other group (AR 0488) originated and rapidly developed in the space between these fields. Thus, the phenomena indicated in the subsection heading took place during the first phase of the solar–terrestrial storm. These phenomena reflect the general regularity in the relation between LOFs and ARs established previously [McIntosh and Wilson, 1985; Ivanov et al., 2001]. The fact that this regularity was for the first time distinctly identified during convergent motions of LOFs of identical polarity was a new element of the regularity.

We continue studying this phase in the present paper in order to specify the LOF structure, configuration, dynamics, and intensity. This became possible after the following recent modification of the software package for modeling solar magnetic fields (ISOPAK) developed by us.

Let us draw a rectangle around the compact D region of open field lines on the photosphere of the form

\[ P = \{ \varphi_{\min} < \varphi < \varphi_{\max}, \lambda_{\min} < \lambda < \lambda_{\max} \}, \]

where \( \varphi \) and \( \lambda \) are heliographic coordinates, in such a way that rectangle \( P \) would not include a root of any open field line except the lines that belong to the D region. We divide rectangle \( P \) into the \( 2\times10 \) network of small rectangles (squares) \( P_{ij} \), where \( 0 < i < n \) and \( 0 < j < m \) (in total, \( n \times m \) squares). We specify any rather dense network of points above rectangle \( P \) on the source surface and descend a field line to the intersection with the photosphere. Write \( E \) for the set of roots of these field lines. The \( E \) set of intersections of these field lines with the photosphere belongs to the \( D \) region of open field lines (since field lines going from the source surface can be only open). In this case the network of points on the source surface should be so dense that even one point of the \( E \) set falls in each small \( P_{ij} \) square crossing the \( D \) region. None open field line falls in squares that do not cross the \( D \) region since these squares completely lie outside the region of open field lines. The magnetic flux through a tube of open field lines is calculated in the following way. The magnetic flux (\( \Phi_{ij} \)) through a \( P_{ij} \) square with even one point of the \( E \) set is equal (with an acceptable error) to the area of this square multiplied into the average value of the magnetic field normal component at points of the \( E \) set within a \( P_{ij} \) square. The magnetic flux through a \( P_{ij} \) square without any point of the \( E \) set is equal to zero.

Having summed the magnetic flux in all squares

\[ \Phi = \sum_{i=0}^{n} \sum_{j=0}^{m} \Phi_{ij}, \]

we obtain the required flux through a tube of open field lines.

Figure 1 presents the LOF maps for three successive rotations centered at October 1, October 28, and November 24, 2003, which are more accurate than the maps shown in Fig. 1 in [Ivanov et al., 2005] obtained with the help of ISOPAK based on the photospheric magnetic field measurements at WSO (Wilcox Solar Observatory, http://quake.Stanford.edu/~WSO). Figure 2 shows the field line configuration and subsector boundary between two low-latitude LOF branches.

Table 1 presents the values of the solar LOF fluxes calculated using the above method and the Ulrich correction, as was recommended in [Obridko et al., 2006],

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