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Research note

Event-oriented modelling of magnetic fields and currents during storms

Natalia Yu. Ganushkina[1], Tuija I. Pulkkinen[1], Marina V. Kubyshkina[2], Masaki Ejiri[3], Howard J. Singer[4] and Christopher T. Russell[5]

[1] *Finnish Meteorological Institute, Geophysical Research Division, P.O. Box 503, FIN-00101 Helsinki, Finland*
[2] *Institute of Physics, University of St.-Petersburg, St.-Petersburg, 198904, Russia*
[3] *National Institute of Polar Research, Kaga 1-chome, Itabashi-ku, Tokyo 173-8515*
[4] *NOAA Space Environment Center, Boulder, CO 80303-3328, U.S.A.*
[5] *Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1567, U.S.A.*

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Abstract: We model the magnetospheric magnetic field during two storms, moderate and intense, using the event-oriented modelling technique which includes the representations of the magnetic field arising from the various magnetospheric current systems. The model free parameters are specified for each time step separately using observations from GOES 8, 9, and 10, Polar, Interball and Geotail satellites and *Dst* measurements. It is shown that the ring current is most important during intense storms, whereas the near Earth tail currents contribute more to the *Dst* index than the ring current during moderate storms.

key words: magnetospheric current systems, magnetic field modelling, storms and substorms

1. Introduction

Many changes occur in the Earth's magnetosphere during magnetic storms, including changes in different current systems, and, hence, in the magnetic field. During the last decades several magnetospheric magnetic field models have been developed (Alexeev *et al*., 2001; Tsyganenko, 2002a, b). Magnetospheric configurations corresponding to average conditions are quite well represented by these models, whereas, fine structure in the magnetic field during substorms or large magnetic field changes during storms cannot be accounted for by these models (Ganushkina *et al*., 2002). Several types of studies require an accurate representation of the magnetospheric configuration during a specific event. It is the magnetospheric configuration that determines how particles move in the magnetosphere, and changes in that configuration provide the particle acceleration. For such cases, event-oriented modeling may be of key importance (Ganushkina *et al*., 2004).

In this paper we model two storm events, one moderate storm on June 25–26, 1998, when *Dst* reached −120 nT, and one intense storm on April 6–8, 2000 when *Dst* dropped to −300 nT. We examine the long-term evolution of different current systems during storm times and compute the relative contributions from the ring, magnetotail and magnetopause currents to the *Dst* index.

2. Description of events

On June 25, 1998 the IMF B_z behavior (Fig. 1a, upper panel) reflected the passage of magnetic cloud: sudden jump to more than +15 nT at 1550 UT and southward turn up to −13 nT around 2300 UT. Solar wind dynamic pressure had several peaks around 8–10 nPa with one peak of about 18 nPa at about 1000 UT on June 26 (second panel from the top). The *AE* index (next panel) showed first increase at about 2300 UT on June 25 and reached a peak value of 1400 nT around 0255 UT on June 26. The *Dst* index (bottom panel) started to decrease at the beginning of June 26 and reached −120 nT around 0500 UT.

April 6–7, 2000 intense storm was caused by coronal mass ejection which took place on the Sun on April 4. IMF B_z reached −30 nT around 1800 UT on April 6 (Fig. 1b, upper panel). Magnetosphere was very much compressed, solar wind dynamic pressure showed several peaks reaching 25 nPa on storm maximum at about 0000 UT on April 7 (second panel from the top). The *AE* index (next panel) showed great increase at about 1800 UT on April 6 with value of 2400 nT. The *Dst* (bottom panel) started to decrease at around 1800 UT on April 6 and reached −300 nT around 0000 UT on April 7.

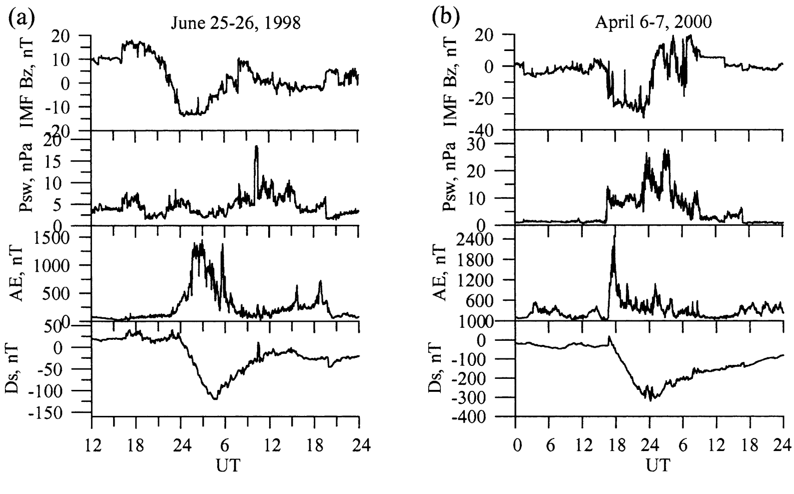

Fig. 1. Event overview for June 25–26, 1998 storm (a) and April 6–7, 2000 storm (b).

3. Modelling results

We model the magnetic field during June 25–26, 1998 moderate storm and April 6–7, 2000 intense storm using Ganushkina *et al.* (2004) event-oriented storm-time magnetic field model. The model used the Tsyganenko T89 magnetic field model (Tsyganenko, 1989) as a baseline, and the ring, tail and magnetopause currents were modified to give a good fit with *in-situ* observations. To represent the storm-time ring current the T89 ring current was replaced by a bean-shaped current system, which has a cross-section that is close to the observed distribution of trapped particles in the inner magnetosphere. It is achieved by representing the current density at a point outside the equatorial plane by the functional dependence similar to that of omni-directional flux along the field line (Roederer, 1970). Ring current has eastward flowing inner and westward flowing outer components. In addition to the symmetric ring current, an asymmetric partial ring current was taken into account with closing Region 2 sense field-aligned currents. For the tail current system both global and local changes were introduced. Global changes include intensification of the tail current sheet as a whole using a tail current amplification factor, which indicates the change of the tail current from the original value, *i.e.* that given by T89 model. A new thin tail current sheet is added as a combination of two vector potentials similar to T89 to account for the local changes during substorms. Magnetopause currents are varied in accordance with solar wind dynamic pressure variations. The free parameters in the model are the radii of the westward and partial ring currents, the maximum current densities for westward and partial ring currents, the amplification factor for the tail current, and the amplitude of additional thin current sheet intensity. Other parameters are either fixed or calculated from solar wind and *Dst* measurements (for details, see Ganushkina *et al*., 2004). We searched the values of the free parameters that give the best fit between the model and the *in-situ* field observations by GOES 8, GOES 9, GOES 10, Polar, Geotail and Interball satellites, and the *Dst* measurements. The details of the fitting procedure can be found in Ganushkina *et al*. (2002).

To get the model *Dst* index, the magnetic field from the extraterrestrial currents was computed at the locations of several stations such as Sun Juan, Tenerife, Tbilisi, Lunping, Kakioka, Honolulu and Del Rio. However, before the model values can be compared with the observed ones, the quiet time level must be subtracted from the model. This is done by modeling the entire duration of the quietest day of the month for each storm event. The quiet level of the magnetic field given by the model is then evaluated at the locations of *Dst* stations. In order to be able to examine the contributions of the different current systems to the *Dst* index, the quiet time levels are also evaluated for the ring, tail and magnetopause currents separately. Currents in the magnetosphere induce currents in the electrically conducting Earth, which are estimated to be about 25% of the measured *Dst* (Häkkinen *et al*., 2002). In comparing our model *Dst* with the observed one, we remove this 25% from the observed *Dst*.

The model allows us to calculate the contributions of tail, ring and magnetopause currents to the *Dst* index. Quiet time contributions for each current system were computed first. Figure 2 shows contributions from the ring current (thick solid curve), tail current (dash-dotted curve) and magnetopause currents (dotted curve) to the observed *Dst* index (thin solid curve) during June 25–26, 1998 moderate storm (a) and April 6–7, 2000 intense storm (b). It is clear that the contributions from different current systems to the *Dst* index depend on the storm strength and change during the storm development. During the moderate storm on June 25–26, 1998, the tail current contributes more than the ring current to the *Dst*. The situation is quite different during the intense storm on April 6–7, 2000: the main contribution to *Dst* comes from the ring current. The ring current contribution gradually increases and reaches maximum at the intense storm maximum, whereas the tail current contribution starts to decrease before the storm maximum. For both storms the tail current intensifies

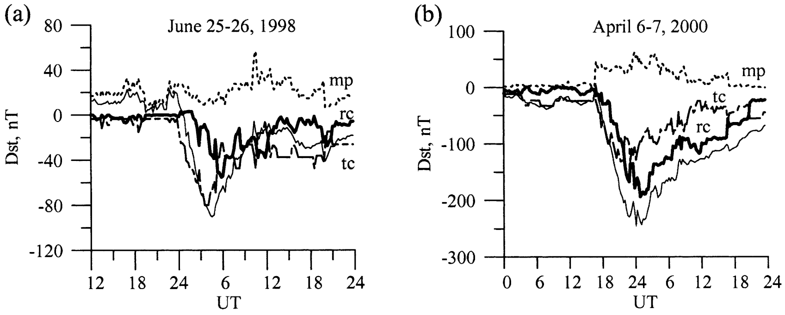

Fig. 2. Contributions from the ring current (thick solid curve), tail current (dash-dotted curve) and magnetopause currents (dotted curve) to the observed Dst index (thin solid curve) during June 25–26, 1998 moderate storm (a) and April 6–7, 2000 intense storm (b).

first at the storm beginning when the *Dst* drops while the ring current develops later and stays longer at an increased level.

4. Conclusions and discussion

In this paper we discuss model results of the evolution of current systems and their contribution to *Dst* index during two storm events on June 25–26, 1998 and April 6–7, 2000 given by event-oriented storm-time magnetic field model by Ganushkina *et al.* (2002, 2004). The model describes the ring current, the tail current, and the magnetopause currents with functions containing free parameters, whose values are defined for each time step separately based on in situ measurements in the magnetosphere, on solar wind dynamic pressure, and on the ground based storm index *Dst*. During intense storms the main contribution to the *Dst* index comes from the ring current, but during moderate storms the tail current contribution can be dominant or comparable to the ring current. The tail current intensifies first, and follows the drop in the *Dst* index. The ring current develops slower, and stays at an increased level longer than the tail current. Three moderate storms and one intense storm were modelled in our previous study by Ganushkina *et al.* (2004), and similar conclusions were drawn. Our results are similar to earlier work (Dremukhina *et al.*, 1999; Alexeev *et al.*, 2001; Ohtani *et al.*, 2001) with regard to moderate storms, but give a quite different picture of the dynamics during intense storms. From the other hand, our results do not agree with the study of Turner *et al.* (2000) study where using Tsyganenko T96 magnetospheric magnetic field model to model one moderate January 1997 storm it was concluded that the tail current contribution is about 25% of the measured *Dst* variation.

When discussing the relative contributions from the ring and tail currents, the key question is how to separate partial ring current and tail current at the inner edge of the plasma sheet. There are two possible ways to give definitions: Using magnetic field observations, current flowing in the region of dipolar field lines is (partial) ring current while current in tail-like field lines is cross-tail current. The other way is to measure the characteristic energy of the current-carrying population and assume that it is ring current (or partial ring current) if the energies are in the range of several tens of keV and tail current if the energies are more typical plasma sheet energies of 10–20 keV. In reality, the ring and tail currents can not be unambiguously separated in this transition region between dipole and tail-like field. Our model uses the observed magnetic field, and it does not contain any predetermined separation between the ring and tail currents in the transition region. If the observed magnetic field is stretched, tail-like (which was actually observed at GOES), the model tries to intensify the tail current. Calculations of model contributions to *Dst* from the parts of the tail current confined in different regions in the tail showed that 40% of our model tail current contribution to the *Dst* index comes from the current that flows inside 8 R_E. It is therefore important to realize that results indicating strong asymmetric ring current and strong inner-tail current are not contradictory but may be the same physical process described with different terminology.

It is interesting to note that our model current systems have different characteristic response times. While the ring current increases quite slowly (much slower than the *Dst* enhancement), the tail current responds very rapidly. Thus, most of the fast decrease of the *Dst* index during the storm main phase in this model is created by the intensifying cross-tail current. The ring current intensification contributes to the magnitude and timing of the storm maximum, as the ring current maximizes at storm maximum. Further analysis on relative contributions to *Dst* from the different current systems including the ring and tail current contributions during storm recovery phase and the contribution of the magnetopause currents is still needed.

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