

CHANGES IN THE MAGNETOSPHERIC CROSS-FIELD CURRENT DURING SUBSTORM ON GEOCENTRIC DISTANCES 5-6 R_E

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Abstract. Magnetic field variations measured by the CRRES at the midnight magnetosphere are studied to estimate the changes in the near-Earth cross-field current J_{\perp} during substorms. The line current model has been used to simulate equivalent currents dJ , associated with differential magnetic field perturbations. We assume that the current dJ is confined to the equatorial plane and has an arbitrary orientation. Analysis of the current perturbations shows that: (1) after the substorm onset the decreases/disruptions of the initial total current J_{\perp} (CD) are detected at geocentric distances of $\sim(5-6) R_E$; (2) during 6 min after substorm onset large changes in the location, magnitude and orientation of the perturbation current dJ occur in the region where the local dipolarization is observed. Individual CD have short time duration ($\sim 10-20$ s) and separated by ~ 1 min. Both Earthward and tailward transient displacements of CD region with the velocity $\sim 200-1000$ km/s were observed. The behavior of perturbation currents are consistent with models of substorm onset based on cross-field current instability or ballooning instability.

Introduction

The magnetic field dipolarization and injection of particles are important effects of substorm. The radial expansion of substorm has been examined by many authors. *Russell and McPherron* [1973] and *Moore et al.* [1981] concluded that the substorm effects had propagated toward the Earth with $v \sim 10-100$ km/s. *Jacquey et al.* [1991] found that the current disruption (CD) was initially very close to the Earth ($6-10 R_E$) and then CD expanded tailward with $v \sim 320$ km/s. *Lui et al.* [1988] concluded that within the CD region (at $r \sim 8.1 R_E$) the complex magnetic field geometry was observed.

In this paper we examine the magnetic field perturbations from the CRRES data to estimate the initial CD site and CD displacements. We investigated two substorms A and B when proton and electron injections were simultaneously observed by the CRRES. The substorm A occurred near Norilsk at about $T_0 = 1658$ UT on February 9, 1991. The CRRES (Orb 484) was located at $r \sim 6 R_E$, $mlat = -4.4^\circ$ and 22.9 MLT.

The substorm B took place near Dixon at about $T_0 = 1938$ UT on March 6, 1991. The CRRES (Orb 540) was located at $r \sim 5.2 R_E$, $mlat = -18.1^\circ$ and 0.01 MLT. In both events the CRRES was located near the substorm onset meridian. *Kozelova et al.* [1996] have reported results of preliminary analysis of substorm A. *Maynard et al.* [1996] have presented electric field and particle (< 20 keV) data during substorm B.

Model for current perturbations in the magnetosphere

We suppose that localized current perturbation in the magnetosphere may be deduced from differential magnetic field perturbation $d\mathbf{B}(t) = \mathbf{B}(t+dt) - \mathbf{B}(t)$. The line current model has been used to simulate equivalent current dJ , associated with the perturbation $d\mathbf{B}$. We assume the current dJ to be confined to the equatorial plane and to have an arbitrary orientation. In the framework of this model, using the Biot-Savart law, we estimate the magnitude, orientation and location of the current dJ . In order to exclude very rapid fluctuations of magnetic field, we used 5s - averaged vector \mathbf{B} and also sliding 30s - smoothing vector $\langle \mathbf{B} \rangle$. In the first case we will refer to the magnetic perturbation $d\mathbf{B}$ and associated current dJ as unsmooth ones, in the second case as smooth ones.

Localized and transient activation

Figure 1 presents the development of the smooth currents for $dt = 10$ s during the substorm A. At this time the CRRES projection was at $r_0 \sim 6 R_E$. From Figure 1 one can see rapid dynamical changes in the magnitude, orientation and location of the perturbation current dJ . The westward current dJ_W is replaced with the eastward current dJ_E . The appearance of the current dJ_E may signify the occurrence of the CD. An individual CD has a short time duration (~ 20 s) and a separation of ~ 1 min which is comparable to the time scale of the substorm activation. Initial CD was observed at $r \sim 6 R_E$. Both Earthward and tailward transient displacements of CD site were observed. Perturbation current dJ had a visible radial component. Before (after) the moment "c" this component had tailward (Earthward) direction. After the moment "a" a dispersionless injection of the electrons E1-E3 (21.5-49.5 keV) at the CRRES was

observed. The absence of pitch angle (PA) and energy dispersion in these flux enhancements may be considered as evidence that the particle acceleration was local. From Figure 1 one can see that the electron flux increased rapidly within ~30s. The commencement of the particle injection coincided with the increase of the current dJ_E near the CRRES.

Local dipolarization and dynamics of currents

Figures 2-3 display the dynamics of the current dJ during the substorm B. Figure 2 shows the smooth current ($dt=15s$), Figure 3 - unsmooth one ($dt=10s$). At this time the CRRES projection was at $r_0 \sim 4.8 R_E$. From Figure 2 one can see that the first significant CD occurred at $r \sim 5-6 R_E$ similar to the substorm A. However, after that the CD dynamics during the substorms A and B was different. In the course of the substorm A (Figure 1), the CD site was displaced first Earthward (with $v \sim 200$ km/s), then tailward (with $v \sim 750$ km/s). During the substorm B, the order of the CD displacements was reverse: at first - tailward (with $v \sim 3 \cdot 10^3$ km/s), then - Earthward (with $v \sim 600$ km/s). After the moment "D2" (Figure 3) the current dJ_E had significant Earthward radial component. The currents observed for 40 s after the moment "D1" may be a signature of a moving current vortex structure in the equatorial plane. In this structure the current rotates counter-clockwise when looking in opposite to **B** direction (from the above plane of Figure 3). Inside this structure the magnitude of the **B** field increases ($\delta B > 0$), resulting in betatron acceleration of particles. Besides, the structure as a whole is moving westward (to the left in Figure 3). This disturbance may be a part of current meander described by *Heikkila and Pellinen [1977]*.

Opposite directions of CD transient displacements during the substorms A and B may be associated with different edges of the disturbance region, i.e. with the inner and outer edges for the substorm A and B, respectively. Indeed, during the substorm A, the first observation of the isotropic electron (< 20 keV) fluxes coincided with the substorm onset (*A. Johnstone, 1994, private communication*). While in the case of the substorm B, the CRRES was already within the plasma sheet when the substorm occurred (*Maynard et al., [1996]*). In the course of this substorm before T_0 , the energetic particle fluxes rapidly decreased. This is typical for observations on board a spacecraft located outside current sheet plane near trapped energetic particle boundary.

Explosive growth phase

Signature of 'Explosive Growth Phase' (EGP) described by *Ohtani et al. [1992]* was displayed during the substorm B. From Figures 2-3 one can see that at the 'EGP' (after T_0 but before T_{dip}) the large increase of the current dJ_W occurred near the CRRES. This current was rapidly displaced tailward with $v \sim 10^3$ km/s. The magnetic field stretching was not monotonous. Two discrete increases of the dJ_W (at S1 and S2) were observed in such short time interval as ~1min. The fluxes of electrons E1 (PA ~ 50 - 140°) and protons P1 (PA ~ 70 - 130°) decreased in association with these stretchings. *Liu [1997]* suggested that sudden increase of magnetic field stretching during 'EGP' could arise as a result of the ballooning instability. In our opinion, dynamics of the dJ_W observed before T_{dip} in the course of the substorm B may support this suggestion.

Conclusion

The analysis of magnetic field and particle data from the CRRES has shown the following:

- 1). Initial decrease (CD) of the total current J_0 was observed at $r \sim 5-6 R_E$.
- 2). Within the dipolarization region the multiple localised and transient CDs occurred. Individual CD has a short time duration (~10-20s) and a separation of ~ 1 min. Both Earthward and tailward transient displacements of the CDs with $v \sim 200-1000$ km/s were observed.
- 3). Rapid increase of the current intensity and tailward displacement of the current dJ_W site were observed at $r \sim 6-8 R_E$ during the sudden increase of magnetic field stretching ('EGP') prior to the local dipolarization.
- 4). Perturbation current had a significant radial component. Before (after) T_{dip} this component had tailward (Earthward) direction. This component may be a part of the large- scale region 1/region 2 current system or a part of the meandering neutral sheet current.
- 5). Dispersionless injections of the particles were observed when the dipolarization process started at $r \sim 5-6 R_E$.

The behavior of perturbation currents may be consistent with such models of substorm onset as cross-field current instability model (*Lui et al. [1991]*) and ballooning instability model (*Erickson and Heinemann [1992]*).

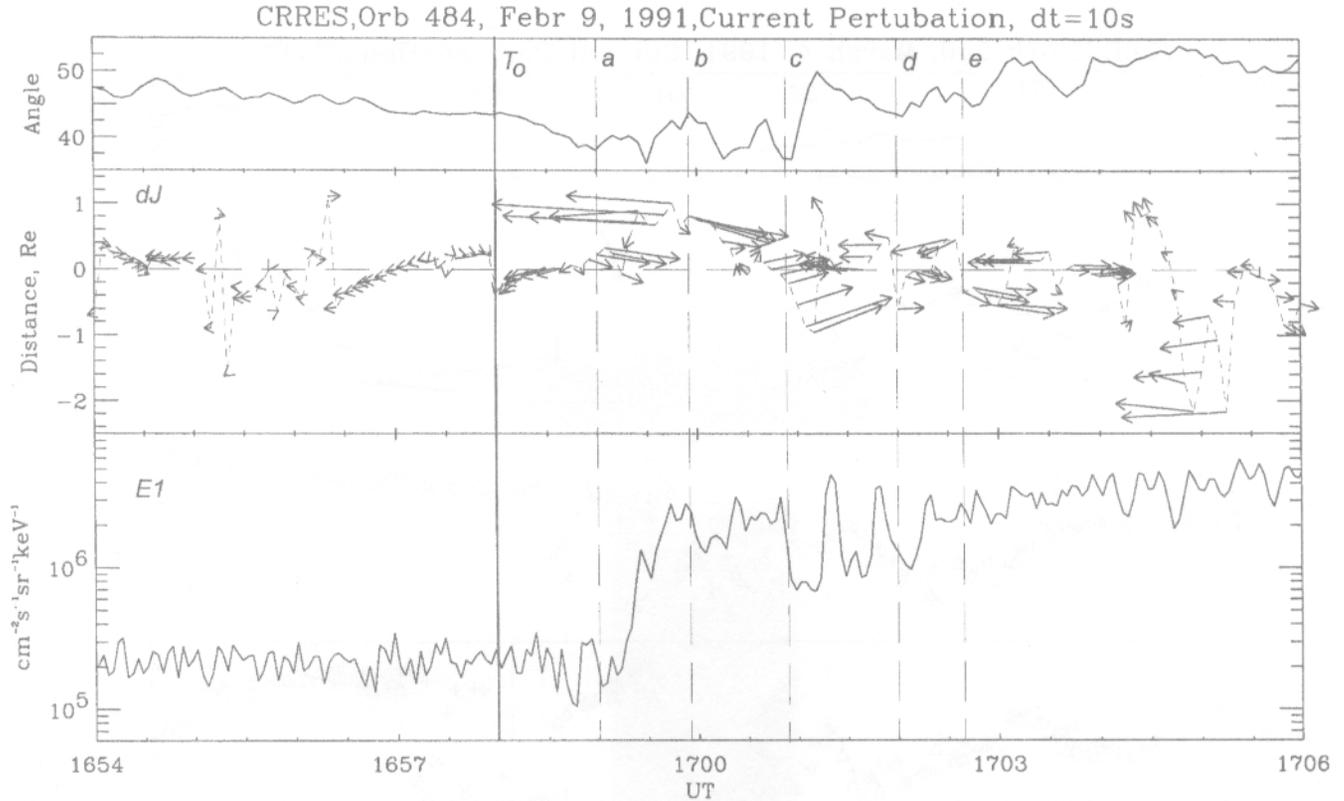


Figure 1. Substorm A. From the top to the bottom: 1. - Inclination angle of magnetic field relative to the XY plane. Decrease (increase) of this angle presents magnetic field stretching (dipolarization). 2. - Smooth current dJ (in arbitrary units) for $dt=10$ s relative to the CRRES projection on the equatorial plane. The positive distance has sunward direction. Current flow to the left corresponds to the westward current dJ_W . Current flow to the right corresponds to the eastward current dJ_E or J_0 current decrease (CD). 3. - Electron data from the channel E1 (21.5 - 31.5 keV).

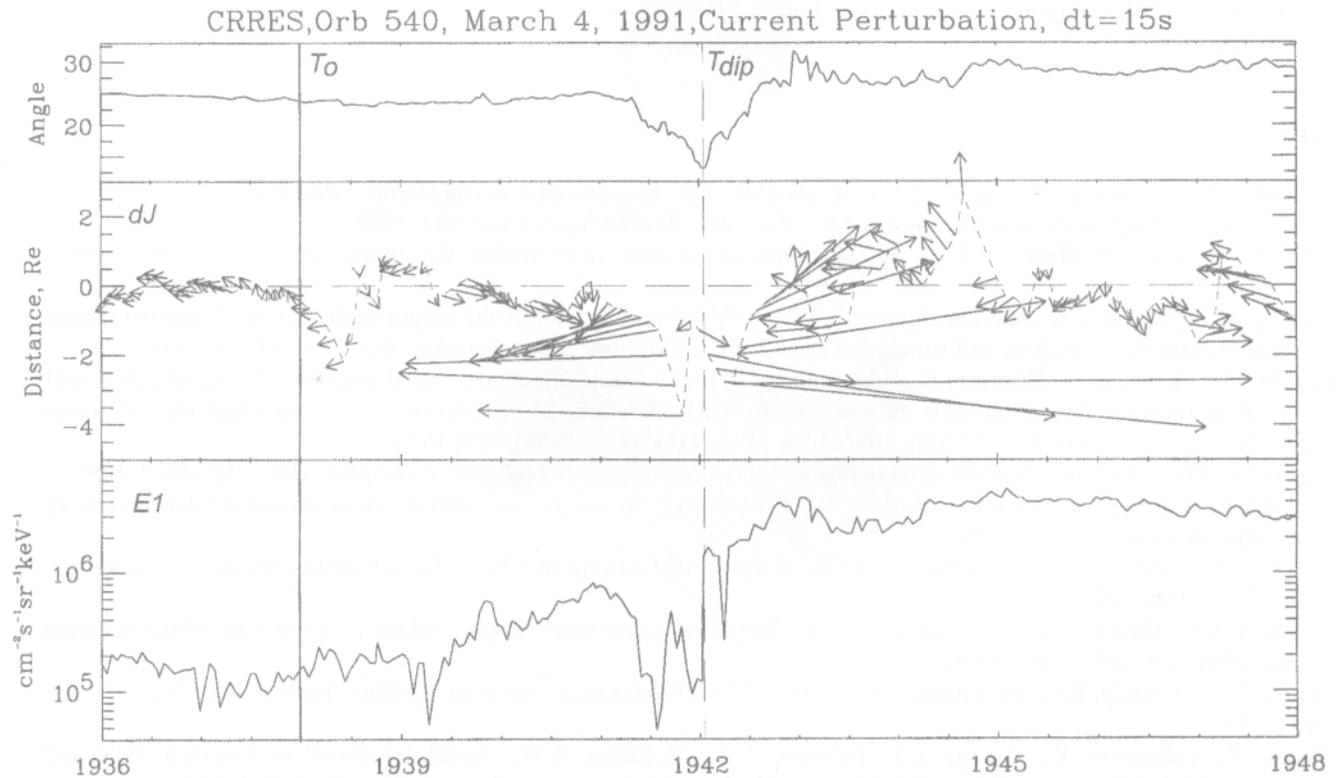


Figure 2. Substorm B. Smooth current dJ for $dt=15$ s. See Figure 1 caption.

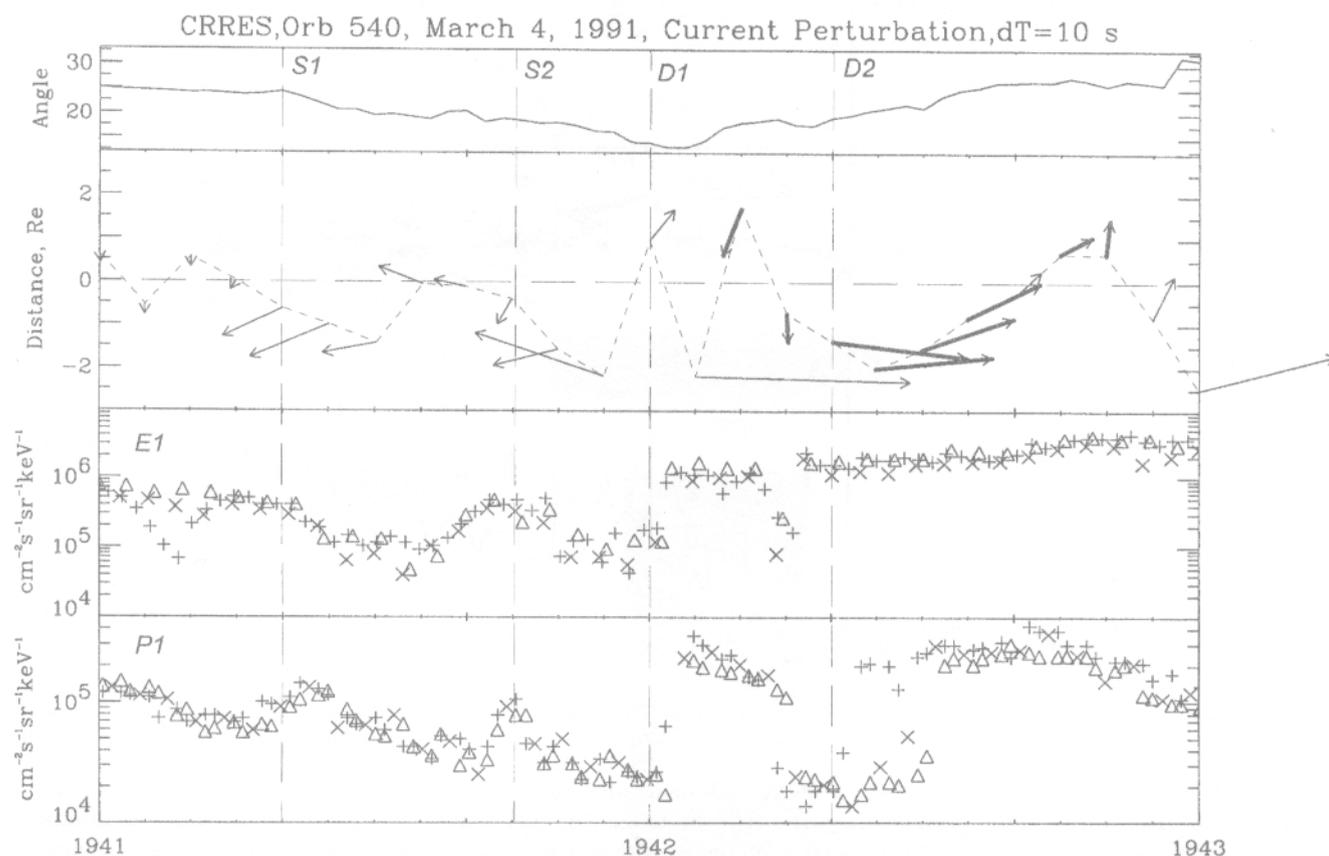


Figure 3. Substorm B. Explosive growth phase and local dipolarization onset. Unsmooth current dJ for $dt=10$ s. Bottom panel presents the proton data from the channel P1 (37-54 keV). The pluses, crosses and triangles correspond to different particle detectors. See Figure 1 caption.

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