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CHANGES IN THE MAGNETOSPHERIC CROSS-TAIL CURRENT DURING SUBSTORM AS OBSERVED BY THEMIS

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Abstract. Magnetic field variations measured by the THEMIS at the midnight magnetosphere are studied to estimate the changes in the cross-field current during the substorm at 4-13 RE. The line current model has been used to simulate equivalent differential currents ***dJ***. We found that the magnetic field and particle flux changes depend upon the position of the observing spacecraft relative to the region of current disruption, which develops discretely by creating new localized CD region outside previous activity. The dynamics of the CD region corresponds to the subsequent development of the ground activity in the given sector.

1 Introduction

The changes of the magnetic field during a substorm in the near-Earth magnetotail follow well established pattern. The growth phase magnetic field line stretching are due to an increase in the intensity and/or earthward motion of the cross-tail current sheet. At substorm onset there is a reconfiguration of the magnetic field toward a more dipolar orientation. This reconfiguration is accompainied by an expansion of the plasma sheet and an injection of energetic particles.

Russell and McPherron [1973] and Moore et al [1981] concluded that the magnetic field dipolarization and the injection of particles propagated toward the Earth with velocity ~ 10-100 km/s. Jacquey et al [1991] found that the current disruption (CD) was initially located at 6-10 R_E and then CD expanded tailward with velocity ~ 320 km/s. Lui et al [1988] concluded that within the CD region (at 8.1 R_E for that event) the magnetic field has the turbulent behavior and the complex magnetic field geometry.

Magnetic field variations can be used to measure changes in the current distribution, even if the changes take place far from the spacecraft and on different field lines. This is in contrast to electric field and particle flux variations. Kozelova et al [1998] using the B-field variations found that both earthward and tailward displacements of the individual CD with velocity 200-1000 km/s were observed by CRRES at distance 5-7 R_E. Impulsive westward electric field (~ 24 mV/m peak) coincides with the local dipolarization, the increases of B-field oscillations and nearly dispersionless energetic particle injection [Kozelova et al., 2001]. In this time the eastward perturbation current appears ~ 1 R_E tailward the CRRES.

In this paper we will examine the ground magnetic variations and magnetic field perturbations from the THEMIS data to estimate the dynamics of initial current disruption (CD) site and the CD displacements at 4 -13 R_E during the substorm intensifications.

2 Model for current perturbations in magnetosphere

We assume that localized current perturbation in magnetosphere may be deduced from differential magnetic field perturbation $\boldsymbol{dB(t)=B(t+dt) - B(t)}$. The line current model has been used to simulate equivalent current ***dj***, associated with this perturbation ***dB***. We estimate the magnitude, orientation, and location of the current ***dj*** using the Biot-Savart law. The eastward differential current $\boldsymbol{dj}_E$ may signify the occurrence of the CD [Kozelova et al., 1998]. We expect that the initial disruption region and its dynamics can be determined by examining the spatial-temporal distribution of westward and eastward currents perturbations $\boldsymbol{dj}_W$ and $\boldsymbol{dj}_E$.

3 Ground observations

During a selected event on 6 Jan 2008, two of the THEMIS spacecrafts A (THA) and C (THC) were located about 20^O eastward the Scandinavian sector at ~ 20 UT and come nearer to Scandinavia at ~22 UT. The observations made by the Scandinavian magnetometers show the several increases of magnetic activity (intensifications). We mark out four ones, Fig.1. At ~ 20:20 UT the first weak intensification began at high-latitude stations LYR-HOR (L ~ 13.8). At ~ 20:40 UT the second intensification began southward of the first one (at HOR-BJN).

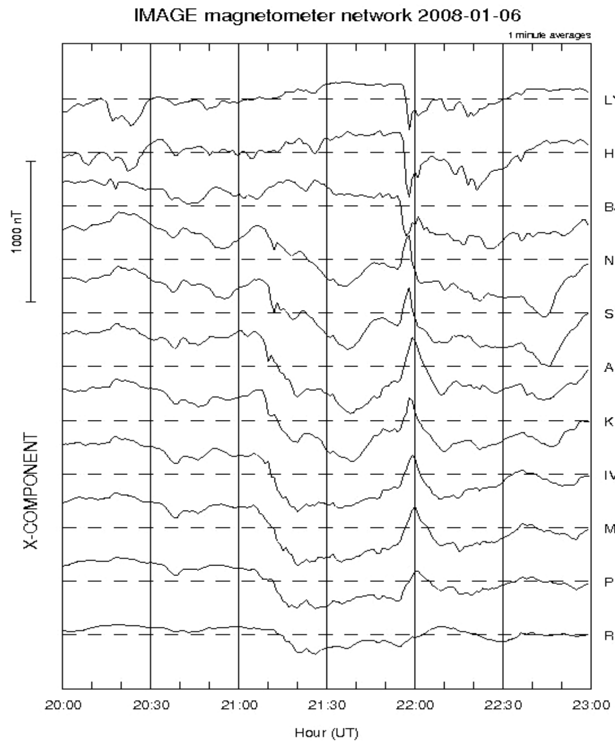

Fig. 1. Magnetic field perturbations at the Scandinavian magnetometers.

The next (third) intensification was the most intense and it was observed more southward of other ones (L ~ 5.5). The gradual initiation of the substorm was observed at stations IVA-MUO-PEL at ~21:05 UT. Further quick increase of the westward electrojet was observed at all stations from NOR to RVK at ~ 21:10 UT. This is associated with the substorm explosive phase. This evolution of ground magnetic perturbations is consistent with the behavior of aurora observed from Loparskaya and SOD. The bright western edge of WTS moved overhead of SOD at ~21:10 UT. At ~22:55 UT the last intensification observed at high-latitude stations LYR-BJN may be associated with a disturbance on the northern edge of auroral bulge.

4 Observations

Fig. 2 presents the value (in relative units), orientation and location of currents ***dj*** (for ***dt*** = 30 s) estimated from the THA and THC in the interval 20:00 – 21:30 UT. At initial moment the THA was near inner edge of the plasma sheet, and the THC was located tailward and below the THA. The GSM coordinates of the satellites were r_{THA} = (-5.2, 1.6, -1.2) and r_{THC} = (-8.6, 1.6, -2.7) in Earth's radii. Both spacecrafts were below the plane of the current sheet.

From 20 UT to 21:05 UT (before the substorm onset 't3'), the large scale magnetic field line stretching was observed both THA and THC. In this time the westward current dj_W was located at r~ 5-10.5 R_E. Monotony of the field line stretching was violate near the moments 't1' and 't2', when enhanced dj_E appeared at r ~ 5-6 R_E in association with the first two intensifications. The largest changes of the differential currents occur during the intensifications 't3' and 't4', which we will consider in details.

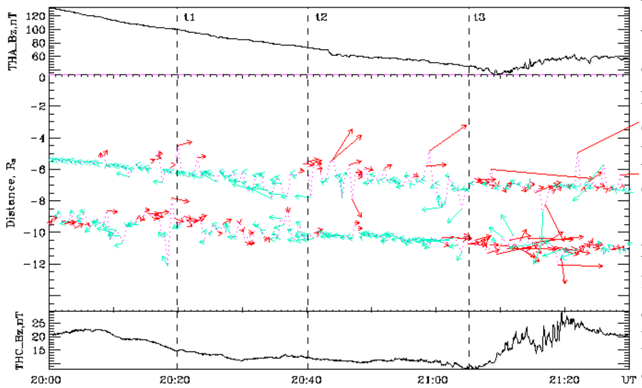

Fig. 2. Magnetic field variations observed by THA and THC and deduced from them current disturbances.

4.1 The substorm

The growth phase. At 20:50-21:00 UT the current dj_W , more intensive at ~10 R_E, presents the magnetic field line stretching observed both at r_{THA} = (-6.5, 1., -1.8)R_E and r_{THC} = (-9.5, 1.7, -3.25)R_E (Fig. 3). At the THA, the average energy of the low energy electrons increases (not shown) that is commonly interpreted as the passage across of the Alfven convective boundary for hot electrons (on the inner edge of the plasma sheet). At 20:58-20:59 UT the dj_E appears at ~ 5-6 R_E simultaneously with increase of 1-7 keV electron flux. We suppose that this current may be the local dawnward inertia current near the breaking point of the earthward flow of the plasma.

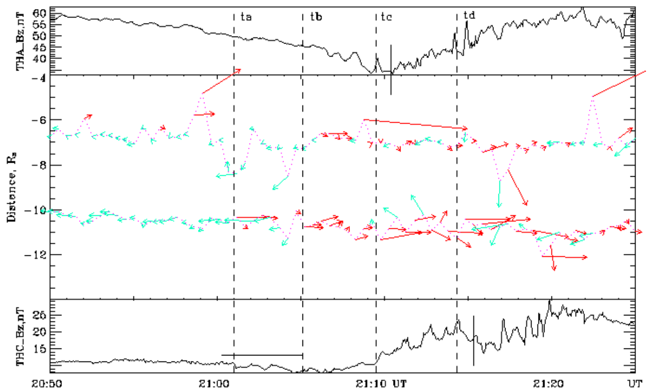

Fig. 3. The same as Fig.2, but for the substorm interval.

Stage of dj_W increasing with low-frequency pulsation. At 21:00-21:05 UT the current dj_W increases locally near the THC projection on XY plane. In this time, the particle fluxes rapidly decreased at the THC, and the B_{tot} increases (not shown) that is typical for observations outside the current sheet. The drop of the particle fluxes is marked as horizontal bar in panel 3 of Fig.3. Thus, the increase of the dj_W at ~10 R_E results in the plasma sheet thinning. Besides, during this interval the magnetic and electric fields and particle fluxes were oscillated with period of 2 min (not shown). The appearance of the oscillations may be interpreted as a beginning of transition from the quasi-steady to more unstable (or turbulent) state of the plasma sheet. Then, short appearance of the dj_E (at ~ 10 R_E) at ~ 21:01 UT (the moment 'ta') may be associated with the first local current disruption. However large scale magnetic field line stretching observed both at the THA and THC continues and the dj_E sinks quickly.

This evolution of magnetic perturbations in the magnetosphere is consistent with the behavior of aurora from Loparskaya and SOD. Before 21:01 UT a weak auroral arc was located in the northern edge of the Loparskaya field of view. At 21:01 UT a new arc appeared in the Loparskaya zenith. At 21:02 UT a new auroral spot appeared to the east of SOD zenith and moved to the south.

Slow 'dipolarization'. In the interval 21:05-21:09 UT (from 'ta' to 'tb') the weak current j_E placed at 10.5 - 11 R_E results in slow increase z-component of magnetic field at the THC. Slow (and nearly smooth) changes of B and E fields have no explosive character (slow 'dipolarization'). At ~ 21:05 UT the particle fluxes restore after the drop. We suppose that these field and particle variations could be associated with a local thickening (along the Z axis) of plasma sheet with small current reduction overhead the THC.

In this time at ~6.5 R_E the THA saw the large scale magnetic field line stretching and the increase of small-scale oscillations of the magnetic field with a period of 60-80 s. The subsequent Alfven layers of 7-9 keV electrons were observed at the THA as during *substorm growth phase*. At 21:07 UT the small current j_E appears at 6.5 R_E simultaneously with brightening of auroral arc which move to the south at Loparskaya and SOD. The time delay between the B_x and the B_z increases suggests that the local dj_E region expands Earthward of the THA.

At ~ 21:08:30 UT a local burst of current j_E appears suddenly at ~ 6 R_E simultaneously with an enhancement of average electron energy from ~2.3 to 4 keV (not shown). However this current dj_E sinks quickly. The local disruption region earthward of THA did not produce considerable change of B field tailward of it.

Auroral breakup. The ground data show that the main auroral activity moved from the east to the west. At ~21:09 UT the bright spot was to the east of SOD, and at ~21:10 UT the sharp western edge of the WTS appeared to the west of SOD. We use this moment of breakup as the onset of the explosive stage (T_{exp} = 21:10 UT).

At T_{exp} new local dj_E occurrs at ~11R_E (moment 'tc'). Simultaneously the injection of the electrons 10-200 keV and ions <100 keV occurs at the THA. We suppose that just in this time the field line threading the THA has the equatorial crossing point at the CD region.

At 21:10-21:15 UT (from 'tc' to 'td') one can see rapid dynamical changes in the magnitude, orientation and location of the perturbation current at ~10- 11 R_E. The dj_E alternated with the dj_W which slow down the development of the dipolization.

At ~21:15 UT from ground data a new increase of westward electrojet occurs simultaneously with sharp variation of the *D*-component at AND. In this time in the magnetosphere the injection of energetic particle was observed at the THC. At 21:16-21:20 UT the dj_E occurred at ~12 R_E and probably the THC field line threaded the CD region.

4.2 High-latitude intensification

At ~21:55 UT a new westward electrojet was observed at stations BJN-HOR-LYR, poleward of the latitude of the previous ~21 UT activity. Besides, BJN and HOR saw the variation of the *D*-component which is the ground signature of a WTS. In the magnetosphere, at 21:53 UT the current dj_W increases suddenly at ~13.5 R_E, presents the magnetic field line stretching observed at r_{THA} = (-7, 0.1, -2.4) R_E and r_{THC} = (-11, 0.8, -3.8) R_E and the local dipolarization at the third more distant spacecraft THB, r_{THB} = (-25.1, -12.1, -12.6)R_E (not shown).

At 21:54 UT (the moment 'k0') the first local perturbation current dj_E appears at ~12.5 R_E (tailward of the THC) (Fig.4). Then, the impulses of the dj_E follow at 11.5-12.5 R_E and at 7.5-8.5 R_E. The time delay between the impulses of the dj_E at different distances may suggest that the local dj_E region expands Earthward.

We will consider in details the dynamics of the particles and fields during the first impulse.

At 21:56:45 UT (the moment 'kC'), significant increase of the dj_E was observed at ~11.6 R_E simultaneously with oscillations of the magnetic and electric fields (with period of ~12 s) and the energetic particle injection on the THC. This local dipolarization and energetic particle injection was accompanied by sharp drop of total particle pressure. The pressure was restored when the current dj_W appeared at ~ 11.6 R_E. At ~ 21:58 UT (the moment 'kA') the particle injection, the particle pressure drop, the local dipolarization and an increase of magnetic pulsation were observed by the THA at r~ 8 R_E. Thus, the front of dipolarization displaces Earthward with the velocity about 340 km/s.

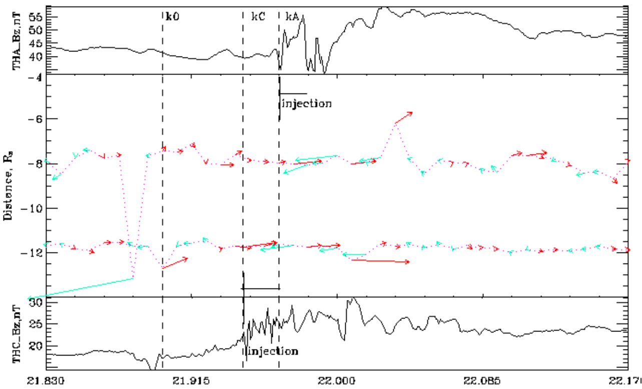

Fig. 4. The same as Fig.2, but for high-latitude intensification.

5 Discussion

Lorez et al [1989] concluded that the features of dipolarizations and the associated injections of energetic particles at distances <10 R_E depend on the position of the observing spacecraft relative to the neutral sheet. A spacecraft located near the neutral sheet will observe an increase in the total magnetic field magnitude, whereas a spacecraft placed far from the neutral sheet will observe a decrease in the field magnitude. We found that at ~ 4-13 RE the current disruption develops discretely by creating new localized CD site outside previous activity. In this situation, the spacecrafts below the neutral sheet saw complex picture. Sometimes the dipolarization and particle injection may seem to be not associated.

Fig. 5 presents a schematic illustration of position of spacecrafts THA and THC relative to the sites of j_E (the circles with a cross) and dj_W (the circles with a point) in different moments of substorm development (1-4). We show outlines of magnetic field lines before some of these moments.

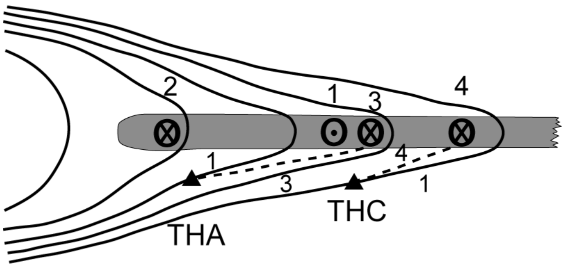

Fig. 5. Schema of magnetic field lines and current locations relative to spacecraft positions.

When the dj_W was at site '1' (overhead of THC at ~21:02 UT), the magnetic field line stretching was observed both at the THA and THC. The plasma sheet thinning result to the drop of the particle fluxes observed at THC.

The appearance the j_E at site '2' (earthward of spacecrafts at ~21:09 UT) results to the increase of stretching more appreciable at THA. The equatorial crossing point of the field line threading the THA approached the site '3', where subsequent CD occurs at 21:10 UT. Just in this time the THA observed the energetic particle injection. The THC observed the particle injection later, at ~21:15 UT, when the field line threading the THC approached to the CD region at site '4'.

Thus, the spacecrafts locates far from the neutral sheet observe local dipolarization and energetic particle injection when the CD region locates tailward the spacecrafts. However the only small increases of low energy particle fluxes and the weak variations of magnetic field occur when the CD region locates Earthward the spacecrafts. This signature of particles and fields variations is not what one would expect if the disruption region were a neutral line.

Another point (matter) concerns the conditions before the substorm explosive phase. We observed two states. First state - *Stage of development with low-frequency pulsations* - observed five minutes before the substorm onset, when the increase of the dj_W was at 8.5-10.5 R_E. Maynard et al [1996] observed similar stage before sustorm onset at CRRES at 5-6.6 R_E. However we found a new signature, i.e. the appearance of earliest localized eastward current j_E stealed into the range of this increasing dj_W at ~ 10 R_E. This may mean transition from a quasi-steady to more unstable state of the plasma sheet. Second state - *Slow 'dipolarization'* - observed four minutes before T_{exp}, when the changes of B and E fields have no explosive character and associated with the local thickening (along the Z axis) of the plasma sheet at 10.5 - 11 R_E.

6 Conclusion

We found that 1) the magnetic field and particle flux changes depend critically on the position of the observing spacecraft relative to the CD region, 2) the substorm current disruption develops discretely by creating the new localized CD region outside previous activity (tailward or Earthward in accordance with large-scale substorm phase), and 3) the dynamics of the CD region corresponds to the subsequent development of the ground activity in a given sector. The spacecrafts, located earthward the CD region, observe the local dipolarization and the energetic particle injection which displaces Earthward with the velocity about 340 km/s. However the only small increases of low energy particle fluxes and the weak variations of magnetic field occurs when the CD region locates Earthward the spacecraft.

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References

Moore T. E., Arnoldy R.L., Feynman J., and Hardy D. A. Propagating substorm injection fronts. - *J. Geophys. Res*., V. 86, NO. A8, P. 6713- 6726, 1981.

Russell C.T., and McPherron R.L., The magnetotail and substorms, *Space Sci. Rev*., 15, 205, 1973

Козелова Т.В., Лазутин Л.Л., Козелов Б.В. Электрические поля во время суббури по данным спутника CRRES, Геомагнетизм и аэрономия.Т. 41.№ 1.с.39-49, 2001

Kozelova T.V.,Kozelov B.V., Lazutin L.L. et al., Changes in the magnetospheric cross-field current during substorm expansion phase as observed by CRRES. Substorm-4.p.393-396, 1998

Lopez et al., Onthe relationship between the energetic particle flux morphology and the change in the magnetic field magnitude during substorms. *J. Geophys. Res*., V. 94, NO. A12, P. 17105-17119, 1989.

Maynard N.C. et al., Dynamics of the inner magnetosphere near times of substorm onsets. *J. Geophys. Res*., V. 101, NO. A4, P. 7705- 7736, 1996.

Jacquey et al., Location and propagating of the magnetotail current disruption durind substorm expansion: analysis and simulation of an ISEE multionset event. *Geophys. Res.Lett.*, 18, 389, 1991.

Lui A.T.Y. et al., A case study of magnetotail current sheet disruption and diversion . *Geophys. Res.Lett.*, 15,721,1988.