MULTIPLE-ONSET SUBSTORM CASE STUDY: PRE-ONSET, AURORAL ONSET AND EXPANSION

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ABSTRACT

We study the ionospheric and magnetospheric signatures during the substorm on March 12, 1991. The breakup (the moment To) begins in the vicinity of the Harang discontinuity (HD). Before To, the CRRES hits into the eastward electrojet region in the pre-HD sector. The substorm onset precursors are weak growth of westward ionospheric electrojet, the increase of the Pi2 oscillation, and in the magnetosphere near inner edge of plasma sheet - the appearance of an oscillation of the Bz component with a period of 2.5 min, and the increase of energetic proton fluxes with rapid change of the pitch angle distribution from cigar type to isotropic.

1.INTRODUCTION

The substorm onset is recognized by sharp X decrease in the ground magnetometer records near midnight and by the breakup of the most equatorward arc. McPherron et al. [1973] suggested the phenomenological model of the substorm current wedge (SCW) in which the pair of field-aligned currents (FACs) is associated with the region of the current disruption (CD). In the paper [Lui et al., 1988] was shown that the CD region on 7-9 Re consists of localized particle intensity increases with short 10-50 s duration. Previous studies have shown that the auroral forms alternately fade and intensify prior to a substorm onset. Maynard et al. [1996] report an oscillations with the periods of 2-3 min which may be associated with the rippling of the inner edge of the plasma sheet.

In this paper we used data from the CRRES satellite [Singer et al., 1992; Korth et al., 1992; Hardy et al., 1993] to examine the evolution of local conditions before and during the substorm onset.

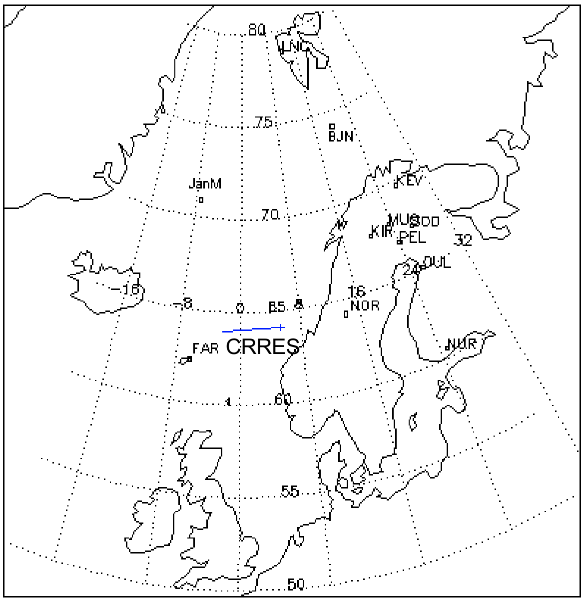

Figure 1: Locations of magnetometers and the CRRES during substorm on March 12, 1991.

2. SUBSTORM EVOLUTION

The day of March 12, 1991, was characterized by a long-lasting ground magnetic activity of 400-800 nT. At the moment T1 = 1950 UT was the beginning of small activity at Dixon and Tixie (geomagnetic longitudes $\Lambda \sim 160\text{-}190^{O}$). After this moment, the southward drifting weak auroral arcs arise near the KIL meridian ~ 117^{O} . The optical breakup begins at the moment To = 2026 UT southward of PEL (latitude $\varphi = 63^{O}$). The CRRES was located westward of the substorm onset (Figure 1).

Figure 2 presents Bz on the CRRES and the magnetometer data at several stations. The short vertical lines indicate the moments of auroral activation. One can note three substorm intensifications denoted by 1-3. During intensification 1 near the KIL meridian the substorm westward electrojet J_W suppresses the global current system locally near the FAR meridian (~80^O). When this intensification recovery, the global current system with eastward electrojet is reestablished on FAR as in [Opgenoorth et al., 1989]. The intensification 2 began near the NOR meridian (~108^O). The Y-component at NOR shows a negative deviation, which might be understood as the HD signature. During intensification 3, the electrojet J_W established over FAR and the CRRES observed the fast local dipolarization.

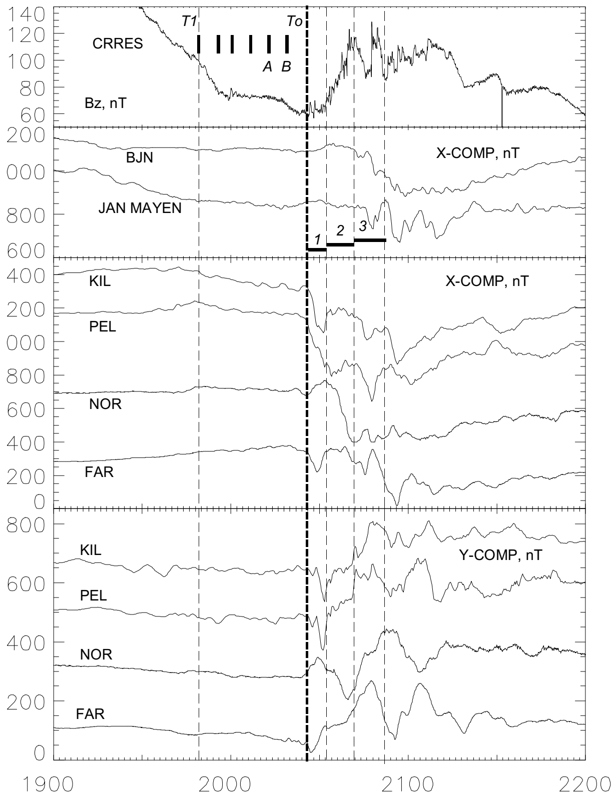

Figure 2: Substorm on March 12, 1991. The Bz component from the CRRES and X and Y components from ground magnetometers.

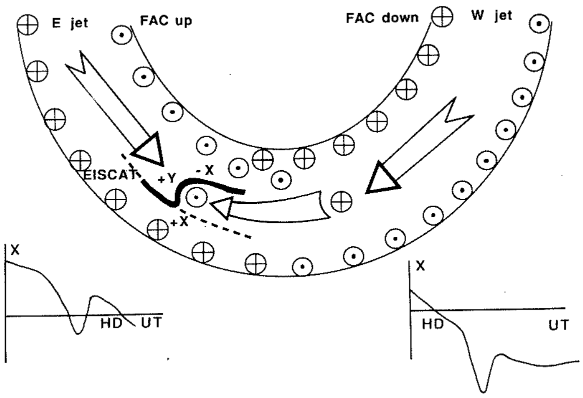

Figure 3: A schematic of superposition of the 3D systems for the global auroral currents and the substorm J_W.

Figure 3 shows a sketch of the superimposed current systems around the HD and the substorm J_W [Opgenoorth et al., 1989]. The westward expansion of the J_W can be identified with the CRRES transition from pre-HD to post-HD sector.

2.1. PRECURSORS OF SUBSTORM ONSET

More intensive activations labeled A and B in Figure 2 represent an auroral pseudobreakups observed as vortex formations with the counterclockwise rotation. They coincide with the growth of the amplitude of small X decreases at KIL and occur 14 minutes before To.

Figure 2 shows that first X decrease began at PEL and FAR at 2022 UT. The rate of the X decrease abruptly increased after To. The weak growth of a electrojet J_W was observed also at Apatity on $\Lambda \sim 127^O$ (not shown). The increases of Pi2 pulsation amplitude were observed at 2022 UT and at 2026 UT (not shown).

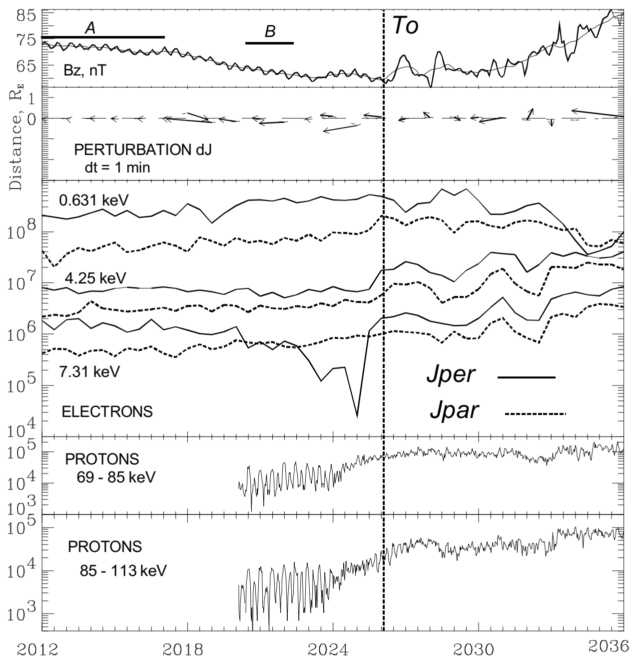

Figure 4: Substorm on March 12, 1991. From top to bottom: the Bz component from CRRES, the location of current perturbations (dj in relative units) on the equatorial plane relative to the CRRES mapping ("distance"=0), LEPA electrons, and energetic ions.

Figure 4 shows the substorm precursors in the magnetosphere: 3 min before the To, the appearance of an oscillation of the Bz component with a period of 2.5 min and the enhancement of

54-147 keV proton fluxes (PA ~ 90^O) at 2024 UT. The PA distribution (PAD) of protons was of sigar (pancake) type before (after) 2024 UT. From Figure 4 we see the increase of tailward magnetic field stretching (after pseudobreakups) associated with the appearance of the westward perturbation current dJ_W on the equatorial plane near the CRRES. This current decreases after To. The evolution of the proton PADs in the interval 2020-2027 UT may be consistent with this current decrease.

2.2. SUBSTORM EXPANSION

Figures 2 and 5 present the substorm expansion. At 2041 UT the activity begins at BJN at $\varphi = 71^O$ ($\Lambda = 125^O$). Two minutes after this time (in the interval "a-b" on Figure 5) the X decrease was observed simultaneously near KIL and FAR, near along $\varphi \sim 65^O$. However the upward FAC associated with the SCW was located eastward or near KIL. In the interval "b-c" the clear onset of the activity occurs at Jan Mayen at $\varphi = 73^O$ ($\Lambda = 100^O$). In the equatorward part of the auroral oval ($\varphi \sim 63\text{-}65^O$), the upward FAC was located near or eastward of NOR. After 2048 UT, the pulsating auroras appear here. The typical current picture associated with the leading edge of the SCW appears suddenly over the FAR meridian and the J_W established here.

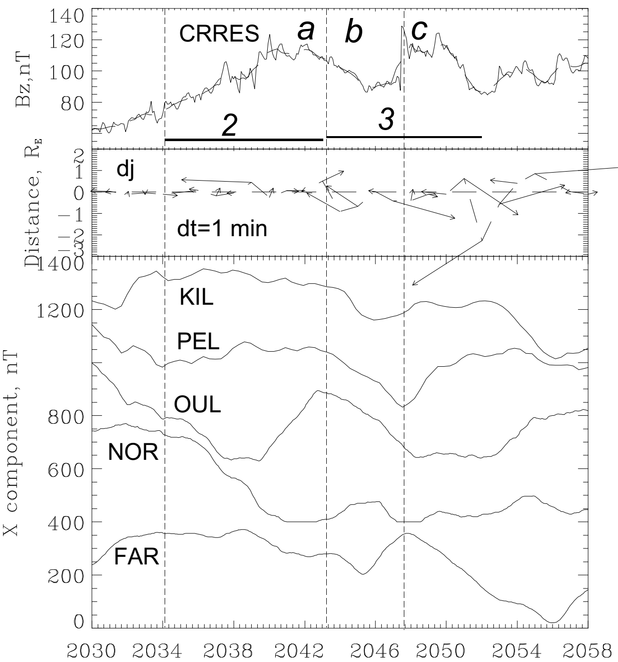

Figure 5: Substorm on March 12, 1991, intensifications 2 and 3.

In the magnetosphere on the CRRES located between the NOR and FAR meridians, one can see the following. Westward of the upward FAC (in "a"-"b"), the Bz-component decreases, the magnetic field lines are tailward stretching, the westward perturbation current dJ_W appears ~1Re tailward of the CRRES. Southward of the upward FAC (in "b"-"c"), the CRRES observed a slow dipolarization and an increase in the field-aligned (0.5-1 keV) electrons [Lazutin et al., 2004].

Eastward of the upward FAC (after "c"), the CRRES observed a fast local dipolarization and the dispersionless injection of energetic 21-150 keV electrons.. The appearance of the eastward current perturbation dJ_E may signify the current decrease (or disruption CD) in this time near 0.5 Re tailward of the CRRES (in other words, on r = 6.8 Re).

3. INNER BOUNDARY OF PLASMA SHEET

Figure 6 shows that after pseudobreakups the CRRES on L ~ 6.3 encountered the Alfven layers of low-energy electrons 0.213-5.57 keV . The lowest energy particles appear first at the CRRES. Near the To, we see the first sharp injection of 7-16.5 keV electrons with PA~ 90^O without significant magnetic field dipolarization.

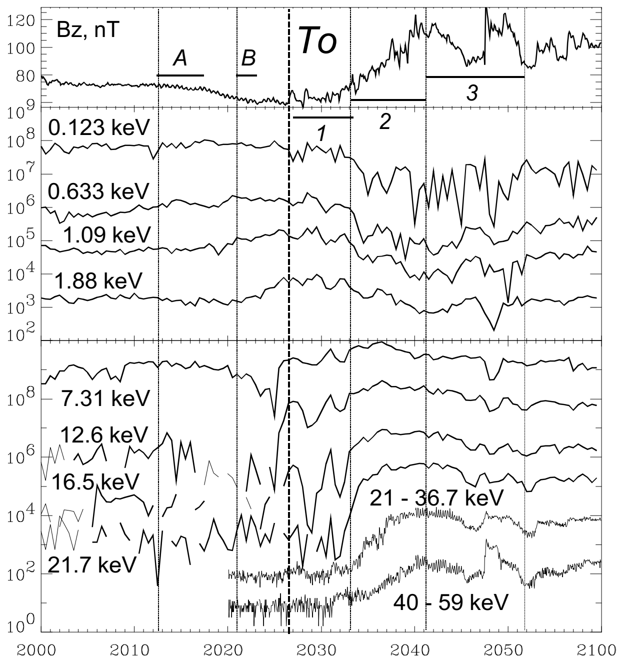

Figure 6. Substorm on March 12, 1991. LEPA and MEPA electron data from CRRES.

Nearly isotropic fluxes of the electrons, that were observed during HD crossing (in the interval 2), usually characterized the inner edge of the plasma sheet. After the HD crossing, the CRRES encountered the region 2 FACs flowing from the ionosphere (see Figure 3). The second main injection of electrons 21-150 keV and fast local dipolarization occurred during local activation near the CRRES meridian in this region of field-aligned currents.

4. SUMMARY

1) After pseudobreakups, the CRRES, located on L ~ 6.3 in the pre-HD sector, observed the tailward magnetic field stretching and encountered the Alfven layers of low-energy electrons. In the end of the substorm growth phase, the trapped orbits of the electrons with the cutoff energy ~ 7.31 keV were located inside the region , where $P_{||} > P_{\perp}$ for the 54-147 keV protons.

2) 3 - 4 min before To the precusors of the substorm onset are: on the ground - (a) weak growth of westward ionospheric electrojet near HD and (b) the increase of the Pi2 amplitude; in the magnetosphere - (c) the appearance of an oscillation of the Bz component with a period of 2.5 min, (d) the enhancement of energetic proton fluxes (PA ~ 90^{O}) and the rapid (in ~1min) change of the PADs from sigar type to isotropic. The first injection of the electron 7-16.5 keV, without significant dipolarization, was observed westward of the onset region.

3) In the post-HD sector, eastward of the local activation onset, the CRRES observed the fast local dipolarization and dispersionless injection of energetic 21-150 keV electrons. The eastward perturbation current dJ_E appeared this time on r = 6.8 Re, which may signify the current disruption in this site.

We suppose that the formation of periodic auroral vortices seen during the substorm growth phase can be an important feature to "trigger" the substorm expansion phase.

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