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SUBSTORM LARGE IMPULSIVE ELECTRIC FIELDS OBSERVED BY CRRES

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Abstract. The CRRES satellite registered large (>20 mV/m) impulsive (~40s) electric fields during substorms at L=6-6.5. These E field impulses correlate with the rapid local magnetic field reconfiguration and have an inductive nature. Orientation of E field in the impulses depends on the CRRES location. Near the PS inner edge, the E field had a dominant azimuthal (westward) orientation. Near the PS outer boundary, the E field had a dominant Earthward direction. Besides some initial perturbations of the E and B fields were present prior to the local B field reconfiguration and depended also on the CRRES location. Since the analysed E and B field variations are associated with the substorm expansion, we suppose that the rapid development of the initial perturbation arising from the cross-field current instability or from the ballooning-interchange instability can lead to the nonlinear process of local B field reconfiguration, which will in turn induce a large E field.

1. Introduction

Direct measurements of E fields in the magnetosphere are very important for understanding the processes during the magnetospheric substorm, but they are very scant. The substorm E field in the near-Earth plasma sheet region is irregular, usually its magnitude is equal to several mV/m and its direction is mainly the dawn-dusk one [Pedersen at al., 1985; Roux et al., 1991; Kozelova et al., 1992; Holter et al., 1995; Maynard et al., 1996].

In this paper we present two substorms, A and B, characterized by large transient E fields and the dispersionless injections of energetic electrons >21.5 keV and protons >37 keV. The purpose of this study is to illustrate correlation of large E field with the local B field changes and consider the perturbations of the E and B fields which were present prior to the local B field reconfiguration. We will also estimate the changes of the magnetospheric currents on the equatorial plane using the B field variations at the CRRES and try to reveal the role that the plasma sheet (PS) region near the CRRES location plays during the local B field reconfiguration.

2. Observations

The substorms, A and B, occurred on March 6, 1991, which was a very active day, Kp = 5. The substorm A took place near Dixon at about To=(16:30-16:35)UT. The CRRES (orbit 545) was located at r~5.56R_E, magnetic latitude -7.2^o, ~21.5 MLT and magnetic longitude ~145^o. The substorm B occurred at To = 20:17 UT westward of the substorm A. The CRRES (orbit 545) was located at r~5.59 R_E, magnetic latitude - 14.8 ^{o}, ~23.6 MLT and magnetic longitude ~120^o.

Model for current perturbations in the magnetosphere. Our interpretation of the B field data is based on the following approach. We suppose that localized current perturbation in the magnetosphere may be deduced from differential magnetic field perturbation d**B**(t) = **B**(t+dt) - **B**(t). The line current model has been used to simulate equivalent current d**j**, associated with this perturbation d**B**. We assume that the current d**j** is restricted to the equatorial plane and have an arbitrary orientation. Preliminary results obtained by this approach to the CRRES magnetic field data were presented in [Kozelova et al., 1996]. In the framework of this model, using the Biot-Savart law, we estimate the magnitude, orientation and location of the perturbation current d**j**.

2.1. Substorm A, March 6,1991, [16:30-16:40]UT

Observation of isotropic fluxes of the lowest energy electrons before To may signify that during the substorm A the CRRES was located near the PS inner edge.

Dawn-dusk electric field. Fig. 1 presents a large (~24 mV/m peak) impulsive westward electric field Ey in the interval (t1-t2). This Ey impulse has a short duration of ~1 min and correlates with: 1) the magnetic field dipolarization; 2) the increases of B field variations on a finer time scale; 3) the onset of energetic electron injection. A similar substorm impulsive E field has been observed by Aggson et al. (1983).

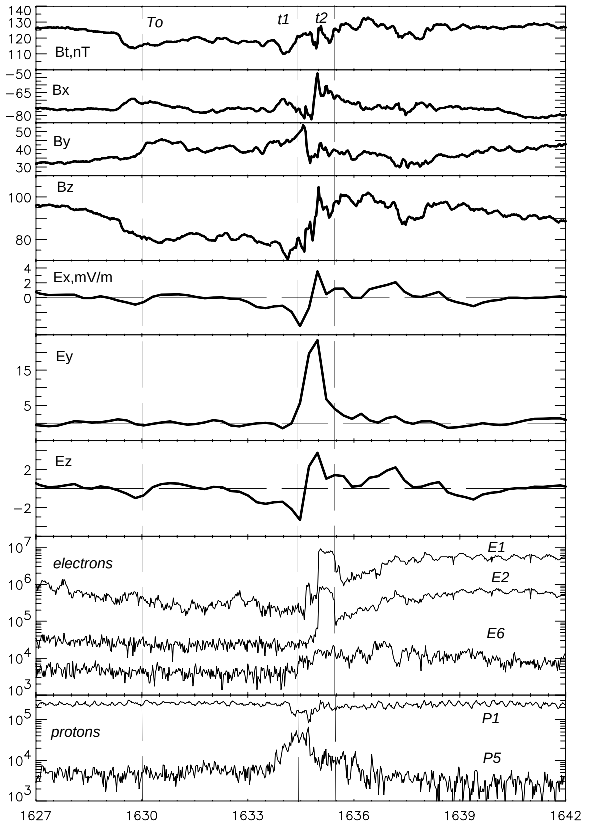

Fig.1. Substorm A. From top to bottom: Components of **B** and **E** fields in the SM-system and the fluxes of electrons in the channels E1, E2, E6 and protons in the channels P1 and P5 [Korth et al., 1992].

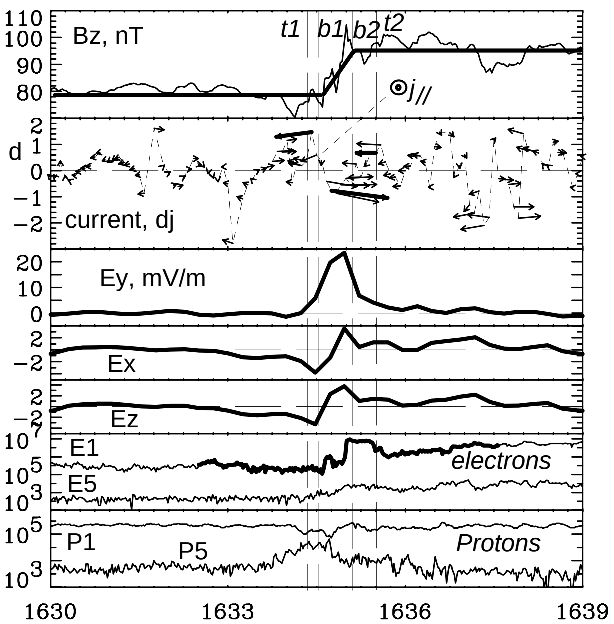

Fig.2. Substorm A. **B** and **E** fields, current perturbation and fluxes of particles. Current d**j** (in arbitrary units) reltive to the CRRES projection on the equatorial plane. The positive distance 'd' (in R_E) is parallel to the **X** axis. Current flow to the left (right) corresponds to the westward (eastward) current djW (djE).

Perturbation currents. Fig. 2 shows rapid dynamic changes in the magnitude, orientation, and location of the perturbation currents **dj** during the dipolarization. At first, the westward current dj_W appeared and was located Earthward of the CRRES. Then the eastward current dj_E appears (0.5 - 1) R_E tailward of the CRRES. Finally, the current dj_W appears again Earthward of the CRRES. The dj_E appearance may signify the occurrence of the current disruption (CD). The interval 'b1 - b2', when current dj_E exists, separates two states of B field with different Bz values. Thick lines denote the two states Bz=const and the transition between these states. Only this transition presents 'local dipolarization' on the CRRES location. Since during this time ($\mathbf{dj} \cdot \mathbf{E}$) < 0, the PS region near the CRRES location plays the role of a generator locally. This current dj_E may be the driven current component in the substorm current wedge [McPherron et al., 1973].

One can see also that the reverse of the meridional component Ex sign near the moment 'b1' is consistent with the upward field-aligned current FAC which moved Earthward.

Thus, the main results of the substorm A analysis are the following:

1) CRRES observed a large (~24 mV/m peak) impulsive westward electric field Ey with a short time ~ 1 min duration. This impulse coincides with the dipolarization and the increases of B field variations on a smaller time scale. We interpret this Ey impulse or, at least, some of its part as an induction electric field.

2) During the Ey impulse, reverse of the meridional component of the E field is consistent with the upward FAC which moved Earthward.

3) The role of the PS region near the CRRES changes during the Ey impulse: first it is a load, then it becomes a generator and, finally, it is a load again. This may be interpreted as follows. The increase of the Ey field and the injection of particles lead to the local enhancement in the current intensity. Then, the current sheet becomes unstable to a cross-field current instability [Lui et al, 1991], which triggers the CD. During a short time, the PS region near the CRRES becomes a generator locally. Initial increase of the Ey field can occur for different reasons, for example, due to the enhancement of the external electric field or from the local generator which occurred somewhere else aside of the CRRES. In the later case, the fields, currents, and particle injections are "engaged" and the region of the increased current "pulls" the region of the CD.

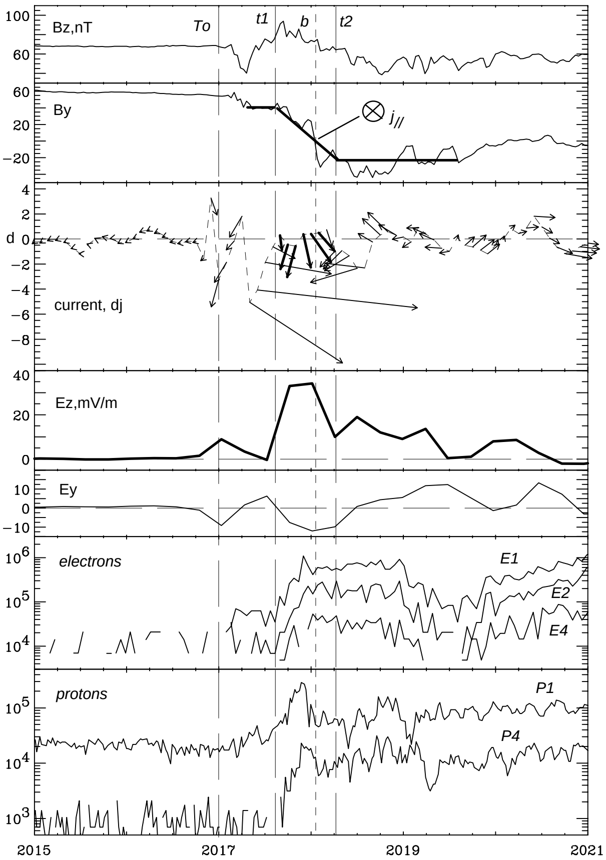

Fig. 3. Substorm B. Shown in the same format as Fig.2.

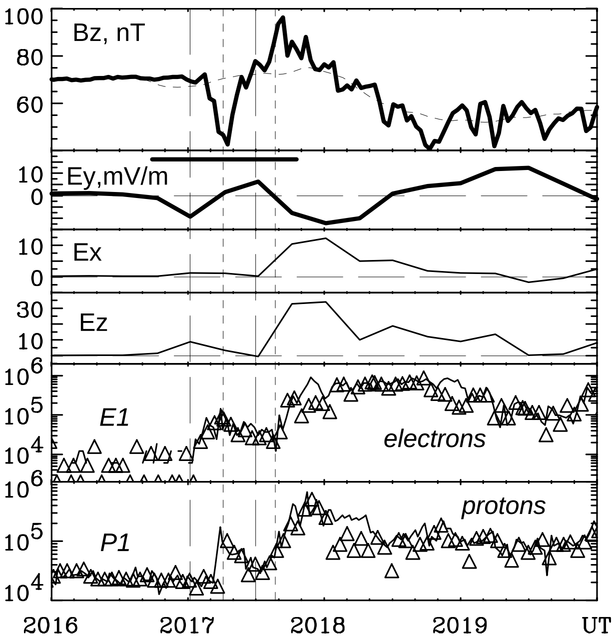

Fig. 4. Substorm B. One oscillation of B and E field before local dipolarization onset.

2.2. Substorm B, March 6,1991, [20:15-20:21]UT

The CRRES was located outside the current sheet plane. Large particle flux decreases (a complete dropout of electrons (31.5-208 keV) and protons (147-800 keV)) and ΔB>0 during the substorm growth phase are consistent with the thinning of the near-Earth PS. Thus, in this event the spacecraft was located near the PS outer boundary.

Fig. 3 shows a large (~34 mV/m peak) impulse of component Ez in the interval (t1-t2). This impulse has a duration ~40 s and correlates with the stepwise change of By component (ΔBy ~ 50 nT). One can say that, at least, any part of the Ez field in the interval (t1 -t2) has an inductive nature.

Meridional component of perturbation current. Fig. 3 show that quasi-radial tailward current djr describes a stepwise change of By component during the interval (t1-t2). Since the Ez (and Ex) component has the Earthward direction, the tailward current dj_r means that the PS region near the CRRES location is a generator, $(\mathbf{dj} \cdot \mathbf{E}) < 0$. Directions of the E field and current dj_r this time consisted in the equatorial currents that link field - aligned currents of the region 1 and region 2 as in the classic 3D current system of the morning type [Iijima and Potemra, 1978].

Azimuthal component of E field. From Fig. 3 one can see that the azimuthal component E_y alters its direction frequently. The maximum value of the eastward Ey field (12 mV/m) was observed during the second activation of electrons and protons. The largest and rapid changes of Bz component were regostered before the moment "t1". The Bz component sharp depression just prior to the local onset of the dipolarization is similar to the Explosive Growth Phase [Ohtani et al., 1992].

Just before the local onset of the dipolarization, one can see one oscillation of the Ey and Bz with quasi-period of ~50 s. The peak-to-peak amplitude of the E field is about 12 mV/m and that of the B field is about 50 nT. One can find a phase shift ~90^{o} between Ey and Bz and Bz lags Ey (Fig.4). This phase relationship is an indication of the even mode standing wave structure with the compressional component.

Besides, in Fig.4, one can see a tendency toward anticorrelation between particle fluxes and B field. This anticorreration may be a signature of slow magnetosonic waves. Holter et al. [1995] interpreted similar oscillation events with periods of about 45-65 s as a coupled shear Alfven-slow magnetosonic mode. These oscillations may be the result of the ballooning instability [Miura et al. 1989].

Thus, the main results of the substorm B analysis are the following:

1) CRRES observed a large (~36 mV/m peak) impulsive meridional electric field with a short time ~ 40 s duration. This impulse correlates with a stepwise change of By component and has an induction nature. The directions of the E field and currents dj

correspond to the ones in a generator for the 3D current system of type II [Bostrom, 1964], or the classic 3D current system of the morning type [Iijima and Potemra, 1978].

2) Just before the local dipolarization onset, the CRRES observed one oscillation of the Ey and Bz components with a quasi-period of ~50 s. The Ey variation leads the Bz variation by 90^{o} in phase, indicating to an even mode standing wave structure.

3. Conclusion

We examined E field variations observed in the near-Earth tail region in association with the substorm onset and local dipolarization. Two main results of the substorm analysis are the following:

(1) Large impulsive electric fields correlate with the stepwise change of B field and have an inductive nature. Orientation of E field in the impulses depends on the CRRES location. Near the PS inner edge, the E field had a dominant azimuthal (westward) orientation. Near the PS outer boundary, the E field had a dominant Earthward direction.

(2) Some initial perturbations of the E and B fields were present prior to the local B field reconfiguration. These perturbations may result from any instability. Near the PS inner edge, there may be a cross-field current instability. Near the PS outer boundary, there may be a ballooning - interchange instability.

Since the analysed E and B variations are associated with the substorm expansion, we suppose that the rapid development of the initial perturbation arising from the cross-field current instability or from the ballooning - interchange instability can lead to the nonlinear process of local B field reconfiguration, which will in turn induce a large E field.

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