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HIGH-SPEED PLASMA FLOWS AND DIPOLARIZATION IN THE MAGNETOPSHERE DURING SUBSTORM

T.V. Kozelova, B.V. Kozelov *(Polar Geophysical Institute, Apatity, Russia)*

Abstract. We analyzed the magnetospheric disturbances in the midnight sector during the substorm on Nov 14, 2014, starting at 18:25 UT. The data used were observed by the THD and THE satellites located in the ~ 00 MLT sector of the magnetosphere at 9-10.5 Re, as well as recording of PiB pulsations at Lovozero, the aurora at the stations Apatity and ground magnetic data. Some 20 minutes before the ground substorm onset, the beginning of the bursty bulk flow (BBF) event was observed by two satellites. The role of fast earthward flows in triggering substorms is not yet known in detail. Here we evaluate the associated changes in the cross-tail current intensity using the line-current model to simulate equivalent current perturbations during the interaction of BBFs with the near-Earth plasma.

1. Introduction

The return of magnetic field to more dipolar configuration, or '*dipolarization*', is a well-known signature of the substorm expansion phase in the magnetosphere. The arrival of BBF at the inner edge of the plasma sheet leads to dipolarization also [*Shiokawa et al*., 1998; *Birn et al*., 1999].

Nakamura et al. [2009] identified two types of dipolarizations. The first type of depolarization (D1) is associated with the beginning of the earthward moving BBF enhancement from the arrival of BBF at the satellite in the inner magnetophere to Vx velocity maximum. The second type of dipolarization (D2) is associated with a reconfiguration of the near-Earth tail currents from a taillike magnetic field configuration to a more dipole configuration. This dipolarization type is observed during the braking of BBF.

We use spacecraft observations from THEMIS during a substorm on 14 Nov, 2014, in conjunction with ground-based magnetic field observations and the aurora at the station Apatity, to examine the role of currents related to BBF on the evolution of the near-Earth current sheet disturbances in midnight sector.

2. BBF and disturbances at r~9-10.5 Re

Fig. 1 presents THD satellite data on 14 Nov, 2014: magnitude of total magnetic field, spectrogram of electrons with >30 keV (SST detector data) and velocity of plasma flow (Vx, Vy, Vz) in GSM system on top panels. The bottom panels show ground-based magnetic field observations at AMD (B_H and B_E components) and azimuthal component B_E at KEV. Vertical line at the moment 'T_f' notes the arrival of BBF at the THD.

Fig. 1 shows that after moment 'T_f' strong magnetic field fluctuations (panel 1), the energetic electron injections (panel 2) and enhanced plasma flow (panel 3) are observed at the THD. The disturbance in the current sheet in the magnetosphere nearly the THD lasted ~ 40 min and decay at ~18:45 UT. Dynamics of the fields and particle fluxes in the near-Earth plasma sheet are discussed in detail in the next sections. Now we note that after the moment 'T_f' near the THD meridian, the negative H bay at AMD begins (panel 4). At 18:15 UT, at AMD the azimuthal D component (or B_E) changes from ΔD >0 to ΔD <0 implying the westward passage of the upward field-aligned current near the AMD. At ~18:35 UT the westward edge of the active auroral region was located over KEV.

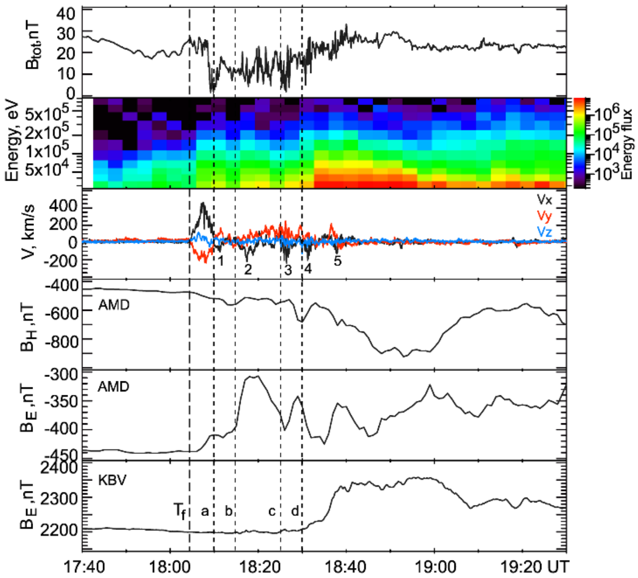

Figure 1. THD data of magnetic field, SST electron spectrograms and BBF velocity and ground-based magnetograms at AMD and KEV on Nov 14, 2014 (details in text).

From Fig. 1, one can see that the duration (~60 min) of negative high-latitude (at AMD) H bay is much larger than the durations of BBF (5 min). This is because, the contribution from the pressure gradient terms is dominant [*Shiokawa et al*., 1998; *Birn et al*., 1999], last longer than inertial current effects and can persist even after the flow burst ends [*Birn et al*., 1999].

During the activations on 14 Nov, 2014 considered here, at LOV two small bursts of PiB-type pulsations are observed at '*a*' =18:10 UT and '*b*'= 18:14 UT and more intensive pulsations at '*c*' =18:25 UT and '*d*'= 18:30 UT. During the first burst at '*a*' =18:10 UT disturbance of the H and D was small < ~ 30 nT. Later, we note this moment as the onset of *pseudobreakup*. During the second burst at '*b*'= 18:14 UT, the D variation increases to ~90 nT. Just at this time, the new auroral arc appears northern of LOV over a longitudinal distance of ~ 25^{O} westward AMD (not shown).

This arc had a longitudinally quasiperiodic structure, its western edge expanded westward and brightened at '*c*' =18:25 UT. The moment '*b*'= 18:14 UT corresponds to an *appearance of brightening arc* at the onset of the Activation A2. The moment '*c*' =18:25 UT corresponds next expansion of active region and new activation.

The moment 18:30 UT, when the most intensive burst 'd' was observed, we note as the onset of completed *substorm expansive phase*. Indeed, after this moment negative H bay increases at high latitude (AMD on panel 4) and positive H bay appearance is observed at mid-latitude (KAK not shown), and magnetic signatures of the WTS are observed at KEV (panel 6).

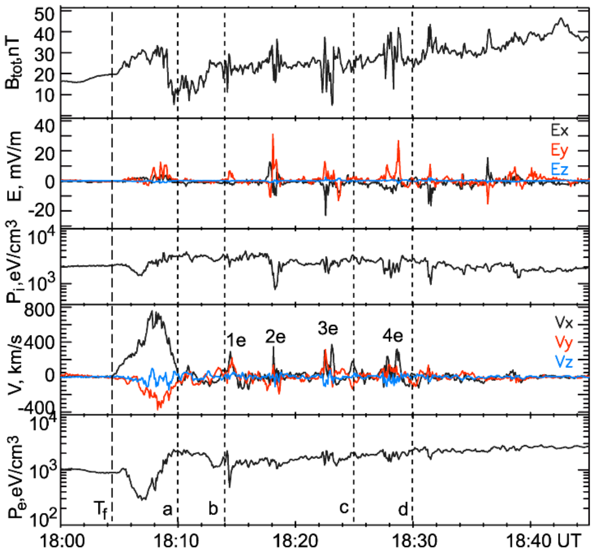

Figure 2. THE data of magnetic and electric fields, and velocity of plasma flow (Vx, Vy, Vz) in the interval 18:00-18:45 UT on Nov 14, 2014.

From Fig. 1, one can see that during our event after the decay of BBF, five tailward flow bursts (FB), denoted as '1' – '5', are observed at the THD with time intervals of 5-6 minutes. This interesting fact confirms the observations that the Earthward flow can change direction in the near-Earth region and is bouncing back [*Panov et al*., 2010a].

The magnetic and electric fields, pressure of ions, plasma flow velocity and electron pressure, observed at the THE, are shown in Fig. 2. The vertical line in Fig. 2 mark the starting time of BBF, which lasted~ 5 min as for THD. After main earthward BBF (700 km/s), four weaker (200-300 km/s) earthward FBs, denoted as '1e' – '4e', are observed at the THE simultaneously with the increases of Bt fluctuations, short bursts of predominant Ey component and a short-time drops in the ion and electron pressure. The interval between bursts '1e' – '4e' was ~ 4-5 minutes. The FBs at THD and THE will be discussed later.

3. Perturbations of magnetospheric currents

During the substorm on Nov 14, 2014, large-scale dipolarization at longitudes of satellites lasted near 40 minutes and consisted of several small-scale activations/dipolarizations, of which two initial activations A1 and A2 were observed during the arrival of a BBF in the inner magnetophere. The dynamics of these activations was analyzed in more detail using the construction of differential current perturbation vectors on the equatorial plane of the magnetosphere.

Differential current vectors. We assume that localized current perturbation in magnetosphere may be deduced from differential magnetic field perturbation $d\mathbf{B}(t)=\mathbf{B}(t+dt) - \mathbf{B}(t)$. The eastward differential current dj_E may signify the occurrence of the current disruption (CD) [*Kozelova et al*., 1998].

Fig. 3 (panel 2) presents the value (in relative units), orientation and location of currents dj (for dt=30 s) estimated from measured magnetic field the THD and THE in time interval 18:00-18:30 UT. Current vectors directed to the left (right) correspond to westward (eastward) current dj_W (dj_E). Panels 1 and 3 show the estimated magnetic field elevation angle ('Ang') relative to the equatorial plane in GSM reference frame for THE and THD, accordingly. At panel 2, two horizontal bars denote the activations A1 and A2.

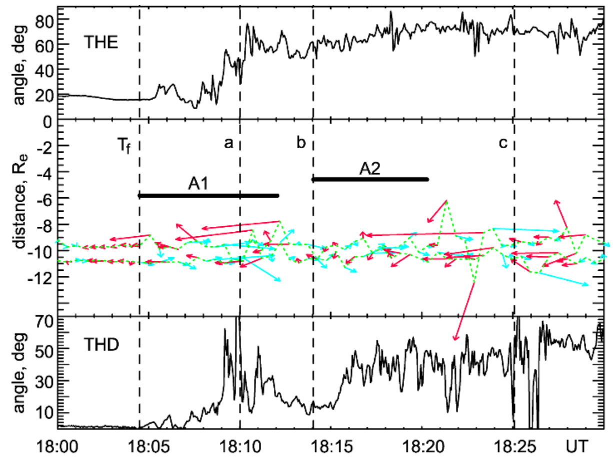

Figure 3. THD and THE data on Nov 14, 2014. First and third panels show the magnetic field elevation angles at THE and THD accordingly, and second panel shows the position of the perturbation current on equatorial GSM plane (details in text).

Currents during the Activation A1. Before the BBF arrival in the inner magnetosphere (at 'T_f'), the quiet westward current dj_W was located at r~ 9-11 R_E between THE and THD. At the moment 'T$_f$', first increase of 'Ang' (signature of dipolarization) occurs at more tailward THD simultaneously with the appearance the eastward current dj_E near THD. 30 s later, the increase of 'Ang' is observed at THE. Thus, during the beginning of the Activation 1, the first type of dipolarization D1 [*Nakamura et al*., 2009] was observed between THE and THD.

Some 2 min after 'T$_f$', the appearance of current dj_W led to the stretching of the magnetic field and the THE detected thinning of the plasma sheet. This stretching was accompanied by a decrease of the cutoff energy of electrons [*Kerns et al*., 1994] from ~ 15 keV to ~ 3 keV, that can be seen in the Fig. 5.

Then, at ~18:08:30 -18:09 UT (~1 min before the pseudobreakup, associated with the PiB burst 'a'), sharp increase of the eastward current dj_E happened earlier at THE and later at THD. Such direction of dj_E movement from earthward to tailward corresponded to the second type of dipolarization D2 [*Nakamura et al*., 2009]. The pseudobreakup lasts only a few minutes near AMD longitude and then at 18:12 UT fades.

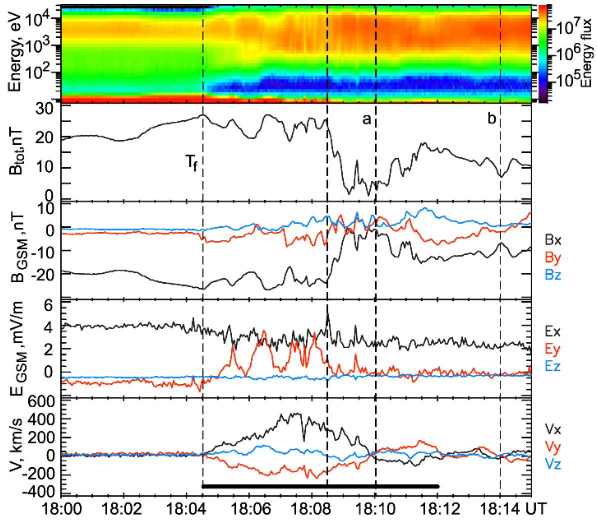

Figure 4. THD data of ESA electron spectrograms, magnetic and electric fields and velocity of plasma flow (Vx, Vy, Vz) in the interval 18:00-18:15 UT on Nov 14, 2014.

Currents during the Activation A2. About 1 min before bursts of PiB-type pulsations at '*b*'= 18:14 UT, a perturbations of magnetospheric currents are beginning on the satellite located closer to the Earth and extend from the Earth to the tail and prevalently in the azimuth direction. During the Activation A2, a current layer between the THE and THD oscillated including one tailward FB (noted '2') at THD (Fig. 1) and two intensive earthward FBs ('1e' and '2e' on Fig. 2) at THE.

Thus, the direction of dj_E movement changed from earthward during the first type of dipolarization D1 to tailward during second type D2.

4. Development of near-Earth current sheet fluctuations

Now, we analyze in detail dynamics of the fields and particle flux variations in the near-Earth plasma sheet associated with the arrival of BBF in the inner magnetosphere (Figs. 4 and 5).

Fig. 4 shows that on Nov 14, 2014, after 'T$_f$' during Activation A1, observed at THD, current sheet fluctuations included oscillations in the Bx, Bz and total magnetic field, and Ey component with a period of ~90s. These fluctuations were accompanied by weak variations Vz (panel 5), and were associated with the beginning of the earthward moving BBF as for the first type of dipolarization D1. They may present the *flapping* oscillations of plasma sheet. Indeed, flapping is an up-down motion of the magnetic field, together with plasma [*Sergeev et al*., 1998]. Flapping perturbations are a standing structure along the magnetic field and a traveling wave across the field [*Golovchanskaya and Maltsev*, 2005]. The main features of this motion are Bx and Vz oscillations [*Runov et al*., 2005].

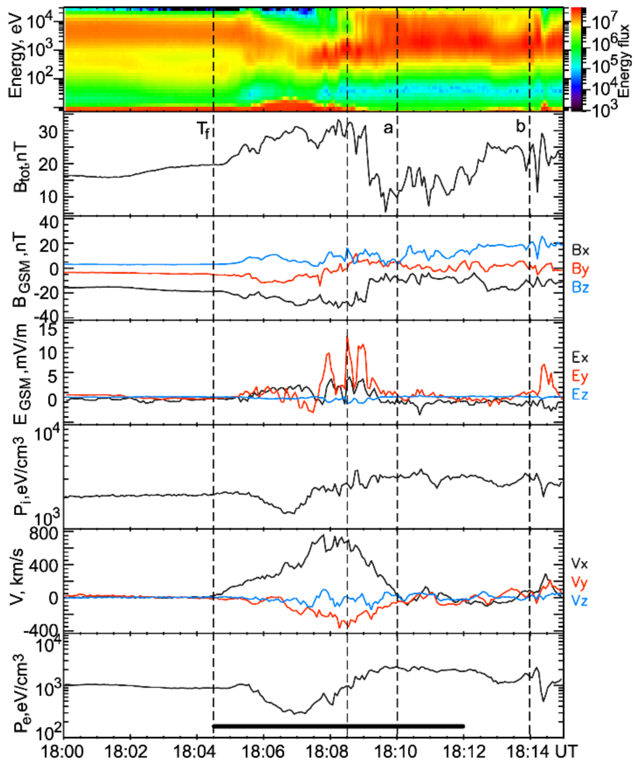

Figure 5. THE data between 18:00 and 18:15 UT on Nov 14, 2014 (details in text).

The appearance of flapping motion at X ~ -10 Re ~ 4 minutes before the onset of pseudobreakup can be important for determing the onset mechanism.

Remember, that the dipolarization D1 [*Nakamura et al*., 2009] represents the first short-time increase in B_z component, followed by the thinning of the current sheet (decrease of B_z) and the oscillation. The thinning of the current sheet during the arrival of BBF in the inner magnetosphere was observed at on the satellite THE located closer to the Earth, than the THD. Evolution of the electron spectrum (< 30 keV), total magnetic field and his components, components of electric field, ion (<30 keV) pressure, velocity of plasma flow (Vx, Vy, Vz) and electron pressure, observed at THE, are shown in Fig. 5. From Fig. 5 one can see that after 'T_f', the stretching was accompanied by a decrease of the cutoff energy of electrons [*Kerns et al*., 1994] from ~ 15 keV to ~ 3 keV (panel 1), and by the oscillations in Bz, Ey and Vz. These oscillations have the period of ~ 40 s and may present also the flapping oscillations of plasma sheet during a phase of the BBF velocity decay as in THD observations.

Transition from the state of an oscillating thin layer to a more dipole configuration is observed at THE simultaneously with onset of pseudobreakup at ~18:08:30-18:10 UT. In this time, the THE spacecraft observed also:

(i) the cutoff energy of electrons increases from ~ 3 keV to ~ 20 keV,

(ii) the injection of more energetic (>20 keV) electrons, and

(iii) the movement of the current dj_E in tailward direction, which is a signature of the second type D2.

5. Summary of observations

Two spacecraft observations separated prevalently in X (fast flow direction) described different types of dipolarization and different states of magnetospheric plasma at 9-10.5 Re observed on November 14, 2014. We note four states in the vicinity of the satellites. The first state corresponds to the outer region with stretched magnetic field lines, the earthward BBFs, the oscillations with the period of 40-60 s and weak perturbation of the magnetic field of D1-type [*Nakamura et al*., 2009]. The second state was observed during the weak pseudobreakup, when small-scale dipolarization occurred near the spacecraft. The third state of plasma was characterized by the bulk flow expansion in the azimuthal direction (westward). Second and third states of plasma were observed *in the braking region* at 9-10.5 Re. After large-scale dipolarization, the fourth state corresponds to more dipolar magnetic field, higher magnetic pressure, maximum values of electron flux during substorm explosive phase.

Conclusions

According to presented observations in this paper, we found:

- Some 4-minutes before the onset of pseudobreakup, flapping motion occurs at X ~ -10 Re and a thinning of the plasma sheet at X ~ -9 Re. It is can be important for determination of the onset mechanism.
- Appearance of brightening arc correspondent to the beginning of the bulk flow expansion in the azimuthal direction (westward), observed in the braking region at 9-10.5 Re.
- The braking region was characterized by strong magnetic field fluctuations, an oscillating thin current layer, changes of Earthward flow direction, and short tailward and earthward flow bursts (FBs).

Thus, analysis of perturbations of fields and particle flux in the midnight sector of the magnetosphere at 9-10.5 Re, observed on November 14, 2014, shows that the appearance of BBF at this event can stimulate the onset of pseudobreakup (~5 min after T_f) and later (~20 min after T_f) the substorm onset.

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