"Physics of Auroral Phenomena", Proc. XXIX Annual Seminar, Apatity, pp. 96-99, 2006

Polar Geophysical Institute

SUBSTORM LOW-ENERGY PARTICLE DECREASE NEAR THE INNER EDGE OF THE PLASMA SHEET

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Abstract. The injections of energetic particles and dipolarization of the magnetic field are well-known signatures of magnetospheric substorm in the near-Earth region of the plasma sheet. However, the variations of low-energy particles in these phenomena are not sufficiently examined. Here we consider the behavior of the low-energy (30 eV – 28.5 keV) particles near the Earthward edge of the plasma sheet as observed by the CRRES satellite during four substorms and their contribution in the total pressure changes. We found that the low-energy ion pressure and total (plasma and magnetic field) pressure at *r*~6 R_E decrease during the local dipolarization. However after a large scale dipolarization, the total pressure increases during the events when the CRRES was located near the equatorial plane.

1 Introduction

Lui [1995] showed that the current intensification during the substorm growth phase is associated with enhancement in the particle pressure at ~8.8 R_E. Similar enhancement in the particle pressure before the local dipolarization onset was observed by CRRES at ~6. R_E also [*Kozelova et al*., 2003]. Besides, *Kozelova et al.* [2003] found that after local dipolarization onset the pressure of energetic (>37 keV) ions decreases. The decrease in ion fluxes at the energies of 37-70 keV gives the main contribution in decrease in total ion energy density. However, a contribution of low-energy (<37 keV) particles in these phenomena are not examined.

In this paper, we consider the data from the CRRES satellite to examine the changes of total (ion and magnetic) pressure and the contribution of low energy (<30 keV) particles to these changes during the substorm.

2 Observations

We examine substorm onset events when the CRRES was located near the Earthward edge of the plasma sheet and energetic particle injections are observed. We use LEPA and EPAS data and the magnetic field data from the CRRES satellite. The LEPA instrument measures low energy (0.1–30 keV) ions and electrons in several channels [*Hardy et al*., 1993]. The EPAS instrument measures energetic electrons (21.5-285 keV, 14 energy channels) and ions (37-3200 keV, 12 energy channels) [*Korth et al*., 1992].

The total ion pressure (from LEPA and EPAS data) and the total pressure (magnetic field and particles) during four substorms have been estimated. We examine the time development of the pressure before and after the observed magnetic field dipolarization.

Table 1 summarizes the CRRES location (MLT, mlat, r), and also the total magnetic field Bt and the angle χ before the first dipolarization onset during these events. The angle χ is the inclination angle of the magnetic field relative to the XY plane (in the GSM-system). ΔP is the large scale change of the total pressure during event, and ΔP_{small} is the total pressure change during individual small scale dipolarizations.

Table 1.

	Day, UT	MLT	mlat	r, R_E	Bt, nT	χ	ΔP	ΔP_{small}
A	24/01/91,16.9	23.55	-0.9^O	6.2	50	63^O	+50%	-20%
B	12/03/91,20.5	21.5	~0^O	6.3	60	85^O	+55%	-20%
C	06/03/91,16.5	21.5	-7.2^O	5.6	110	45^O	-16%	-16%
D	08/02/91,23.8	0.3	0.2^O	6.3	50	50^O	+37%	-12%

2.1. Substorm A, Jan 24, 1991. During this substorm the CRRES at the orbit 445 was located near the equatorial plane on L~6.2 in the midnight sector (~23.55 MLT, mlat ~ -0.9^O).

Figure 1 presents the Z-component of the observed magnetic field and the EPAS particle flux variations. The interval from 't1' (1654 UT) to 'td' (1711 UT) separates two states of different Bz values in the CRRES vicinity, the change of the Bz from 50 nT to 90 nT presents a "large scale dipolarization". Besides, a few "small scale localized dipolarizations" were observed during this interval. We want to pay attention to three local dipolarization observed near 't1', 't2' and 't3' moments. Onsets of energetic electron injections coincide with these local dipolarizations. The energetic (69-197 keV) ion injection develops just 20-30 s prior to the first local dipolarization.

The contribution of different sources to the total pressure is illustrated in panels 4 and 5 of Figure 1. The low energy (<30 keV) ion pressure P_{iL} and the high energy (>37 keV) ion pressure P_{iH} are shown in panel 4 as well as total ion pressure P_i=P_{iL}+P_{iH}. In panel 5, the magnetic field pressure P_B and the total (of the plasma and magnetic field) pressure are shown also. From Figure 1 one can see that:

- During the large scale dipolarization, the total (of the plasma and magnetic field) pressure increases from 10 nPa (before 't1') to 15 nPa (after 'td'), i.e. ~50% enhancement of the total pressure.
- Near the onsets of the small scale dipolarizations ('t1', 't2', and 't3'), the total pressure decreases, despite the enhancement of the magnetic field pressure. During the first local dipolarization ('t1'), the reduction is ~2 nPa, i.e. ~20% reduction from the initial value of 10 nPa. The total pressure reduction is caused by the reduction of the

plasma pressure.

• The reduction of total ion pressure coincides with the drop of the low energy ion pressure, while the high energy ion injections occur.

• Before the onset of the first local dipolarization (moment 'ta'), the total and the plasma pressure increase. Near the moments 'tb', 'tc' and 'td' the total and plasma pressure increase also. After these moments the Bz component is nearly constant during a certain interval.

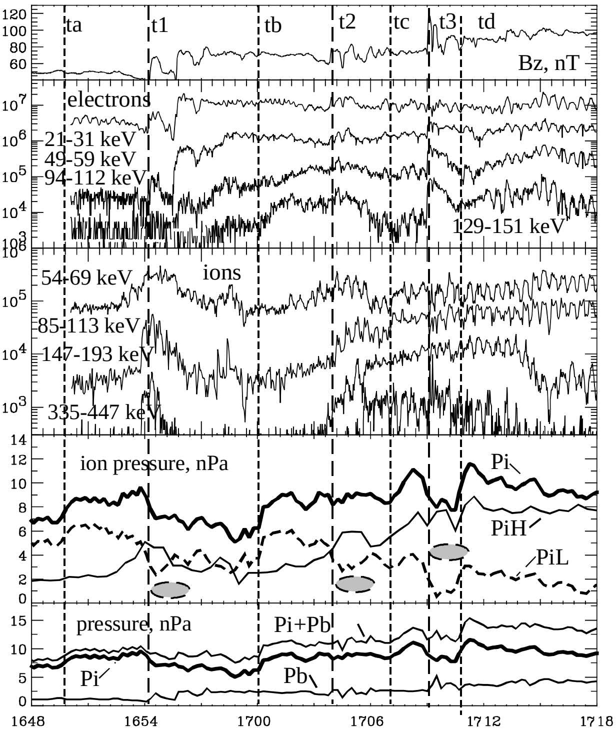

Fig. 1. Substorm A. From top to bottom: Z component of magnetic field, the fluxes of energetic electrons and ions in several channels, ion pressure Pi (PiL + PiH) and total pressure (Pi+Pb), where PiL (PiH) – low (high) energy ion pressure and Pb – magnetic pressure.

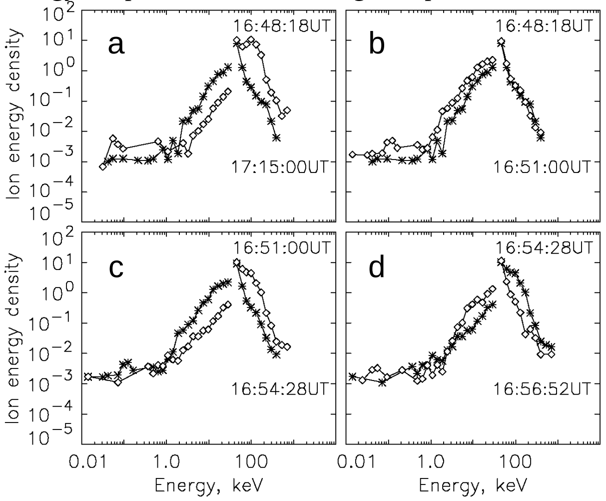

Fig. 2. Substorm A. The changes of ion energy density (in keV/cm^3) after large scale dipolarization (panel a) and during local dipolarization (panels b-d).

• The electron injections coincide with local dipolarization onsets and with the drop of the low energy ion pressure.

Figure 2 presents the ion energy density as a function of the energy for several time intervals during the considered event. The panel 'a' illustrates the total change of the energy density spectrum during the large scale dipolarization: the asterisks show the spectrum on 1648 UT, before any enhancement of particle fluxes, and the diamonds are the spectrum on 1715 UT, after the injections. Before dipolarization the peak in the energy density and, thus, the peak contribution to the pressure, is at about 40 keV. After the large scale dipolarization the peak is moved to ~100 keV.

The panels 'b'–'d' show the variation of the ion energy density spectrum at the beginning of the considered event, from 1648 UT to 1657 UT. This interval contains a small scale local dipolarization ('t1'). Before the local dipolarization onset, during the development of a tail-like magnetic field in the vicinity of the CRRES (see the Figure 1), an increase of the energy density at low energies (<37 keV) occurs (Figure 2-b).

The ion energy density spectra in the panel 'c' clearly show the drop of the energy density at low energies (< 37 keV) and the enhancement of the energy density at the high energies (> 60 keV). We suppose that this enhancement of the energy density or the appearance of the 'hillock' (or 'bump') at the high energies (60-300 keV) may be associated with the local acceleration of particles during the local dipolarization within the inner plasma sheet.

The disappearance of this hillock and the increase in the energy density at low energies (<37 keV) can be seen about 3 min after 't1' (the panel 'd').

2.2. Substorm B. March 12, 1991. During this substorm the CRRES at the orbit 560 was located near the equatorial plane on L~6.3 in the premidnight sector (~21.5 MLT, mlat ~ 0^{O}).

The Z-component of the observed magnetic field and the particle flux and pressure variations during this substorm are shown in Figure 3. The interval from 't1' to 't3' presents the large scale dipolarization when the Z-component changes from 60 nT to ~110 nT. We want to pay attention to three local small scale dipolarization observed near the moments of 't1', 't2' and 't3'. The onsets of energetic electron injections coincide with these local dipolarizations. The energetic (54-147 keV) ion develops just 2 minutes prior to the first local dipolarization.

As a result of the large scale dipolarization, the total pressure increases from 7 nPa (at 2023 UT) to 11 nPa (at 2048 UT), i. e. ~55% enhancement of the total pressure. Near the onsets of the small scale dipolarizations ('t1', 't2', and 't3'), the total pressure reduction decreases. Near the onset of the local dipolarization at 't1', the total pressure reduction is from 10 nPa to 8 nPa, i. e. ~20% reduction. The reason of this reduction is a reduction of the plasma pressure. The reduction of total ion pressure coincides with a drop of the low energy ion pressure, while the high energy ion injections occur.

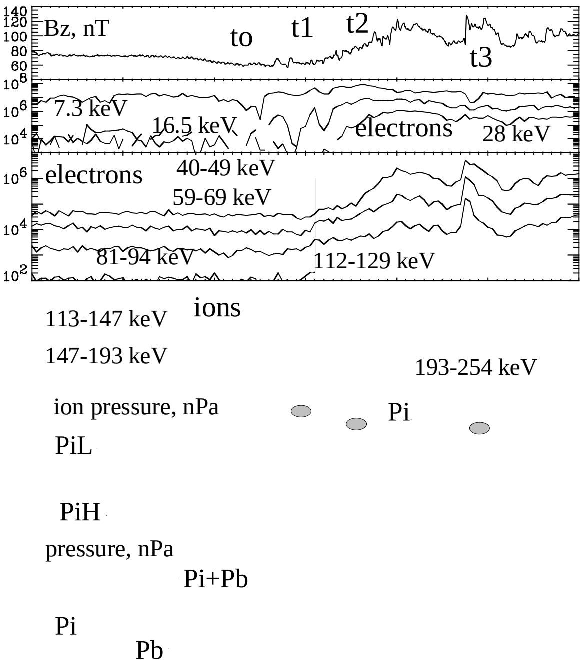

Fig.3. Substorm B. Shown in the same format as Fig.1.

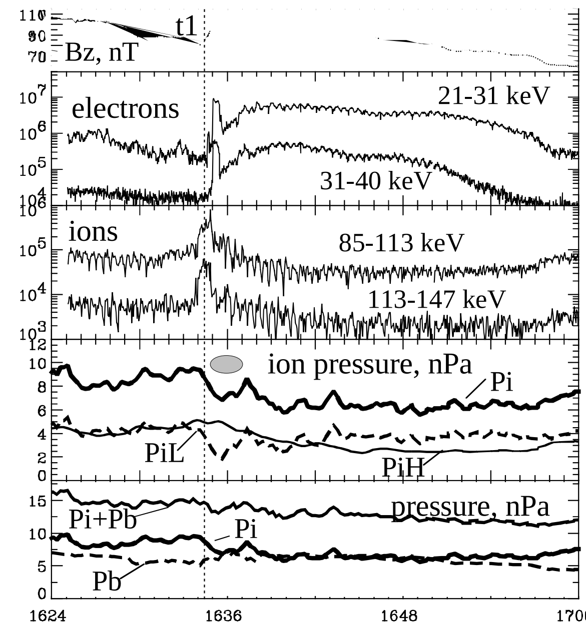

Fig. 4. Substorm C. Shown in the same format as Fig. 1.

2.3 Substorm C, March 6, 1991. During this substorm the CRRES at the orbit 545 was located outside the equatorial plane on mlat = -7.2^{O} in the premidnight sector, ~21.5 MLT. The day of March 6, 1991, was characterized by long-lasting ground magnetic activity from 1530 UT to 2200 UT. The main substorm onset was at the moment ~ 2000 UT. However, the first small substorm activation was observed with onset at 1635 UT. We analyze the magnetic field and variations of particle flux during this small substorm activation. Before the activation onset, the pitch-angle distributions had a pancake form for the ions with the energies of 37-69 keV and were nearly isotropic for the ions with the energies >69 keV.

Figure 4 presents the variations of the plasma and magnetic field pressure during the activation. From this figure one can see that the total pressure decreases from 15 nPa to ~12.5 nPa after the local dipolarization onset, i. e. ~16% reduction. A decrease of the ion fluxes at low energies makes the main contribution to the reduction of the total pressure.

2.4. Substorm D, Feb 8-9, 1991. During this substorm the CRRES at the orbit 482 was located near the equatorial plane on mlat = 0.2^{O} in the postmidnight sector, ~0.3 MLT. The ground magnetic activity is observed from ~2130 UT. The brightening of the aurora occurs at 2342 UT westward of the CRRES.

From Figure 5 one can see that the total pressure increases from 8 nPa before ‘t1’ to ~11 nPa at the end of this time interval, i. e. ~37% enhancement of the total pressure occurs during a large scale dipolarization. A sole local dipolarization was observed at the moment 't1' simultaneously with the high energy electron injection. Near this moment the decrease of the total pressure was ~12%. A decrease of the ion fluxes at low energies gives the main contribution to the reduction of the total pressure after local dipolarization onset and an increase in the ion fluxes at high energies gives the main contribution in the increase of the total pressure at the end of the large scale dipolarization.

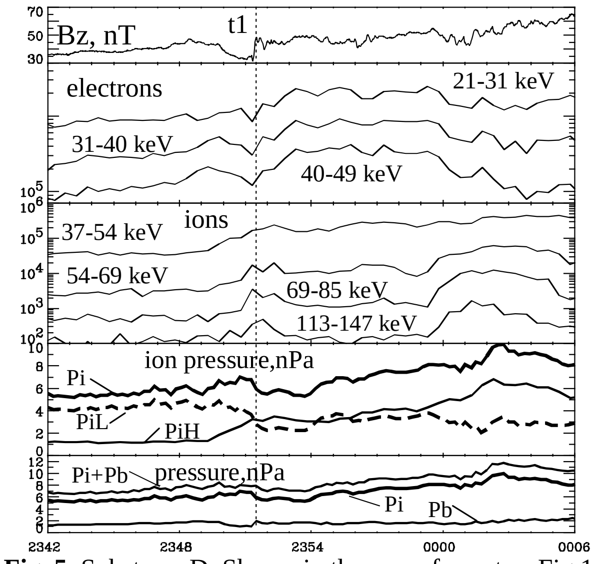

Fig. 5. Substorm D. Shown in the same format as Fig.1.

3 Discussion

There have been very few direct measurements of the change in the equatorial plasma pressure within the near-Earth plasma sheet during substorms. In brief outline, the changes of the pressure obtained from different measurements can be considered depending on the satellite position relative to the substorm onset region.

For radial distances of less than 10 R_E the total pressure tends to increase with the injection, see [*Kistler et* *al*., 1992] for r<10 R_E; [*Daglis et al.*, 1994] at r~8–8.8 R_E; [*Lui*, 1995] at 8.8 R_E.

For radial distances outside 10 R_E the total pressure tends to remain the same or to decrease [*Moortgat et al*., 1990; *Kistler et al*., 1992; *Lyons et al*.,. 2003; *Nakai and Kamide*, 2004]. The changes in the total pressure outside 10 R_E can be understood in terms of the unloading of energy in the magnetotail and the resulting change in the magnetic field configuration.

In this study we have found that for radial distances ~6 R_E during the large scale dipolarization, the total (plasma and magnetic field) pressure increases for the events observed near the equatorial plane. However, the total pressure temporarily decreases near the onsets of small scale dipolarizations, despite the enhancement of the magnetic field pressure and the high energy particle flux. These variations of the total pressure are consistent with previous measurements of pressure changes at substorm onset if we take into account the substorm dynamics.

Indeed, it is well known that during the magneto-spheric substorm the initial disturbance begins in a localized region which then expands in all directions. The substorm expansion phase occurs in association with a region of reduced cross-tail current (current dis-ruption, CD) that is connected to the ionosphere by field-aligned currents. A number of localized small scale dipolarizations occurs during the large scale dipo-larization of the magnetic field.

The radial expansion of the substorm has been examined by a number of authors. *Jacquey et al* [1991] found that the CD was initially very close to the Earth (6-10 R_E) and then CD expanded tailward with velocity ~320 km/s.

We suppose that during the substorm expansion the CRRES location is changing relative to the substorm activation site. Firstly, the CRRES was located near (or within) the local substorm activation region and, at the same time, the total pressure decreases during the local dipolarization onset. The reason of this total pressure reduction is the reduction of the low energy ion pressure. Then, after the ending of the local activation tailward the CRRES, the total pressure is increasing. There the increase of the high energy ion pressure is the main cause of the increase of the total pressure.

4 Conclusion

We have examined the variations of the total pressure during the four substorms when the CRRES was located near the Earthward edge of the plasma sheet and energetic particle injections were observed. The main results are the following:

- Large scale dipolarization leads to an increase of the total (of the plasma and magnetic field) pressure by 37-55% for the events when the CRRES was located near the equatorial plane. The total pressure decreases by 16% for the event when the CRRES was located outside the equatorial plane.
- Near the onsets of the small scale dipolarizations the total pressure can decrease by ~20%, despite the enhancement of the magnetic field pressure. The total pressure reduction is caused by the reduction of the plasma pressure.
- The reduction of the total ion pressure coincides with the drop of the low energy (<30 keV) ion pressure, while the high energy ion injections occur.
- Before the large scale dipolarization, the peak in the energy density, and, thus, the peak contribution to the pressure, is located at about 40 keV. After the large scale dipolarization the peak is moved to ~100 keV.
- During the small scale dipolarization, the ion energy density has a drop in the energy density at low energies (< 37 keV) and an enhancement or a hillock at the high energies (60-300 keV), which may be associated with the local acceleration of the particles during the local dipolarization within the inner plasma sheet.

The CRRES observations of the substorm variations of the plasma and the magnetic field, when the satellite was located near the inner edge of plasma sheet in the night sector, support the near-Earth current disruption model of the substorm onset.

Acknowledgments. The study of the PGI team was partly supported RFBR grant 06-05-65044, by the Presidium of the Russian Academy of Sciences (RAS) through the basic research program “Solar activity and physical processes in the Sun-Earth system”, and by the Division of Physical Sciences of RAS through the program “Plasma processes in the solar system”.

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