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SUBSTORMS ASSOCIATED WITH THE FRONTS OF STREAMS IN THE SOLAR WIND

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Abstract. It is well known that the various structures in the solar wind flow are either related to the solar corona structure or are created along solar wind propagation. Structures created while the solar wind propagates through the Solar system are the regions of compressed plasma at the fronts of recurrent solar wind streams (CIR) and magnetic clouds (Sheath). Auroral disturbances observed by Polar spacecraft during Sheath and CIR events had an unusual form. On one side these disturbances exhibited typical substorm signatures, but on the other side they had very large longitudinal dimensions and covered a very large area. To examine weather these disturbances represent substorms we considered data from the Geotail spacecraft in the magnetotail. Auroral bulge parameters were obtained by the UVI onboard Polar; solar wind parameters were taken from the OMNI data base. All auroral disturbances observed by Polar during Sheaths and CIRs for the periods 1997-1998; 2000; October 2001 and December 1996 were studied. We show that some signatures of a typical substorm were observed in the magnetotail, namely: 1) fast plasma flows associated with a reconnection process (tailward/earthward flows) 2) a sharp decrease of the total pressure following the interval of a pressure increase. This enables us to consider the auroral disturbances during the fronts of high-speed streams as substorm.

Introduction

Solar wind is not a uniform flow, various large-scale structures and streams exist within it (Pudovkin, 1996). The streams and structures in the solar wind could be two types: quasi-stationary and disturbed (Yermolaev et al., 2009). To the disturbed type belong the interplanetary manifestations of coronal mass ejections that can include magnetic clouds (MC) and EJECTA (or interplanetary coronal mass ejection). Disturbed structures are also structures generated in the interplanetary medium along solar wind propagation - compression regions in front of incoming fast recurrent streams (CIR) and magnetic clouds (Sheath) (e.g. Klein and Burlaga, 1983; Balong, 1999). The disturbed solar wind structures – magnetic clouds (MC) and the compression regions in front of streams (Sheath and CIR), have a noticeable in magnitude and duration south component of the magnetic field (Bz<0) and could trigger geomagnetic storms (Yermolaev et al., 2010). The relationship between storm time substorms and isolated substorms is still an open question. Many researches find no differences between storm-time and nonstorm classical substorms, while others find substantial difference between them, e.g during storm-time substorms they observe lack of bulge, lack of bifurcation of aurora (e.g. McPherron et al., 2002; Hoffmann et al., 2010).

Recently we considered auroral bulge developments during 4 solar wind structures: magnetic clouds (MC), recurrent streams (RS), and regions of their interaction with undisturbed solar wind (Sheath and CIR) (Despirak et al., 2009). It was demonstrated that during the impact of compression regions Sheath and CIR peculiar auroral disturbances of large area and very large longitudinal and latitudinal dimensions are observed.

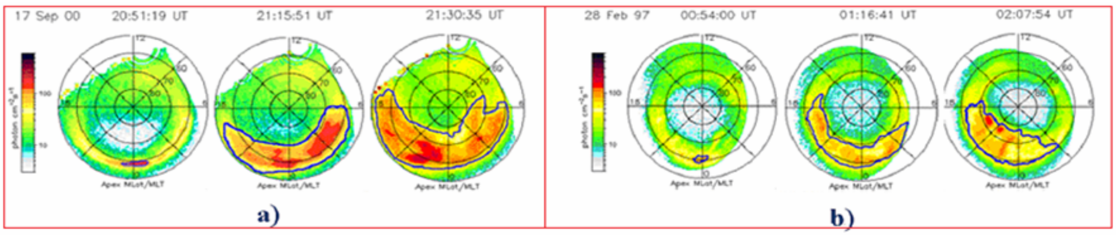


Fig. 1. Examples of auroral disturbances development by Polar UVI data during Sheath, 17 September 2000 (a) and during CIR, 28 February 1997 (b). On each auroral image the blue curve delimits the bulge region.

Although the auroral disturbances during Sheaths and CIRs have signatures of an auroral substorm development - localized onset and formation of the auroral bulge, a question arises if these disturbances are substorms. To answer this question we investigat magnetotail plasma dynamics in the course of the auroral bulge formation when the magnetosphere is driven by Sheaths and CIRs.

In the course of a substorm fast plasma flows in the magnetotail are observed and satellites in the near or middle tail can register a reversal of a tailward plasma flow to an earthward plasma flow. The observation of fast flow reversal by a spacecraft in the plasma sheet is a substorm signature - it indicates passage of the reconnection site around the spacecraft in the NENL model (e.g. Yahnin et al., 2006a) as shown in Fig. 2, or passage of the current disruption region in the Current Disruption model (e.g. Lui et al., 2008]).

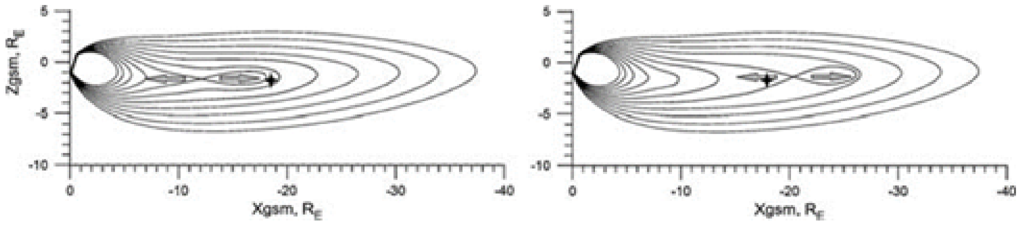


Fig. 2. Schematic view of the situation when a satellite in the magnetotail observes a reversal of fast fowls. The region where tailward and earthward flows (shown by arrows) are generated is associated with the X-line. (Figure taken from Yahnin et al., 2006a)

During substorm growth phase, as a result of reconnection at the magnetopause magnetic flux is stored in the magnetotail lobes, and in the course of an auroral disturbances this flux is 'unloaded' down to the ionosphere. So the total pressure increase followed by a decrease observed during the substorm-related fast flows is one of the signatures of substorm development in the magnetotail.

Data used

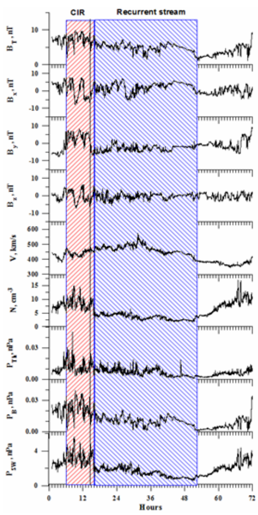
The auroral disturbances are studied by Polar UVI data in the LBHL band (1600-1800Å); Geotail plasma measurements by LEP instrument, and magnetic field measurements by MGF instrument; the solar wind and interplanetary magnetic field parameters measured by Wind spacecraft were taken from OMNI database.

All auroral disturbances observed by Polar during Sheaths and CIRs for the periods 1997-1998; 2000; October 2001 and December 1996 were studied, 8 events when Geotail was in the plasma sheet during the auroral bulge formation connected to Sheath and CIR impact were selected. We present two of them.

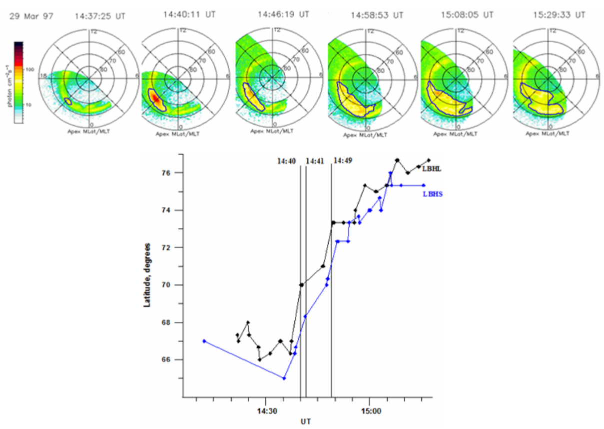
Results

1) Auroral disturbances during CIR - 29 March 1997

A recurrent stream reached the Earth at about 16 UT on 29 March and passed away at about 04 UT on 31 March 1997 (as deduced from Wind data). The CIR was registered from about 06 UT to 16 UT. Substorm was observed at 14:37 UT.

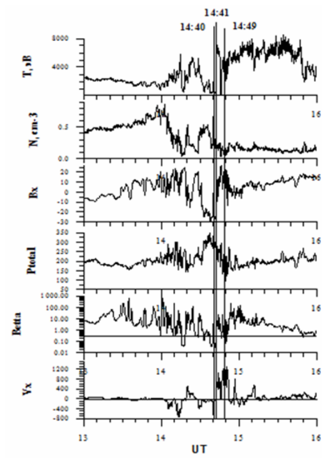


(a)
Solar wind and IMF
From top to bottom:
total magnetic field B, three magnetic field components, SW flow velocity and V_x, density, thermal pressure, magnetic pressure, dynamic pressure



(b)

Auroral disturbances development by POLAR UVI
Top: auroral bulge development from onset to maximal phase. The blue curves delimit the bulge region
Bottom: keograms in the LBHL emission (black line) and LBHS emission (blue line) at the meridian of Geotail footprint. Vertical lines indicate the times of of plasma flows in magnetotail by Geotail data



(c)

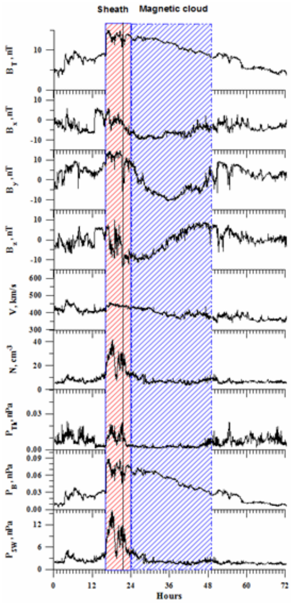
GEOTAIL data
From top to bottom:
temperature; density, MF component Bx, total pressure, plasma β, GSM X component of the plasma velocity

Fig. 3 Auroral disturbances during CIR - 29 March 1997

The blue line on (a) delimits the intervals of CIR and RS, the black solid line shows the onset time of the substorm. Keograms on bottom panel of (b) demonstrate the clear poleward expansion of the bulge. Geotail (c) started registering fast tailward plasma flows about 14:40 UT, a flow reversal took place at ~ 14:41 UT and maximum of earthward flow is at 14:49 UT. The flow reversal is associated with a decrease of the total pressure.

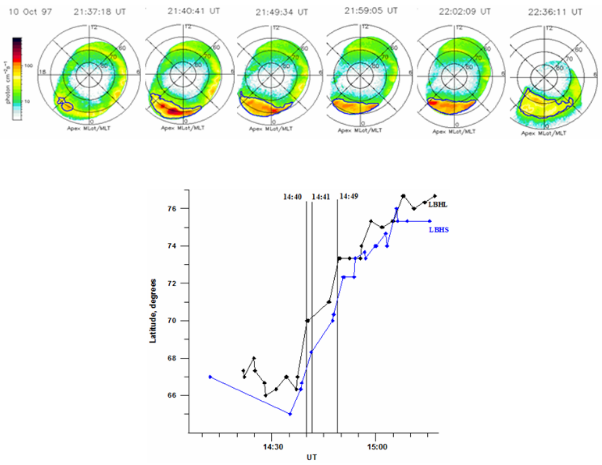
2) Auroral disturbances during SHEATH event - 10 October 1997

A magnetic cloud arrived at ~ 23:08 UT on 10 October and passed away at ~ 01 UT on 12 October 1997 (as deduced from Wind data). The Sheath was registered from about 16 UT to 23:08 UT. Substorm was observed at 21:39 UT.



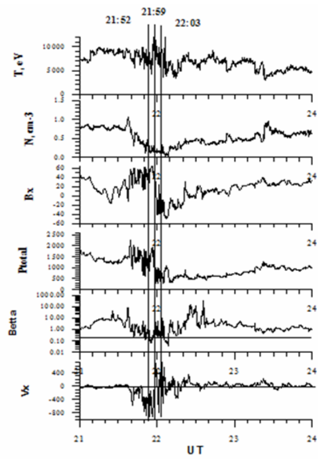
(a)

Solar wind and IMF
From top to bottom:
total magnetic field B, three magnetic field components, SW flow velocity and V_x, density, thermal pressure, magnetic pressure, dynamic pressure



(b)

Auroral disturbances development by POLAR UVI
Top: auroral bulge development from onset to maximal phase. The blue curves delimit the bulge region
Bottom: keograms in the LBHL emission (black line) and LBHS emission (blue line) at the meridian of Geotail footprint. Vertical lines indicate the times of of plasma flows in magnetotail by Geotail data



(c)

GEOTAIL data
From top to bottom:
temperature; density, MF component Bx, total pressure, plasma β, GSM X component of the plasma velocity

Fig. 4 Auroral disturbances during SHEATH event - 10 October 1997

The format of the Figure 4 is the same as that of Figure 3, the red crosshatched region in (a) shows the time of the Sheath. Geotail (c) registers fast tailward flow with a maximum at 21:52 UT, a flow reversal – at 21:59 and earthward flows with a maximum at 22:03. The flow reversal is associated with a decrease of the total pressure.

Discussion

In both cases presented here, Geotail in the magnetotail registered a reversal of a tailward plasma flow to an earthward plasma flow. The observation of oppositely directed flows is interpreted as tailward movement of the reconnection site (Hones, 1979; Runov et al., 2003), the tailward flow being inside a plasmoid. In the near-Earth initiation scenario oppositely directed flows are also observed, but not organized by the magnetic field; their generation evoked by current disruption (CD), the region of current disruption and dipolarization proceeds progressively down the magnetotail (e.g. Lui et al., 2008). The earthward flow is observed in the depolarized region, the tailward flow – tailward of the CD region. So the observation of fast flow reversal by a spacecraft in the plasma sheet is a substorm signature - it indicates passage of the reconnection site around the spacecraft in the NENL model (e.g. Yahnin et al., 2006a) or passage of the current disruption region in the CD model.

In the magnetotail at Geotail location a sharp decrease of the total pressure following the interval of pressure increase was observed. The total pressure decrease is associated with the time of plasma flow direction change. From the pressure balance condition, which is suggested to held across the plasma sheet and tail lobe boundary, the total pressure in the plasma sheet must be equal to the lobe magnetic pressure. The decrease below the lobe magnetic pressure characterizes that part of the magnetic energy stored in the tail, which dissipates during the substorm. As is well known, during substorm growth phase, as a result of reconnection at the magnetopause magnetic flux is stored in the magnetotail lobes, the volume of the flux stored depending on solar wind parameters and interplanetary magnetic field (e.g. Shukhtina et al., 2005). During auroral disturbances this flux is 'unloaded' down to the ionosphere. However it is possible that during a substorm not all the stored flux but only a part of it is dissipated in the ionosphere. The area of the auroral bulge could be a measure of the dissipated magnetic flux (Miyashita et al., 2003; Yahnin et al., 2006b). So the total pressure increase followed by a decrease observed during the substorm-related fast flows is one of the signatures of substorm development in the magnetotail.

Conclusions

In all eight cases we have analyzed, in the course of auroral disturbances development in the ionosphere during Sheath and CIR, in the magnetotail typical substorm signatures are observed:

- fast plasma flows associated with the reconnection process (tailward/earthward flows)
- a sharp decrease of the total pressure following the interval of pressure increase.

This enables us to consider the auroral disturbances during Sheath and CIR as substorms.

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