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Small-amplitude bipolar flows in the near-Earth tail

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Abstract. Geotail observations in the near-Earth magnetotail at $X_{GSM} = -11R_E$ revealed the small-amplitude bipolar (first tailward then earthward) ion flow signature. Tailward-flow part contained spikes of negative GSM B_z magnetic field, while earthward-flow part included transient B_z increase and subsequent dipolarization. This and similar structures had maximal velocities less than 200 km/s, duration of about one minute and were associated with a stretched magnetotail configuration and substorm activity. We interpret them as tailward-propagating reconnection events involving only magnetic field lines adjacent to the neutral sheet and therefore having low merging rates. Such structures might also be important because they increase the normal magnetic field component and stability in the neutral sheet.

1. Introduction

Plasma flows are an essential part of the Earth's magnetotail activity during substorms [*Angelopoulos et al.*, 1992]. Recent Geotail (GT) measurements revealed that earthward flows dominate in the magnetotail inside $X_{GSM} = -20R_E$, while plasmoids and tailward flows are typically tailward of $X_{GSM} = -25R_E$ [*Nagai et al.*, 1998; *Baumjohann et al.*, 1999; *Ieda et al.*, 1998]. Although plasmoids are also occasionally observed closer to the Earth [*Ieda et al.*, 1998], on average the large-scale reconnection activity is believed to start somewhere tailward of $X_{GSM} = -20R_E$.

However, rather frequent pre-substorm observations of a very stretched magnetic field configuration with GSM $B_z \sim$ 1-2 nT in the near-Earth magnetotail ($X_{GSM} > -15\ R_E$) suggest that non-detection of the reconnection pattern at such distances might be due to observational rather than physical limitations. For example, a reconnection process at its initial stage involves only closed field lines filled with relatively dense plasmas and should exibit a low merging rate because of the small local Alfvén velocity. One might speculate that it is unlikely to produce strong macroscopic tailward flows with pronounced negative B_z which are characteristic signatures of plasmoids and reconnection when outer plasma sheet and lobe field lines with high local Alfvén velocity (and high merging rate) are involved. Also, at least initially, the reconnection scale should be confined in the cross-tail dimension.

Small-amplitude phenomena, that might provide evidence for the reconnection process in the near-Earth tail, can be missed during statistical studies because of the usually introduced threshold velocity of about 200 km/s. Such a choice is quite natural for an automated investigation as it excludes the possible influence of the background variations always present in the data. We visually examined near-tail data collected by GT during the summers of 1995-1997. In order to exclude field aligned flows in the PSBL, the study was limited to the close proximity of the neutral sheet. As well, occasional tailward flows within and after earthward bursty bulk flows (BBFs) were not taken into account. The description of a new small-scale tailward flow phenomenon discovered in the near-Earth tail is the subject of this report.

We used the GT low energy plasma (LEP) experiment [*Mukai et al.*, 1994] data at 12-s resolution. The full resolution 16-Hz magnetic field measurements [*Kokubun et al.*, 1994] were used to resolve fine structure in the magnetic field. In what follows all coordinates and vector components refer to the GSM frame of reference, except X ground magnetograms, which refer to standard geographic coordinates.

2. Case Study: Substorm Timing

Here we present one example of the described phenomenon that was detected at ~ 0555 UT, 30 August, 1996 near the onset of a big substorm. In this section we briefly describe only general substorm features, which are relevant to the breakup positioning and timing.

The GT spacecraft was located at [-10.8, 1.68, -0.18] R_E, i.e., nearly at midnight and just 50 km away from the model position of the neutral sheet (Z coordinate in the GSM-corrected frame of reference). Right before the event a very stretched configuration of the plasma sheet with $B_z \sim$ 1 nT was observed (Figure 1). CANOPUS ground magnetometers conveniently spanning the wide range of magnetic local times permitted us to determine the spatial and temporal evolution of this substorm (Figure 2).

The first magnetic breakup was registered at 0555 UT by the Fort Smith magnetometer (at ~2145 MLT, Figure 2). It was accompanied by a small variation in the Gillam magnetogram (at ~2320 MLT). Large magnetic activation around magnetic midnight (second breakup) was registered at Gillam at 0600 UT. The analysis of meridian scanning photometer keograms from the same stations (not shown here) confirmed the existence of two breakup regions at different MLT.

GT recordings (Figure 1) are consistent with those at Gillam (spacecraft footpoint was within 3^o longitude from the station). A very strong earthward ion burst and dipolarization were detected at 0600 UT. The velocity of this burst is strongly underestimated in Figure 1 because most of ion flow was in the energy range above that of the LEP spectrometer [*Nagai et al.*, 1999]. The first ground breakup

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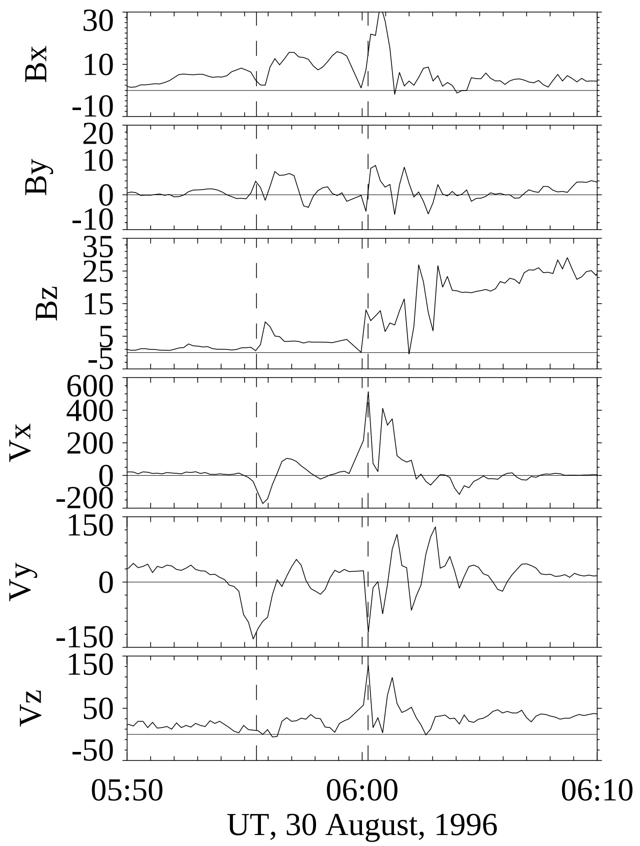

Figure 1. Geotail GSM magnetic field (nT) and ion bulk velocity (km/s, on-board calculated moments) for August 30, 1996. Vertical lines show ground breakups.

(registered at 0555 UT nearly two hours MLT westward) resulted only in a rather small activation (Figure 1, 0555–0557 UT) at the GT position. In the following we will concentrate on this specific activation.

3. Case Study: Small-amplitude Bipolar Flow

Figure 3 shows the detailed graph of GT magnetic field and plasma velocity during this interesting small activation. The maximal amplitude of the flow velocity was less than 200 km/s. However, the clear bipolar form of both V_x and V_y velocity components permitted the visual identification of this phenomenon.

To understand the nature of this bipolar flow it is helpful to take a closer look at the full-resolution (16 Hz) magnetic field measurements (Figure 3): The profile of the normal magnetic field component (B_z) started with the very small pre-event level of 1 nT, then sharp minima with negative B_z were embedded in the tailward flow (at 0555:26, 0555:40, 0555:54 UT). The last minimum at 0555:54 UT was also characterized by a nearly zero total magnetic field amplitude. The sharp increase of B_z up to nearly 15 nT and peak of B_y were observed just before the bipolar flow reversal (0555:56 UT). Later, simultaneously with the decay of the earthward flow, the B_z returned to its post-event level of 4 nT.

Negative B_z values embedded in the tailward flow and the pile-up of the (reconnected) magnetic flux appearing as the B_z maximum on the earthward flow side are consistent with the signatures of the active reconnection pattern. The amplitude of the outflow velocity is equal (in theory) to the Alfvén velocity on the inflow field lines. In our case the observed outflow velocity and local (neutral sheet) Alfvén velocity were approximately equal and were about 100 km/s. Therefore the reconnection process was likely limited to the field lines adjacent to the field reversal in the neutral sheet, and the merging rate was very low. Such slowness of the reconnection process might account for observations of only spikes of negative B_z inside the tailward flow. Note, that even in a well-identified plasmoid (e.g., [*Petrukovich et al.*, 1998]) periods with negative B_z values are usually rather intermittent and are embedded in longer intervals of tailward flow. Furthermore, the GT particle experiment with 12-s time resolution may be unable to properly resolve effects related to the negative B_z spikes with the few-second duration. Such averaging of the plasma data might smear sharp flow bursts that accompany magnetic field minima, so that they are not as pronounced in the velocity data.

The time of the B_z reversal (0555:55 UT) appears to be somewhat shifted relative to the time of the velocity reversal (0556:12 UT). However it is natural to interpret the observed velocity pattern as a bipolar velocity burst moving tailwards and dawnwards with small bulk velocity (shown by dashed lines in Figure 3). Note that substraction of such an offset will make the bipolar variation more symmetrical. When this is done, the amplitudes of both velocity components are about 100 km/s. As well, then the direction of the bulk velocity is consistent with the position of the first breakup, viz. (~22 MLT) which is duskward and probably earthward of GT (~2320 MLT). We may suppose that the bipolar structure was generated during this first substorm activation and propagated tailward and dawnward along the neutral sheet (plasma β was higher than 10). The piling up

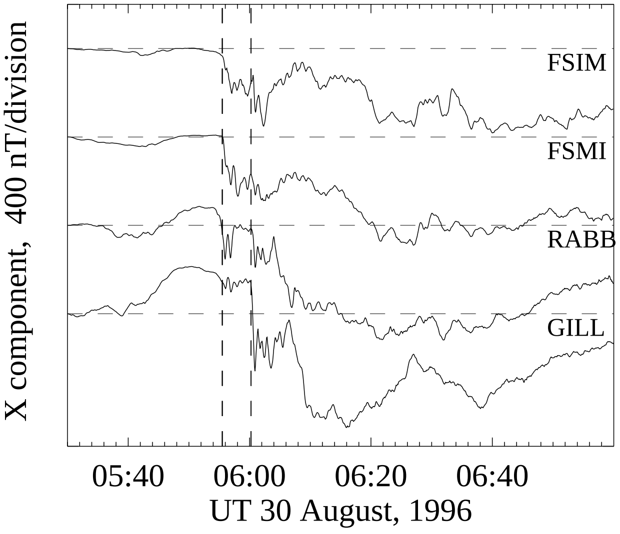

Figure 2. X-component magnetograms of the selected CANOPUS stations (top to bottom): Ft.Simpson, Ft.Smith, Rabbit Lake, Gillam. Vertical lines show ground breakups. Geographic coordinates (latitude and longitude) of stations are as follows: Ft.Simpson (FSIM, 67.2°, 291.9°), Ft.Smith (FSMI, 67.8°, 304.6°), Rabbit Lake (RABB, 67.5°, 317.0°), Gillam (GILL, 66.9°, 331.4°).

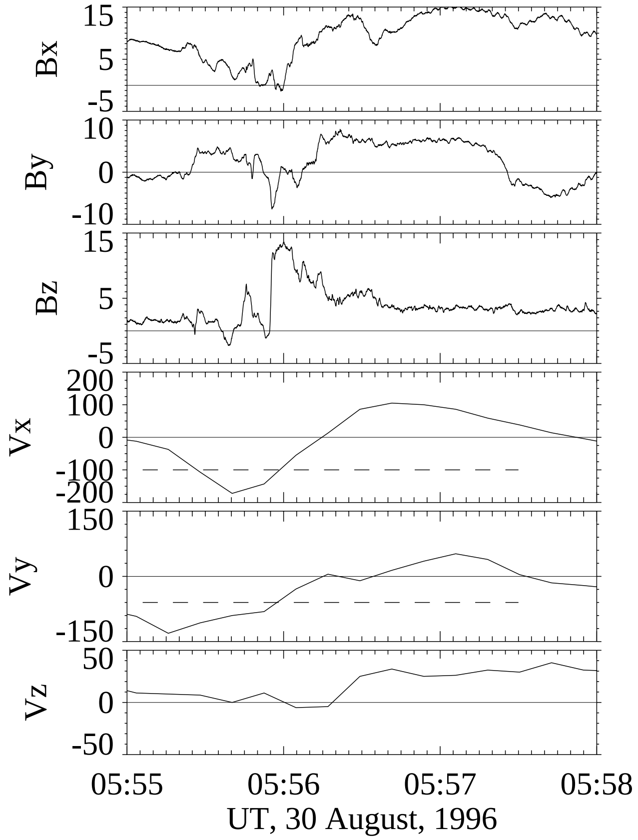

Figure 3. Geotail GSM high-resolution magnetic field (nT) and ion bulk velocity (km/s, on-board calculated moments) for August 30, 1996. Dashed horizontal lines show assumed bulk velocity.

of B_z earthward of the reconnection point might account for such tailward motion. The reconnection point had to shift further tailward from this pile-up (in a region with a stretched magnetic configuration), or die out.

We interpret our observations as the crossing of a moving X-line. We would like to stress that the described phenomenon is different from other structures with negative B_z variations which are often detected in the magnetotail. (1) It is quite different from the BBF-related activity (a good example of the latter was actually detected at 0600 UT, Figure 1); our bipolar flow started on the quiet background with tailward flow and negative B_z spikes, while in BBFs tailward flows and negative B_z are registered in a rather turbulent environment after the initial strong earthward flow [*Angelopoulos et al.*, 1992]. (2) The bipolar velocity variation alone may be alternatively attributed to the crossing of a vortex-like structure [*Fairfield et al.*, 1998]. However, a strong and definitely asymmetric magnetic field variation relative to the velocity reversal point is not consistent with such an explanation.

4. Other Observations

About 5 similar cases were found in the GT data. All events were characterized by small-amplitude velocities and contained leading sharp B_z minima and subsequent dipolarization. All were registered either 1-2 minutes after substorm onsets or during geomagnetically active periods and in association with the very stretched magnetic field configuration ($B_z < 5$ nT). All were apparently propagating tailward and outward (that is, e.g., dawnward on the dawn flank) and had significant V_y and B_y components, including those observed nearly at midnight.

The relatively small number of observations might be explained by rather small amplitudes complicating event identification on the noisy background. Also, potentially interesting intervals are limited to the vicinity of neutral sheet. Simple orbital analysis shows that GT is positioned in the magnetotail within $15R_E$ radial distance and within $1R_E$ from model neutral sheet only during ~65 hours per year. Note that the spacecraft should also be in a fortuitous position with respect to the breakup region.

5. Conclusions

Examination of small-amplitude variations detected by the Geotail spacecraft in the near-Earth tail at $X_{GSM} = -11R_E$ revealed bipolar (first tailward, then earthward) ion flow signature. Tailward-flow parts contained spikes of negative B_z, while in the trailing parts and after the events B_z increased. This phenomenon is distinctly different from BBF activity in which occasional tailward flows and negative B_z variations are observed after the initial earthward flow.

We interpret our observations as active but small-amplitude (possibly, newly born) reconnection sites involving only magnetic field lines adjacent to the field reversal and therefore having low merging rates and low outflow of the reconnected field lines. They were likely generated during substorm breakups in the very stretched near-Earth tail and moved outward from the Earth. Reconnected magnetic flux, piling up on the earthward side, may account for such outward motion.

Variations in the B_y and V_y components were of the order of that in B_z and V_x, suggesting essentially a three-dimensional nature for our phenomenon. Due to the small amplitude it is unlikely to be observed outside the neutral sheet vicinity and only sufficiently coherent structure might be recovered from the background variations.

However, they could be of interest because: (1) This is an example of a reconnection pattern observed at the $X_{GSM} \sim -(10-15)R_E$ and it is different from the large-scale X-line which is supposed to form in the mid-tail; (2) After the event the magnitude of the magnetic field B_z component and, hence, stability of the current sheet are increased; (3) Such structure might initiate large-scale reconnection in the appropriate conditions (e.g., when it will reach the middle magnetotail). Alternatively, our small-scale phenomenon might be just a weak flank effect of the main activation.

A significant extension of the current analysis is necessary to develop the mechanism of their generation and to understand the relative importance of the observed phenomenon.

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