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The response of the near earth magnetotail to substorm activity

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Abstract

The large scale structure of the current sheet in the terrestrial magnetotail is often represented as the superposition of a constant northward-oriented magnetic field component (B_z) and a component along the Earth–Sun direction (B_x) that varies with distance from the center of the sheet (z_0 in GSM) as in a Hams neutral sheet. The latter implies that $B_x = B_{Lx} \tanh((z - z_0)/h)$ where B_{Lx} is the magnitude of the B_x component in the northern lobe. Correspondingly, the cross-tail current should be approximated by $J_y = (B_{Lx}/h)\,\mathrm{sech}^2((z - z_0)/h)$. Using data from the fluxgate magnetometer (FGM) on the Cluster II spacecraft tetrad, we have used measured fields and currents to ask if this model represents the large-scale properties of the system. During very quiet crossings of the plasmasheet, we find that the model gives a reasonable estimate of the trend of the average current and field distributions, but during disturbed intervals, the best fit fails to represent the data. If, however, the parameters z_0 and h of the model are taken as variable functions of time, the fits can be reasonably good. The temporal variation of the fit parameter h that characterizes the thickness of the current sheet can be interpreted in terms of thinning during the growth phase of a substorm and thickening following the expansion phase. Ground signatures that give insight into the local time of substorm onset can be used to interpret the response of the plasmasheet to substorm related changes of the global system. During a substorm, the field magnitude in the central plasmasheet fluctuates at the period of Pi2 pulsations.

Keywords: Magnetic storm; Substorm activity; Near earth magnetotail response

1. Introduction

In this brief report, we introduce an approach to the analysis of the temporal variation of the location and thickness of the magnetotail plasmasheet based on data from four Cluster spacecraft. The model is indubitably an oversimplified one, but the results are promising, allowing us to infer thickening and thinning of the plasmasheet at times consistent with complementary evidence of substorm expansion.

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2. The Harris neutral sheet model

The current structure in the magnetotail is often approximated by using the analytic expression referred to as the "Harris neutral sheet" that represents the component of the magnetic field along the Earth–Sun direction as

$$B_x = B_{Lx} \tanh((z - z_0)/h), \qquad (1)$$

where B_{Lx} is the magnitude of the x-component of the magnetic field in the northern lobe (Harris, 1962). Here, z_0 represents the position of the center of the current sheet and h is the scale of the plasmasheet thickness. Correspondingly, the cross-tail current density is

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$$J_y = (B_{Lx}/h)\,\mathrm{sech}^2((z - z_0)/h). \qquad (2)$$

Field curvature is obtained by adding a constant northward-oriented magnetic field component (B_z) with no associated current. With Cluster, we measure both **B** and **J**, the latter being evaluated from the four spacecraft data intercalibrated using techniques described by Khurana et al. (1996, 1998). B_{Lx} can be approximated from lobe measurements made before the spacecraft enter the plasmasheet. We comment below on proposed methods for incorporating more realistic time dependence into the estimate of this parameter.

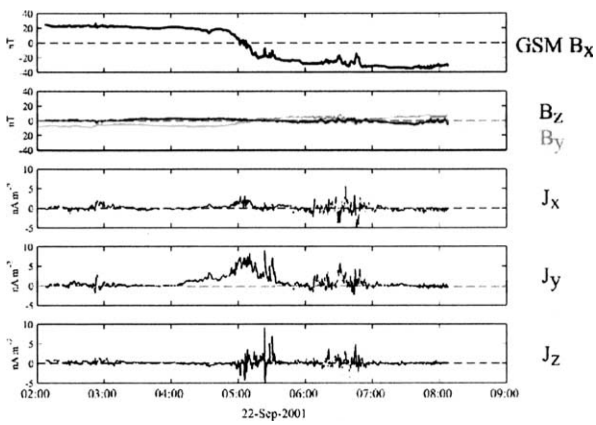

Fig. 1. (Upper two panels) Magnetic field components in nT measured by Cluster 1 for the current sheet crossing of September 22, 2001 (GSM coordinates). (Lower three panels) Current density in nA/m^2 obtained from magnetometer measurements on all four Cluster spacecraft.

3. Cluster plasmasheet crossings during quiet and disturbed intervals

During the interval July–October 2001, Cluster repeatedly crossed the tail plasmasheet near apogee (at radial distance near $19R_E$) progressing from the dawn flank towards the dusk flank. Typical plasmasheet crossings lasted for ~6 h but the duration of the crossings ranged from 2 to 12 h. Although some crossings occurred during quiet geomagnetic conditions, the intervals of the plasmasheet encounters were commonly punctuated by substorm activity, and some passes were so disturbed that no stable current sheet model was applicable.

The early part of September 22, 2001 was unusually quiet with the AE index remaining below 100 nT until 0600 UT and below 200 nT until 0730 UT. Fig. 1 illustrates the magnetic field from the FGM magnetometer on Cluster 1 (Balogh et al., 1993, 1997) for the plasmasheet crossing. The cross-tail current density (J_y) rises to a maximum in the vicinity of the current sheet crossing where both B_x and B_y vanish. The change of sign of B_y at this time reflects the flaring of the magnetotail in the post midnight sector (with the field pointing slightly towards dusk in the northern hemisphere and towards dawn in the southern hemisphere). This feature (and the small increase of J_x in the center of the tail) would disappear in a skewed coordinate system slightly rotated around the z_{GSM} axis, but is not important for the purpose of this analysis.

Superimposed on the slowly varying structure of the current are short duration fluctuations that are present in all three components. Such fluctuations are particularly prominent from 0600 to 0700 UT when magnetic

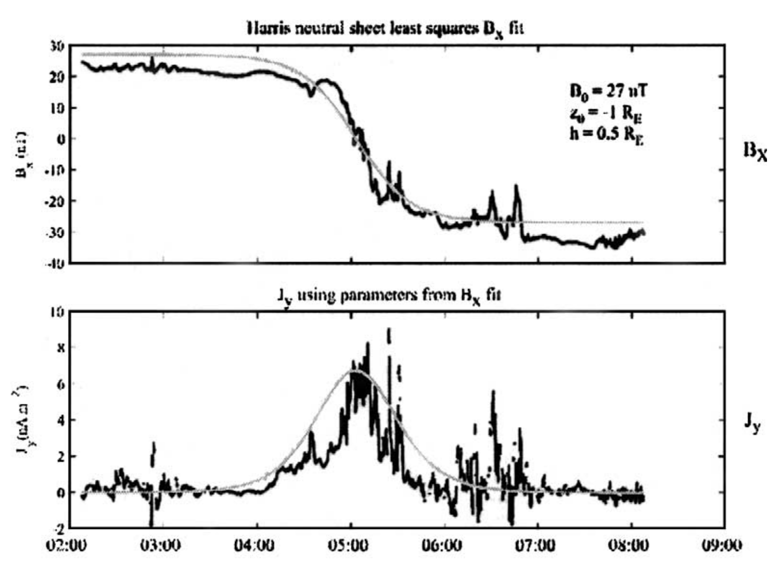

Fig. 2. (Upper panel) The measured B_x component of the field in the plasmasheet and a fit of the data to a static Harris neutral sheet model for the plasmasheet crossing of September 22, 2001. (Lower panel) The measured cross-tail current and the current inferred from the fit.