

## IS NEAR-EARTH CURRENT SHEET THINNING THE CAUSE OF AURORAL SUBSTORM ONSET?

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### 1. INTRODUCTION

The onset of the expansion phase of an auroral substorm is a time of sudden brightening of the midnight aurora, accompanied by a rapid intensification of the westward electrojet flowing beneath the aurora. In the near-tail region of the magnetosphere there are numerous changes associated with this onset. These changes have been interpreted differently by advocates of various models of the magnetospheric substorm (Baker et al., 1984; Akasofu, 1979; Rostoker, et al., 1984.) As yet there is no universal agreement concerning the physical process responsible for the substorm onset, or the subsequent expansion phase.

Processes that appear to trigger the expansion onset have been identified by various investigators and include sudden impulses (Kokubun et al., 1977) and northward turnings of the IMF (Caan et al., 1977; Rostoker, 1983). Not all expansions appear to be triggered, however. McPherron, et al., 1986, have shown that a fraction of all substorms with sharp onsets cannot be correlated with any obvious fluctuation in the solar wind. This result suggests that the onset is an internal magnetospheric process which is sensitive to conditions external to the magnetosphere. Such a process may be thinning of the near-earth current sheet.

In one of the first detailed studies of a magnetospheric substorm in the near-tail region it was found that the expansion onset appeared to be preceded by thinning of the plasma sheet (McPherron, et al., 1973 and references therein.) The disappearance of energetic particles at synchronous orbit prior to expansion onset has been interpreted in a similar way, (Walker et al., 1976.) Later studies of energetic particles in the near-tail led to the same conclusions (Pytte, et al., 1976.)

In all of these studies it may be argued that the behavior of the energetic particles does not necessarily reflect that of the background plasma. In this report we attempt to remove some of this ambiguity by studying the temporal characteristics of the cross-tail current during a

substorm growth phase. While knowledge of the current does not identify the particle populations producing the current, it certainly reflects the properties of the bulk of the plasma. The database used for this study is that prepared by the NSSDC for the sixth Coordinated Data Analysis Workshop (CDAW-6). An overview of this event is presented by McPherron and Manka, 1985. Subsequent papers in the same issue present details.

## 2. NEAR-TAIL MAGNETIC FIELD OBSERVATIONS

The CDAW-6 substorm expansion onset of 1054 UT, March 22, 1979 occurred at a time when the earth's dipole axis was almost precisely orthogonal to the earth-sun line. As shown in Figure 15 of McPherron and Manka, the ISEE 1/2 spacecraft were inbound at 0130 local time, approximately  $13 R_e$  behind the earth. At onset both spacecraft were situated roughly  $1 R_e$  below the expected position of the neutral sheet. Magnetic field data from the ISEE-1 spacecraft presented in Figure 16 of the same paper demonstrate that a change in the solar wind and IMF caused the neutral sheet to move down over the spacecraft allowing both to probe the structure of the current sheet as it passed by. Shortly after the expansion onset the spacecraft observed a pulse of southward field near the neutral sheet accompanied by a rapid tailward plasma flow. These observations have been interpreted by advocates of the neutral line model as consequences of the formation of a localized near-earth neutral line and release of a plasmoid (Paschmann, et al, 1985.) The question considered here is whether these phenomena were preceded by detectable changes in the current sheet which are consistent with the neutral line model.

### A. Transformation to neutral sheet coordinates:

Since the magnetic data indicate that the neutral sheet was not parallel to the earth-sun line, it is necessary to transform the magnetic data to a more appropriate system. Several techniques including principal axis analysis suggest that this system is rotated  $15^\circ$  about  $z$ (GSM) and  $10^\circ$  about the new  $y$  axis. These rotations line up the  $x$  axis with the magnetic field in the north and south lobes while maintaining the same equatorial plane as in GSM coordinates. This constraint on the new  $x$  and  $y$  axes corresponds to the assumption that the tail current flows in the GSM equatorial plane. We note here that we find, as do McComas et al., 1986, that magnetic meridians are tilted about  $30^\circ$  with respect to the equatorial plane of our rotated axes.

### B. The data in transformed coordinates:

The magnetic data from the two spacecraft at one minute resolution were converted from GSM to transformed coordinates and are plotted in Figure 1. The top panel presents the  $x$  component (sunward) which contains the information required to deduce the structure of the cross-tail current. The middle panel shows the  $y$  (azimuthal) component of the field which we use as an indicator of the presence of field aligned currents. The third panel contains the  $z$  (vertical) component. Negative values of  $B_z$  are usually interpreted as indicative of a neutral line earthward of the spacecraft. The vertical dashed line at 1054 UT is the time of expansion phase onset as deduced from ground observations (McPherron and Manka, 1985.)

Multiple neutral sheet crossings are evident from zeros in the x component of the field. After the onset and during the interval 1057-1108 UT, both spacecraft were on opposite sides of the neutral sheet near the boundaries of the current sheet with the tail lobes. Since the spacecraft were only separated by about 3000 km in the transformed coordinates, it is evident that the current sheet must have been relatively thin after expansion onset. For the ISEE-1 spacecraft, the rotation about z (GSM) virtually eliminates the azimuthal component  $B_y$  of the magnetic field until well after the onset. This is not true at ISEE-2, however, which recorded a large positive perturbation. Similarly, it is evident that the  $10^\circ$  tilt about the y axis virtually eliminates any z component of the field at ISEE-1. This is nearly true for ISEE-2 as well, except for one residual negative spike at 1059 UT. High resolution data show that the magnetic field pointed almost exactly southward with magnitude of 60 nT for 20 seconds of this one minute averaging interval.

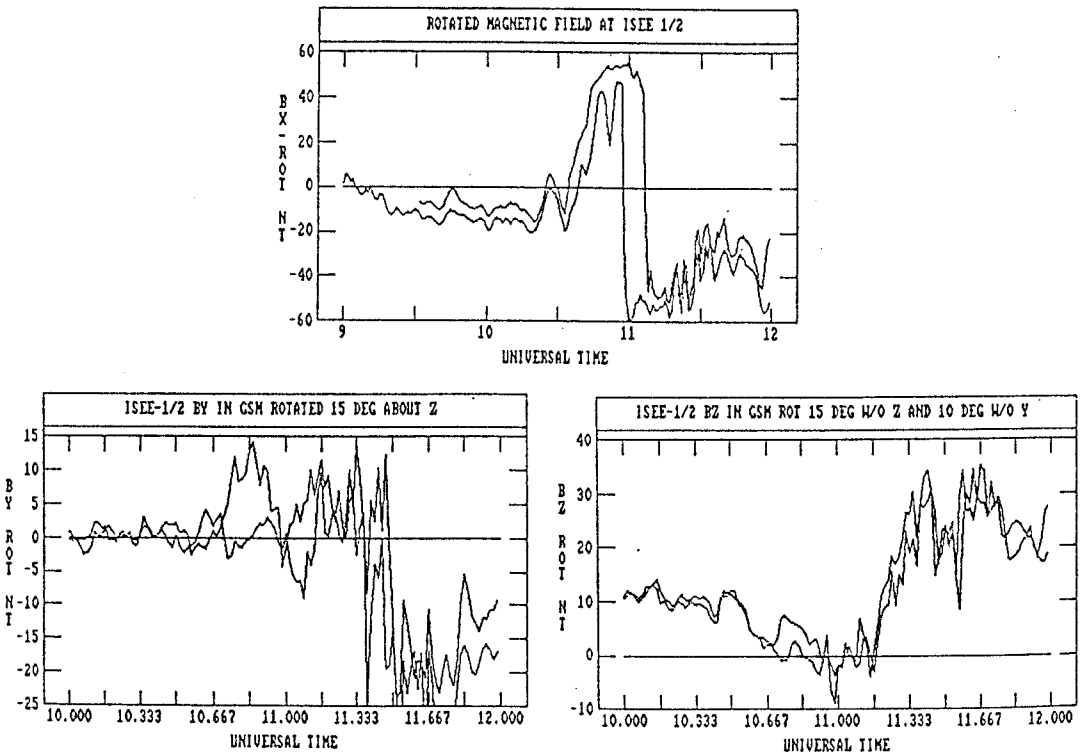


Figure 1 Components of the magnetic field in neutral sheet coordinates as observed by the ISEE-1/2 spacecraft in the near tail. Panel 1 shows the sunward component ( $B_x$ ), panel 2 the cross-tail component ( $B_y$ ), and panel 3 the vertical ( $B_z$ ) component.

### 3. HARRIS MODEL OF THE CURRENT SHEET

#### A. The Harris model of the equilibrium current sheet

The current density at a point in space may be calculated from observations of the magnetic field using Ampere's law [ $\nabla \times \mathbf{B} = \mu_0 \mathbf{J}$ ]. This calculation requires knowledge of the magnetic field and six of its partial derivatives. With vector measurements at two, closely spaced spacecraft the field and three directional derivatives can be determined. To make the problem unique we assume a slab current flowing along the y axis so that  $B_y$  and  $B_z$  are zero, and  $B_x$  varies only in the z direction. If we then assume that the slab is convected across a pair of spacecraft we can show that the instantaneous vertical sheet velocity is given by

$$V_z = - [\delta B_x / \delta t] / [\Delta B_x / \Delta z]$$

We have applied this model to the data shown in the first panel of Figure 1. We integrate the velocity to obtain the location of the current sheet relative to the spacecraft and compare the calculated neutral sheet crossings to those observed. The model fails completely! We conclude that the time invariant slab model is incorrect. Thus, during disturbed times we cannot use the this technique to determine the actual current sheet structure as McComas et al., 1986, did for quiet times.

To progress further we are forced to assume a simple model of the current sheet structure and attempt to determine the time variations in the model parameters. For this purpose we assume that the field is described by the Harris (1962) equilibrium current sheet for which

$$B_x = B_0 \tanh[(z - z_0) / \lambda]$$

This is a three parameter model where  $B_0$  is the asymptotic field of the lobe,  $\lambda$  is the scale height of the current sheet, and  $z_0$  is the location of the current sheet relative to one of the spacecraft). In the transformed coordinates there are only two measurements at any instant, the  $B_x$  component of the field at the two spacecraft. We remove the ambiguity by noting that the total pressure in the current sheet should equal the asymptotic magnetic pressure of the lobe. Since the bulk parameters of the plasma are known for this event (Paschmann, et al., 1985) we can infer the lobe field and other parameters.

#### B. Current sheet thinning during the growth phase

Applying this model to the transformed data we obtain the results summarized in Figure 2. From 0940 UT until 1020 UT the properties of the current sheet remain relatively stable. At 1010 the IMF turned southward at the solar wind monitor just outside the magnetosphere. After a delay of 10 minutes the magnetosphere began to respond. The neutral sheet ( $z_0$ ) moved towards the spacecraft crossing ISEE-2 once during the growth phase, and once again soon after the expansion onset. The scale height of the current sheet ( $\lambda$ ) remained about  $5 R_e$  until the effects of the IMF change were felt. It then decreased rapidly displaying large, wave-like perturbations in thickness. By the time of the expansion onset the scale height had decreased to less than  $1 R_e$  and the two spacecraft were no longer simultaneously within the current sheet. The dotted lines superimposed on the parameters indicate linear and exponential fits to the parameters. Apart from the wave-like perturbations, the scale height appears to decrease with a time constant of 13 minutes. For this event the duration of the growth phase was about 40 minutes, corresponding to three e-folding times of the thinning.

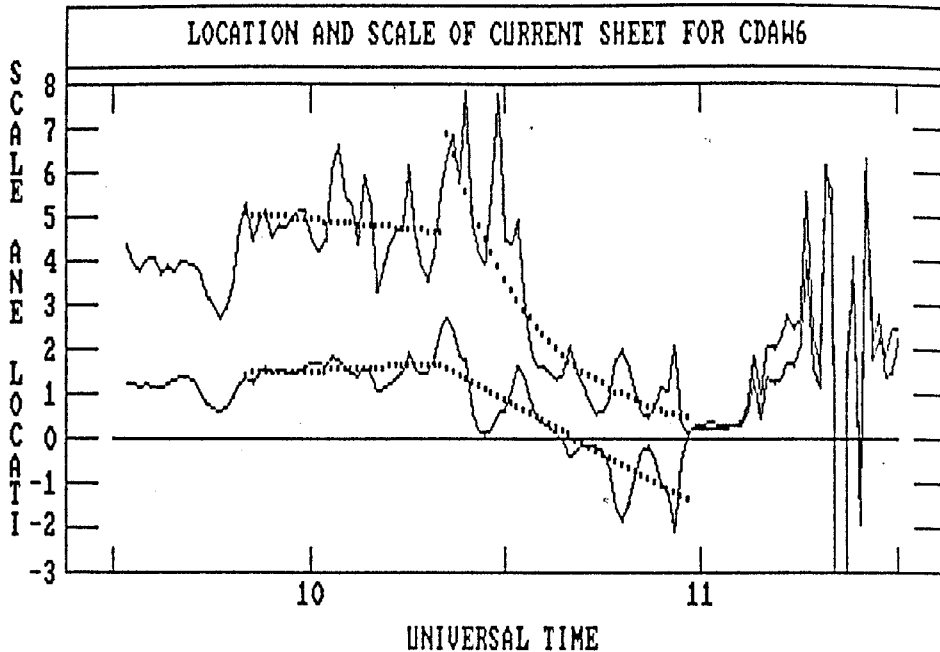


Figure 2 Properties of the near-tail current sheet as deduced from transformed magnetic field data. Plotted versus time, the parameters include the location ( $z_0$ ) of the neutral sheet relative to ISEE-2 spacecraft and the scale length ( $\lambda$ ) of the calculated current sheet.

#### 4. CONCLUSIONS

The CDAW-6 substorm described above occurred under fortuitous circumstances which made it possible to determine the structure of the near-earth current sheet prior to expansion onset. At a time when the neutral sheet should have been found in the GSM equatorial plane, a change in the solar wind velocity vector caused the sheet to move downward across the ISEE spacecraft carrying magnetometers and plasma detectors. We found that the observations could not be explained by a time-invariant current slab. Instead we assumed a Harris equilibrium current sheet and found that the apparent scale height decreased exponentially with time. At the time of expansion onset this height had thinned to less than the 3000 km vertical separation of the spacecraft. Data not shown here for lack of space, indicate that subsequent to expansion onset the scale height was about 400 km.

These observations demonstrate that the interaction of a southward IMF with the earth's magnetic field can lead to a rapid thinning of the near-earth current sheet. Presumably this is a result of a combination of compression by the lobe field and convection induced by the magnetospheric electric field. Since the lobe field increased while the thinning was in

progress, the total current in the current sheet had to as well. In the Harris model the neutral sheet current density is given by  $J_{\max} = B_0/\lambda\mu_0$ , indicating that the maximum current density increased dramatically with time. We postulate that the particles in the thin current sheet are not able to carry the necessary tail current and an instability develops. This instability allows reconnection to occur and a neutral line is formed in the region of ultra-thin current sheet. We note that as the sheet becomes thinner it is likely to become progressively more sensitive to external perturbations. For example, sudden increases in solar wind pressure might compress the current sheet still further initiating the instability. A similar role might be played by compressional waves. Alternatively, a northward turning of the IMF might alter the convection electric field with similar results.

## 5. ACKNOWLEDGMENTS

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