Abstract. No high-speed flows or discernible countercflowing ion beams were observed during a series of plasma sheet boundary encounters resulting from solar wind-driven plasma sheet motions. We conclude that the boundary may be active primarily during plasma sheet "recovery". A temporal onset of flows in the inner plasma sheet (IPS) was associated with the appearance of countercflowing beams embedded in an already isotropic plasma sheet distribution, suggesting that high-speed flows at the plasma sheet boundary and close to the neutral sheet may have a common generation mechanism.

Introduction and Datasets Used

Substorm recoveries are often associated with entries of spacecraft from the lobes into the central plasma sheet (CPS) at distances > 10 Re [Hones et al., 1987] though not always on a one-to-one basis [Li et al., 1977]. Such entries, termed "plasma sheet recoveries", appear to be expansions of the plasma sheet, characterized by sharp increases of the particle fluxes, high-speed flows lasting 10-15 minutes, ion heating and magnetic field dipolarizations [Hones et al., 1971; Pytte et al., 1976; Li et al., 1977; De Coster and Frank, 1979].

The outermost layers of the plasma sheet contain fast earthward ion beams [Li et al., 1983; Takahashi and Hones, 1988]. Tailward beams appear as the distance from the boundary increases; eventually isotropic distributions dominate in the CPS. Plasma sheet boundary layer (PSBL) ion beams can be found for a wide range of geomagnetic activity and irrespective of substorm phase. Eastman et al. [1984] and Takahashi and Hones [1988] argued that such beams are nearly always present at the plasma sheet-lobe interface. However, PSBL ion flows remain below 100 km/s more than 60% of the time under all AE conditions [Baumjohann et al., 1988] (Figure 9). Since a small PSBL ion velocity may also result from a slight imbalance between countercflowing beams [Eastman et al. 1984] the question whether ion beams represent a permanent feature of the PSBL remains unanswered.

Here we present a series of plasma sheet boundary crossings during which the plasma velocity was small and the ion distributions were essentially isotropic. We used data from the Los Alamos/MPF Fast Plasma Experiment [Bame et al., 1978a] and the UCLA magnetometer experiment [Russell, 1978] on ISEE 2. The time to measure an ion distribution function is 3 s (spin period) but the sampling interval is 12 s (at low data rate mode). The plasma moments were running-averaged with a 36 s window to reduce scatter; magnetic field and plasma moments are plotted at 12 s resolution. The ion distribution functions were averaged at 2 min resolution to reduce noise, but they are qualitatively similar to the unaveraged ones. As a solar wind monitor, we used 64 s resolution data from the vector helium magnetometer [Frandsen et al., 1978] and 5 min resolution data from the LANL electrostatic analyzer [Bame et al., 1978b] on ISEE 3. IMP 8, closer to Earth, was used to establish the propagation of solar wind features from ISEE 3 to the near-earth environment, but was inappropriate as a principal solar wind monitor because its plasma data were sparse and noisy during this interval. We used 64 s resolution magnetic field data and 1 min resolution plasma data measured on IMP 8, after we running-averaged the data with a 10 min window. Ground magnetometer data from Alaskan and Western Canadian stations [Russell, 1987] at 1 min resolution were also used.

Magnetotail Observations

On March 16, 1979 at 0600 UT, ISEE 2 was in the northern tail lobe (Figure 1) at a large distance Dns from the expected position of the neutral sheet [Dandouras et al., 1988] but was closing upon it fairly quickly, mostly because the tilt angle of the Earth's dipole (\(\chi\)) was increasing. We identified the plasma sheet by requiring the ion pressure to exceed \(10^{-2}\) nPa, the inner plasma sheet (IPS) by requiring that the ion beta, \(\beta_i\), exceed 0.5 and the outer plasma sheet (OPS) by \(\beta_i<0.5\). The various regions are denoted by the grey-scale below the AE index in Figure 1; our definition of OPS is inclusive of the PSBL as defined by Baumjohann et al. [1988].

All boundary crossings took place at large Dns; given the < 3 RE statistical plasma sheet half thickness near local midnight.

Fig. 1. Magnetic field and plasma moments measured on the ISEE 2 satellite. Position is also shown at the bottom. Coordinates: Magnetic field, position in GSM; Ion velocity in GSE. Units: Density \(N_i\) in cm\(^{-3}\); Temperature \(T_i\) in keV; Velocity \(V_x, V_y\) in km/s; Position in RE. AE (nT) is at 1 min resolution. The bar indicates magnetotail regions: White is lobe, grey is OPS, and black is IPS. Dots above \(N_i\) indicate times for which distribution functions appear in Figure 2.
isotropic, hot plasma sheet ion population. A tailward moving beam was also seen at the same time; the imbalance between the two beams contributed to the observed earthward flow velocity at \(-1239\) UT. A tailward flow at \(-1250\) UT was also accompanied by two countstreaming ion beams, with the tailward beam being faster and denser than the earthward one. At 12:55 the ion velocity switched back to earthward and was, again, accompanied by an earthward beam.

\section*{IMF and Ground Conditions}

Data from ISEE 3, located at (243, -81, -14) RE, and IMP 8, in the dawn magnetosheath at an average position of (-23, -31, 5) RE during the 6-hr period of interest, are presented Figure 3 in GSM coordinates. The z component of the Interplanetary Magnetic Field (IMF) was predominantly northward from 0700 UT to 1300 UT on ISEE 3 (0800 UT to 1400 UT on IMP 8), but transient intervals of southward IMF can be seen both on ISEE 3 and on IMP 8; these were probably responsible for the relatively weak auroral electrojet activity in the plotted AE index.

A solar wind discontinuity was detected at ISEE 3 at 0700 UT. A decrease in ion density started at 0635 UT (line A). Given the observed velocity of 350 km/s and allowing for a 10 min delay downstream of the bow-shock, line A at ISEE 3 corresponds to the beginning of a decrease in the density at IMP 8, 90 minutes later. An anti-sunward rotation of the IMF at ISEE 3 started at 0640 UT and ended at 0700 UT (line B); line B corresponds to an anti-sunward re-orientation

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Solar wind data from ISEE 3 at a position of (243, -81, -14) RE and IMP 8 at a position of (-23, -31, 5) RE. Coordinates: GSM Units: same as in Figure 1. The solar wind velocity elevation angle, \(\lambda\), at ISEE 3 is shown grey-shaded.}
\end{figure}
of the IMF at IMP 8 80 minutes later, in accordance with IMP 8 can be reproduced by a simple convection delay of 450 km/s behind the discontinuity. Although few of the measured solar wind speed of 400 km/s. A time delay between 0750 UT and 1100 UT should influence the near-earth environment with a 75 minute delay. In particular, an increase of the solar wind velocity elevation angle, \( \lambda \), by approximately five degrees at 0705 UT, followed by a decrease starting at 0740 UT, are features large enough to be reflected in the magnetotail’s motion 75 min later. The double southward turning seen at ISEE 3 between 1120 UT and 1300 UT was convected downstream from the Earth’s bow shock almost unchanged. We extract a time delay of 60 min from the sharp northward turning at ISEE 3 at 1200 UT and at IMP 8 at 1300 UT. Thus, solar wind features seen on ISEE 3 between 1100 and 1300 UT should have influenced the magnetotail environment at the distance of ISEE 2 about 60 min later. In particular, the large increase of \( \lambda \) starting around 1100 UT, peaking at 1140 UT and subsiding after 1300 UT should have influenced the magnetotail with a 60 min delay, i.e., from around 1200 UT to after 1400 UT. A snapshot of the auroral oval at 1000 UT is shown in Figure 4, with a corrected geomagnetic (CGM) coordinate grid superimposed on it. The CGM midnight meridian is the vertical line that passes just west of Norman Wells (NOW). The auroral oval for the Kp activity level of the time is superimposed in grey shading. Figure 5 presents ground magnetograms from the stations shown in Figure 4. At -0950 UT a small activation was detected everywhere from Lynn Lake (LYN) in the east, to NOW in the west, thus extending over 2.5 hours of local time. (By “activation” we mean an increase of the AE or a decrease of the H component of the ground magnetograms; it may correspond to a substorm although we have no information about possible plasma sheet boundary events at this time. The lobe field started to dipolarize at ~1130 UT. ISEE 2 was not in a position to detect any counterstreaming beams. Although we have no information about possible plasma sheet boundary activity during the onset of this activation (ISEE 2 was in the lobe at that time), it is noteworthy that during the recovery of the electrojet currents the boundary was inactive.) At 0950 UT an intensification of the auroral electrojet with a large longitudinal extent occurred near the footprint of ISEE 2. An ensuing gradual ISEE 2 entry to the OPS was followed by a slow exit to the lobe. Neither crossing was accompanied by high speed flows or counterstreaming beams. Although we have no information about possible plasma sheet boundary activities. At 1050 UT a possible substorm onset was detected more than an hour in local time west of the expected footpoint of ISEE 2. The plasma sheet boundary, sampled twice during this period, had a small (<100 km/s) ion flow velocity and roughly isotropic distributions that evolved in the way shown in Figure 2.

At ~1125 UT, high latitude stations near the ISEE 2 footprint detected a third electrojet intensification extending over more than 2 hours of local time. ISEE 2 was in the lobe at that time. The lobe field started to dipolarize at ~1130 UT. ISEE 2 was not in a position to detect any counterstreaming beams and high speed flows at the boundary during the initial phase of the magnetic field dipolarization. Only at 1145 UT did ISEE 2 encounter the OPS, possibly in response to...
an increase in $\lambda$ at ISEE 3 60 min earlier. The plasma sheet — lobe interface passed over the spacecraft in a quasi-static state. There was no evidence of counterstreaming beams, the ion distributions were isotropic and became gradually more dense and hot as the spacecraft moved from the lobe to the CPS and into a dipolarized but slowly convecting IPS. The slow transition from the lobe to the plasma sheet differentiated this particular plasma sheet boundary entry from the typical plasma sheet expansions.

The dramatic increase in $\lambda$ seen at ISEE 3 at 1130 UT should have brought the neutral sheet closer to ISEE 2 about 60 min later. The above scenario may account for the fortuitous presence of ISEE 2 near the center of the plasma sheet when a high speed flow event started at 1225 UT. There is no evident ground magnetic signature associated with the fast flows at ISEE 2. The temporal onset of the high speed flows was accompanied by an onset of counterstreaming beams embedded within a fairly isotropic IPS distribution. The imbalance between the two beams is consistent with a net earthward or tailward flow velocity. The beams developed within an isotropic, hot ion population after an entry through a plasma sheet boundary that featured no ion beams.

Discussion and Conclusions

It is widely accepted that a recovering plasma sheet is accompanied by high speed flows and counterstreaming beams at its boundary, under a variety of geomagnetic conditions. However, it is not clear whether fast flows and/or ion beams are persistent features of the plasma sheet — lobe interface. Here we presented a series of plasma sheet boundary crossings which took place under AE conditions that varied from 50 nT to 300 nT. The boundary was devoid of fast flowing ions under quiet as well as moderately active conditions, i.e., during the subsidence of auroral electrojet intensifications at the footpoint of ISEE 2, and during the possible onset of a small substorm two hours of local time away from the footpoint of ISEE 2. Using ISEE 3 data we argued that the plasma sheet encounters were due to solar wind variations. In the cases presented, the ion distributions at the interface between lobe and plasma sheet were roughly isotropic. More case studies of such encounters and the conditions under which they occur are necessary to address the generality of the above statements. However, our counter-examples suggest that high speed flows and velocity filtered counterstreaming ion beams are not permanent characteristics of the plasma sheet boundary.

High speed flows in the CPS have been reported in the past. Huang et al. [1987] argued that during a geomagnetically active time event (AE &gt; 500 nT) distributions of high speed flows in the neutral sheet were qualitatively similar to PSBL distributions. Angelopoulos et al. [1992] showed that CPS high speed flows can have the same properties (10 min time scale, are concurrent with magnetic field dipolarizations and ion heating, produce significant earthward transport even if they are spatially localized) as PSBL high speed flows [Lui et al., 1977; De Coster and Frank, 1979].

Here we also presented a near-neutral sheet fast flow event whose onset was probably due to the temporal onset of acceleration tailward of the spacecraft. The event took place during quiet to moderate geomagnetic activity (AE &lt; 200 nT). Its ion distributions were reminiscent of previously reported PSBL high speed flows. This observation supports the suggestion of Huang et al. [1987] that CPS and PSBL high speed flows may be produced by the same acceleration processes. The lack of persistent beam structures at the plasma sheet boundary at all times and the temporal onset and subsidence of IPS high speed flows also suggest that such acceleration processes are inherently time dependent and are not always operating at a given local time.

Acknowledgments. V.A thanks the SST-8 group of LANL for their hospitality and for stimulating discussions. V.A. was supported by grant LANL/UCRP 304, C.F.K by NSF grant ATM 91–20591, F.V.C by NASA grant NAGW 2626, M.G.K. by NSF grant ATM 91–15557, R.J.W. by NASA grant NAG 5–1530. Access to the IMS magnetograms was supported by NSF grant ATM 90–16900. Access to the ISEE 2 magnetometer data was supported by NASA grant NAG 5–1967.

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(Received: December 28, 1992; revised: May 31, 1993; accepted: July 7, 1993.)