

ISEE-1 AND 2 OBSERVATIONS OF FIELD-ALIGNED CURRENTS IN THE DISTANT MIDNIGHT MAGNETOSPHERE

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ABSTRACT

Magnetic field measurements obtained in the nightside magnetosphere by the co-orbiting ISEE-1 and 2 spacecraft have been examined for signatures of field-aligned currents (FAC). Such currents are found on the boundary of the plasma sheet both when the plasma sheet is expanding and when it is thinning. Plasma sheet boundary layer current structure and substorm associated dynamics can be determined using the two spacecraft, although for slow traversals of the FAC sheet the spatial/temporal ambiguity is still an issue. We often find evidence for the existence of waves on the plasma sheet boundary, leading to multiple crossings of the FAC sheet. At times the boundary layer FAC sheet orientation is nearly parallel to the X-Z GSM plane, suggesting 'protrusions' of plasma sheet into the lobes. The boundary layer current polarity is, as expected, into the ionosphere in the midnight to dawn local time sector, and outward near dusk. Current sheet thicknesses and velocities are essentially independent of plasma sheet expansion or thinning, having typical values of 1500 km and 20-40 km/s respectively. Characteristic boundary layer current densities are about 10 nanoamps per square meter.

INTRODUCTION

Field-aligned currents in the distant nightside magnetosphere communicate stresses and magnetospheric reconfigurations to lower altitudes. The ISEE-1 and 2 spacecraft are ideal for studying the structure and dynamics of these currents in the magnetotail. Eastman et al. /1/ have discussed the dynamic nature of the plasma sheet boundary layer and its importance in tail phenomena. We concentrate on the field-aligned currents found there. Kelly et al. /2/ have used the ISEE magnetometer data to study an oscillating plasma sheet boundary layer current sheet following a substorm. Using the separation of the two spacecraft it is possible to obtain scale sizes, velocities and current densities of these structures and relate them to substorms and the magnetospheric state in general. We shall discuss briefly the observations and techniques for determining the above information, and then examine some of the substorm related observations in the plasma sheet boundary layer. We shall see that the field-aligned current sheet does not always have the expected orientation. Finally we shall touch on the global boundary layer FAC sheet characteristics such as polarity, thickness, and typical current densities.

PLASMA SHEET BOUNDARY LAYER CURRENTS

The plasma sheet boundary layer is a region of dynamic plasma intermediate between tail lobe and true plasma sheet. Within this region strong flows, beams and anisotropies are found /1/, as well as field-aligned currents which presumably map down to the ionosphere. These currents are evident in the data as perturbations to the main lobe field, with the sense of perturbation usually in the Y GSM sense. This corresponds to a sheet current flowing parallel or antiparallel to the lobe field, and confined to a comparatively thin boundary. There may also be diamagnetic currents flowing if the plasma within the boundary layer has a thermal pressure approaching the local magnetic pressure.

Figure 1 shows an encounter with the boundary layer currents as evidenced in the magnetic field data. The coordinates are referenced to the main lobe field, with a model removed. The main field is along Z, and Y is in this case eastward. The currents cause the perturbation in the Y component seen at 2137 UT. In this case, the sense of the perturbation indicates that the current is flowing out of the ionosphere. To determine the thickness, velocity, and current density in this structure, we must know the orientation of the current sheet. This can be determined from analysis of the field variation, either a minimum variance analysis or one based on the assumption that the boundary is a tangential discontinuity. Once the sheet normal has been determined, one must know the separation of the two spacecraft along this normal; if the current sheet motion is along the normal, the

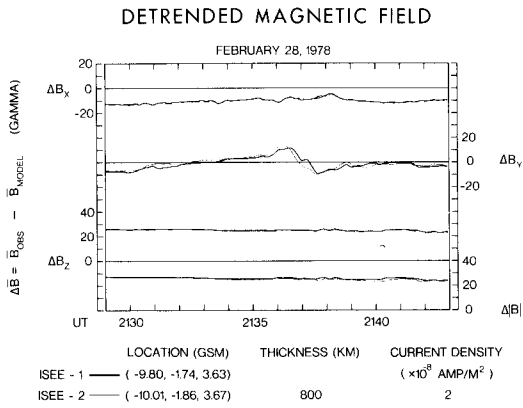


Fig. 1. Plasma sheet boundary layer field-aligned currents crossed on 28 February 1978. Data in field-aligned coordinates.

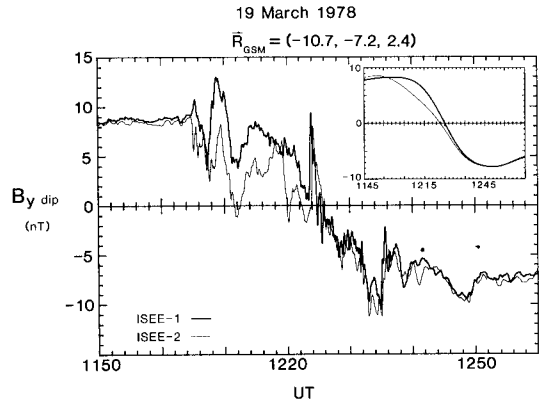


Fig. 2. Detail of the field-aligned current sheet on 19 March. Note structure and variation in the current sheet. Inset shows low-pass filtered data for determination of motion and thickness.

velocity is the spacecraft separation divided by the observed lag time between the two satellites. The current sheet thickness is the velocity times the observed duration of the structure, provided the velocity is constant. For this case, the ISEE-1 and 2 lag indicates that the current sheet thickness is roughly 800 km, the current density is 20 nanoamps per square meter and the current sheet is convecting past the spacecraft at roughly 10 km/s.

FIELD-ALIGNED CURRENT STRUCTURE AND DYNAMICS

On 19 March 1978 ISEE-1 and 2 were near the plasma sheet when a substorm was observed by ground stations at 1132 UT. At this time the field at the spacecraft became more dipolar, and still later the spacecraft entered the plasma sheet boundary layer. A strong field-aligned current associated with this entry was observed near 1210, as shown in the data in Figure 2. Here we have plotted the perturbation, seen mainly in the B_y GSM component, as observed at high resolution (0.25 s data). The crossing through this current sheet is slow, taking 35 minutes or more; during this time, considerable variation is seen within the current sheet. In order to obtain an average thickness and current density, one must filter out the high frequency variations and lag the filtered data, as shown in the inset. This case illustrates the need for a rapid crossing of the current sheet to ensure getting a 'snapshot' of the actual structure.

At times, multiple substorms can cause the boundary layer current sheet to cross the spacecraft several times as the plasma sheet expands and thins. In Figure 3 we show such an occurrence. Here we have plotted ISEE-1 data in spacecraft coordinates (roughly GSE); the spacecraft are in the northern lobe. A substorm onset soon after 0200 (observed at Hermanus, S.A.) leads to the plasma sheet expansion and boundary layer current crossing seen at 0222. The currents are flowing into the ionosphere. Subsequent plasma sheet thinning carries the current layer across the spacecraft at 0255; the currents on this crossing are smaller. Finally, near 0317, another substorm-related expansion carries an intense boundary layer current over the spacecraft. Curiously, this substorm is very weak in ground station data.

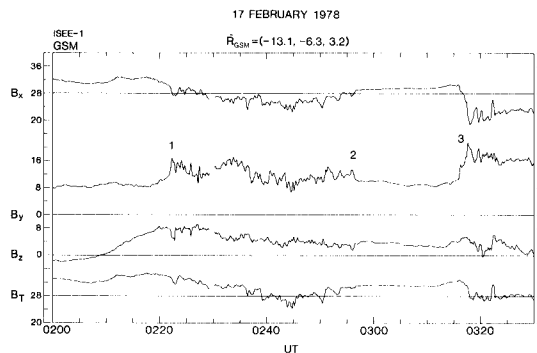


Fig. 3. Substorm related current sheet crossings on 17 February 1978. Substorm onsets occurred soon after 0200 and near 0300.

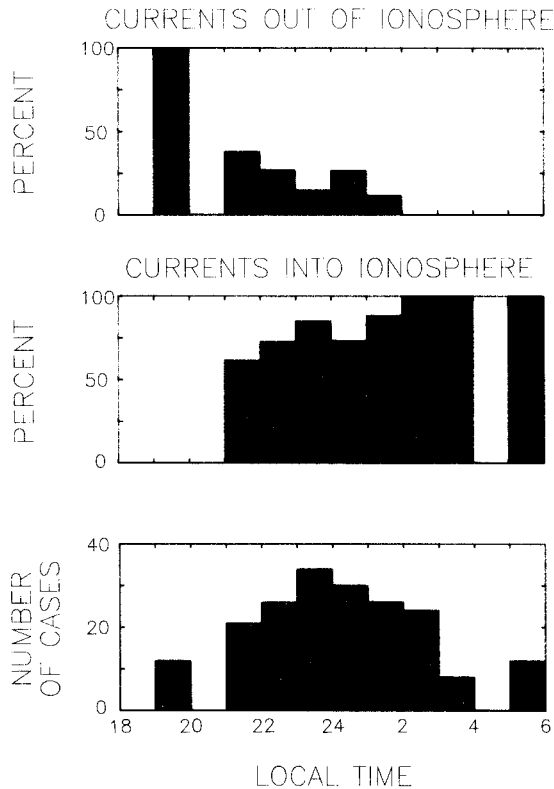


Fig. 4. Boundary layer current polarities versus local time. Most currents are observed flowing into the ionosphere. Outwardly flowing currents are found between midnight and dusk.

From the variation in the field as the currents pass over the satellites, one can obtain the normal to the plane of the current sheet. The normals for the first and third crossings from the case above are typical, i.e. roughly in the GSM Z direction, but the second crossing, during plasma sheet thinning, yields a normal pointing much more nearly earthward. This surprising result may be due to uncertainties associated with the weakness of the field. Sometimes the boundary current sheets have a wholly unexpected orientation. One can find crossings showing a mainly Bz GSM perturbation, yielding a normal in the Y GSM direction: the plane of the current sheet is nearly parallel to the X-Z GSM plane. Plasma data too indicate the presence of a Y GSM gradient in flux, not a Z gradient as would be expected of the normal plasma sheet (C. Huang, private communication). This almost certainly means that the plasma sheet has 'protrusions' rising up into the lobe. Huang et al. [3] have suggested that such structures may be associated with polar cap arcs. In most other ways, the currents are typical: sheet thickness of about 1000 km, flowing into the ionosphere with current densities of several nanoamps per square meter.

GLOBAL BOUNDARY LAYER CURRENT CHARACTERISTICS

It is of interest to connect the observed polarities of the plasma sheet boundary layer field-aligned currents to the observed low altitude, high latitude field-aligned currents. A preliminary survey of the ISEE data yields the results shown in Figure 4. Here we have plotted histograms of the occurrence of currents flowing into and out of the ionosphere as a function of local time. The boundary layer crossings used here are primarily from the northern lobe, with only a few from the southern lobe. The top panel shows that currents flow out of the ionosphere mainly in the dusk sector, but that current flow into the ionosphere (center) is seen from dawn until well past midnight. Moreover, current flow out of the ionosphere is not seen as frequently overall as current flow into the ionosphere, shown in the middle panel. The bottom panel shows the number of cases going into each local time bin. The polarity sense of these currents is the same as the high latitude Region I currents observed at low altitudes. However, their scale size when mapped down to ionospheric altitudes is much smaller than the Region I scales.

A preliminary determination of boundary layer FAC characteristics shows no dependence on plasma sheet expansion or thinning, or the polarity of the current. For example, current

densities in 12 crossings during plasma sheet expansion were typically 10 nanoamps per square meter, independent of whether the currents were flowing into or out of the ionosphere. For 14 cases of plasma sheet thinning, the values were about the same. Velocities of the current sheet motion are also independent of expansion or thinning, being typically several tens of kilometers per second in either case. The inferred current sheet thickness is likewise independent of plasma sheet thinning or expansion, having average values of 1500 km.

SUMMARY

The ISEE data are well-suited to studying the field-aligned currents in the plasma sheet boundary layer. The currents show considerable structure and variability, which can lead to problems in determining thickness, velocity and current density. However, rapid crossings of the current regions can yield reasonably certain values. Boundary layer current sheet orientations can be obtained from the magnetic signatures, and for multiple crossings the wavelike nature of the plasma sheet can be inferred. Some current sheet orientations suggest the existence of protrusions of plasma sheet into the tail lobes. These may be associated with polar cap arcs.

Most of the observed currents are flowing into the ionosphere, and these are found at all local times between dawn and midnight, and beyond. Outwardly flowing currents are confined to the dusk-to-midnight regions. Typical current densities are 10 nanoamps per square meter, current sheet thicknesses are usually about 1500 km, and their motion is usually a few tens of kilometers per second. These quantities appear to be independent of plasma sheet expansion or thinning or the polarity of the current.

ACKNOWLEDGMENTS

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