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THE VARIABILITY OF MAGNETIC FIELD PERTURBATIONS AND IMF CONTROL OF FIELD-ALIGNED CURRENTS IN THE INNER MAGNETOSPHERE

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ABSTRACT

Magnetic field perturbations and field-aligned currents are observed by the ISEE-1 and -2 spacecraft. We use the two spacecraft to separate the temporal current variations from the spatially varying currents. We find that the majority of the magnetic field perturbations are due to currents for which we cannot clearly resolve temporal from spatial variations. On examining the variability of the magnetic field perturbations at different spacecraft separations, we find a spacecraft separation of greater than one minute and less than five minutes is optimum for analysis of spatially varying currents. We find that the spatially varying field-aligned currents occur more for a southwardly directed Interplanetary Magnetic Field (IMF), while the occurrence of temporally varying (or inadequately resolved) currents does not depend on the IMF. Both types of current tend to increase in intensity for a more southward field.

INTRODUCTION

Magnetic field perturbations have been observed using the International Sun-Earth Explorer (ISEE) -1 and -2 spacecraft. We have detrended the data using Tsyganenko '95 and the IGRF model fields. The data were rotated into a field-aligned coordinate system so that the field-aligned current signatures seen by the two spacecraft are primarily in the B_y direction.

One of the advantages of having two spacecraft is that it is possible to separate the temporal variations due to ULF waves or intensifications of field-aligned currents from spatial structures convected from one spacecraft to the other. With two spacecraft it is also possible, by looking at different spacecraft separations, to determine how magnetic field perturbations structures change over time. Moreover, without a clear separation of spatial and temporal signatures, current sheet properties that depend on scale size are not well determined.

For a southward Interplanetary Magnetic Field (IMF) there is a coupling between solar wind and terrestrial magnetic field lines. Due to this coupling, many effects are observed for a southward-directed IMF. Field-aligned currents play an important role in the coupling between interplanetary space and the auroral ionosphere, so it would therefore be expected that certain characteristics of these currents should show a close correlation with such interplanetary parameters as the direction and the intensity of the IMF. We have used both ISEE-3 and IMP-8 to determine the magnitude and direction of the IMF B_z component. We have computed the current intensity for the magnetic field perturbations and compared them with the direction of the IMF.

allow for any other current-sheet parameters such as current density, sheet velocity, and thickness to be derived as spatial scales cannot be determined with any certainty.

Figure 3 shows an alternate configuration of the ISEE spacecraft corresponding to a current-sheet crossing by the spacecraft. As the current-sheet is first crossed by ISEE-1 and then by ISEE-2, each spacecraft sees a change in B_y indicative of the current intensity of the current-sheet. The bottom of the figure shows current-sheet crossings as seen by both spacecraft. Again, the B_y measured by ISEE-1 is the thicker of the two lines. Two current-sheet crossings are observed by ISEE-1 and -2. The first is seen by ISEE-1 from 12:23:20 to 12:24:00, and about 40-s later by ISEE-2 from 12:23:55 to 12:24:40. The spacecraft are separated by approximately one minute along their trajectory at this time. The second current-sheet crossing for the two spacecraft is seen by ISEE-1 from 12:24:05 to 12:25:10, and later by ISEE-2 from 12:24:40 to 12:25:55.

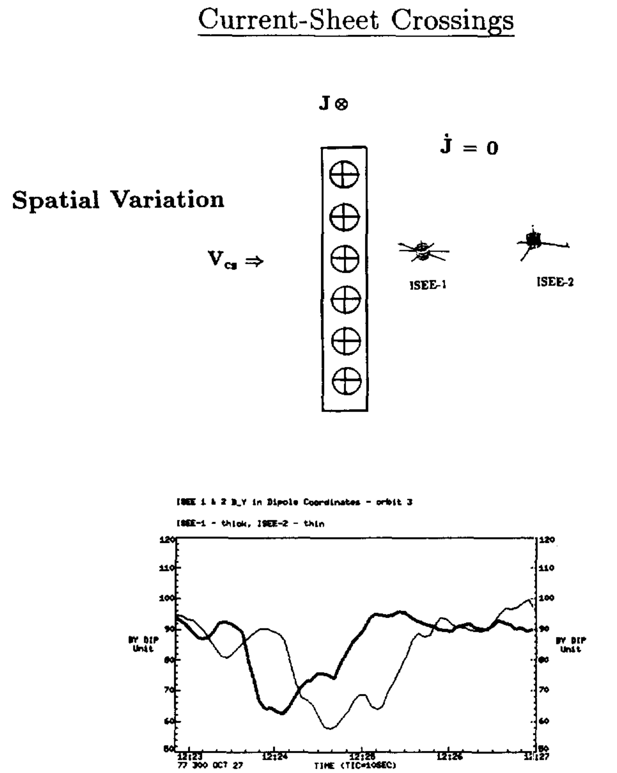

Fig. 3. Example of a clear spatial structure. In this case the signatures are well separated in time and the spacecraft attack angle is perpendicular to the current sheet.

We limited the separation strategy of the spacecraft to less than five minutes for optimum confidence in our analysis of field-aligned currents. Temporal variations mask the underlying structure for greater separations. We also removed all of the events that had an attack angle of greater than 80 degrees to the current-sheet normal since the distinction between temporal and spatial variations is then very difficult. We have calculated the current intensity from the change in B_y for the signatures that are clearly spatial structures passing over the spacecraft. For temporal variations the change in B_y gives the change in the current intensity. Both these calculated variables have been mapped to the ionosphere (c.f. *Rich et al.*, 1981; *Kelly et al.*, 1986; *Chun*, 1992). This normalization removes any effects due to differences in position.

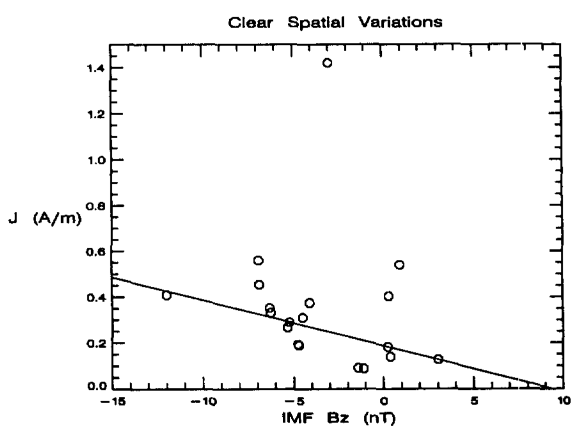

Fig. 4. Current intensity versus IMF B_Z for well resolved spatial structures.

The current intensity for the spatially varying currents versus the IMF direction

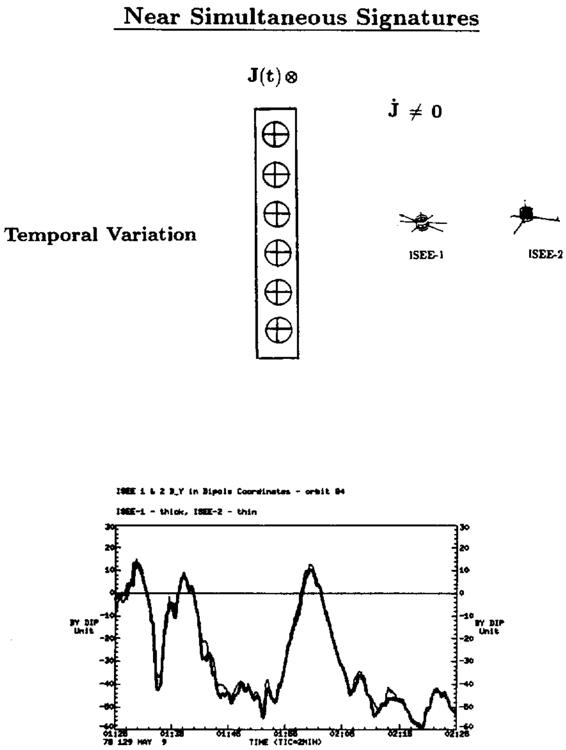

Fig. 1. Nearly simultaneous current signatures observed at both ISEE-1 and -2. Even though the spacecraft separation vector is perpendicular to the current sheet, both spacecraft see the same changes in B_y. In this case we cannot resolve temporal versus spatial structure. We refer to such structures as "temporal" variations.

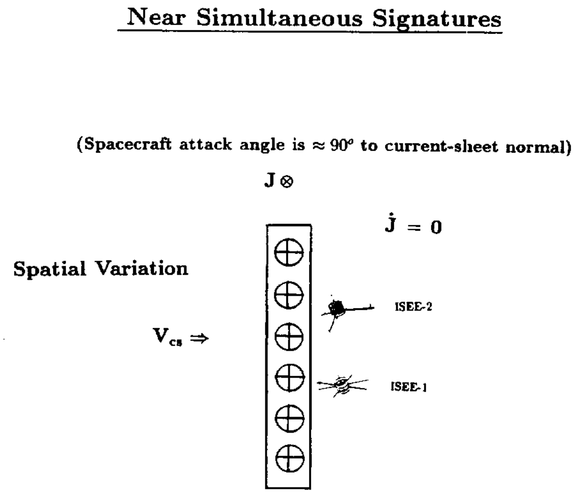

Fig. 2. Current sheet geometry for which simultaneous signatures will be detected. In this case the spacecraft separation vector is nearly parallel to the current sheet, and again spatial structure cannot be resolved adequately.

OBSERVATIONS AND DISCUSSION

Figure 1 shows one possible configuration of the ISEE spacecraft with a current-sheet. In this case, temporal changes in the current within the current-sheet will be associated with a simultaneous change in the B-field seen at ISEE-1 and -2 even though they are some distance away from the actual current-sheet. An example of the nearly instantaneous variations in the magnetic field as seen by ISEE-1 and -2 caused by temporal changes in the current-sheet can be seen in the bottom half of this figure. Here the ISEE-1 B_y data are shown with a thick line and the ISEE-2B_y data are the thin line. The two spacecraft are separated by 5 minutes time during this orbit, but still the variations in the magnetic field are seen simultaneously. For a current-sheet structure, such simultaneous variations in the magnetic field must be due to temporal variations in the currents, unless the spacecraft attack angle is nearly perpendicular to the current-sheet normal, which it is not in this case. Figure 2 shows another configuration of the ISEE spacecraft relative to a current-sheet. A simultaneous change in B_y is also seen, but in this case the current is constant in time but moves across the spacecraft. Because the spacecraft separation vector is nearly in the plane of the current-sheet, both spacecraft cross the current-sheet at nearly the same time and they see a nearly simultaneous change in the magnetic field. Hence simultaneous changes in B_y can be due to the two different configurations as shown in Figures 1 and 2. When the attack angle is nearly perpendicular to the normal, it is impossible to distinguish between temporal and spatial variations in the current-sheet. However, when the attack angle is more nearly parallel to the normal, variations in B_y seen simultaneously at both spacecraft correspond to temporal changes in the current-sheet.

It is important to note that temporal variations in the current-sheet as seen by ISEE-1 and -2, represent a change in the intensity of the current-sheet while spatial changes (current-sheet crossings) actually measure the current intensity within the current-sheet. In either case, near simultaneous signatures do not is seen in Figure 4. The majority of the field-aligned current events occur for southward fields, and there is a trend toward an increase in current intensity as the field becomes more southward. The straight line through the data, given by $J = 0.188 - 0.0120B_Z$, where J is the current intensity and B_Z is the z-component of the IMF, is a fit determined through minimization of the sum of the modulus of the residuals. This is a more robust fit parameter than least squares, as the former is analogous to the median of a distribution, while the latter is analogous to the mean (*Press et al.* 1986). To test the significance of the correlation we use Spearman's rank correlation (*Pollard*, 1977), and find that the rank correlation coefficient is –0.414, significant at the 90% level for 19 data points, but not significant at the 95% level.

Figure 5 is a plot of the changes in current intensity versus IMF B_Z for temporally varying currents. There are approximately the same number of southward events as the number of northward events. The occurrence of temporal variations do not seem to be controlled by the direction of the IMF. However the change in intensity also shows a trend, given by the line $\delta J = 0.330 - 0.0172B_Z$. For these data the Spearman rank correlation coefficient is –0.336, significant at the 98% level for 56 data points. At this stage it is not clear if this correlation indicates that the change in current intensity for "temporal" variations is controlled by the IMF, or if the "temporal" events include inadequately resolved spatial structures.

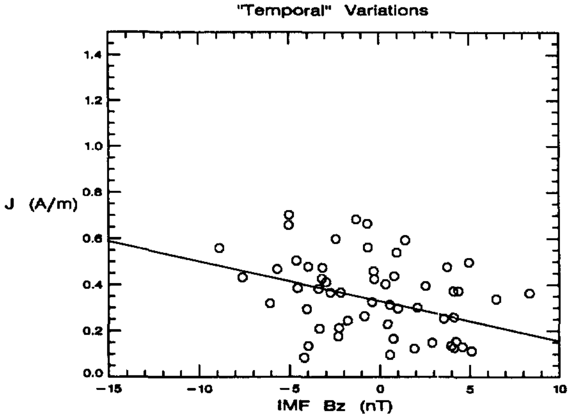

Fig. 5. Changes in current intensity versus IMF B_Z for "temporal" variations.

CONCLUSIONS

At least two spacecraft are required to resolve temporal versus spatial variations in the currents. Both have changes in B_Y of approximately the same magnitude. A separation along the orbit of less than five minutes is required for optimum confidence in an analysis of field-aligned currents since temporal variations mask the underlying structure for greater separations. A separation of greater than one minute is needed to separate the temporal changes from the spatial variations. The majority of the field-aligned current events occur for southward IMF, and there is a trend toward an increase in current intensity as the field becomes more southward. Temporal current variations occur equally for southward and northward IMF, but they also show a trend toward increasing current density for more southward IMF. The majority of the events in the database correspond to temporal (or inadequately resolved spatial) variations and therefore any statistical analysis which does not distinguish between temporal and spatial signatures will tend to give results corresponding to temporal fluctuations not quasi-static FACs.

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