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Investigation of the Dayside Boundary Region of the Magnetosphere

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INTRODUCTION

The region near the dayside boundary of the magnetosphere is of particular interest mainly because it is the most likely site for solar wind energy transfer. Exactly where and how this transfer occurs is one of the basic problems of magnetospheric physics. Two of the most important discoveries of the ISEE spacecraft relevant to this problem are flux transfer events [Russell and Elphic, 1979] and accelerated boundary layer flows [Paschmann et al., 1979]. These small-scale features are interpreted as signatures of the most commonly proposed energy transfer process, magnetic merging or reconnection.

The research performed under this grant addresses the global nature of the energy transfer process. In order to test whether energy transfer affects the large scale plasma flow in the magnetosheath, global properties of the magnetosheath were analyzed and compared to models with no energy transfer. Also, global models of merging sites on the magnetopause were modeled with the aid of the magnetosheath models.

Since energy transfer and intrinsic magnetosheath properties depend upon the orientation of the interplanetary magnetic field (IMF), it was essential to have an IMF monitor for these studies. In the course of using ISEE 3 in this role, statistical studies were performed to test the accuracy of using data from an orbit so far upstream.

The results are summarized below in the abstracts of papers written with the support of this grant.

RESULTS

Magnetosheath Data Analysis

Global properties of the magnetosheath energetic ion population, magnetic field strength and orientation, and flow pattern were determined with ISEE data in the following four papers:

1. Crooker, N. U., T. E. Eastman, L. A. Frank, E. J. Smith, and C. T. Russell, Energetic magnetosheath ions and the interplanetary magnetic field orientation, J. Geophys. Res., **86**, 4455-4460, 1981.

This paper was presented at the ISEE Workshop on Upstream Waves and Particles, Pasadena, April, 1980.

Abstract

Times when energetic ions are absent and present in ISEE 1 magnetosheath plasma spectrograms are correlated with ISEE 3 IMF orientation measurements. The study indicates that when the plasma at the spacecraft is traced along a streamline to the bow shock surface, the angle between the surface normal at that point and the IMF is greater than 60° when the energetic ions are absent and less than 60° when they are present. The pattern is consistent with the ions coming from the same regions of the bow shock where intermediate and diffuse ions are found on the upstream side. The 60° criterion is used to draw schematic patterns of the location of energetic ions in the magnetosheath as a function of IMF orientation. Some orientations result in layers adjacent to the magnetopause and other orientations give layers adjacent to the bow shock.

2. Crooker, N. U., G. L. Siscoe, and P. R. Mullen, Magnetic field compression at the dayside magnetopause, J. Geophys. Res., **87**, 10407-10412, 1982.

This paper was presented at the Fourth Scientific Assembly of IAGA, Edinburgh, August, 1981.

Abstract

The degree of compression sustained by the solar wind field as it convects to the magnetopause has been determined empirically with magnetometer data from ISEE 3 in the solar wind and ISEE 1 in the magnetosheath. At the stagnation point, the strength B_{SH} of the magnetosheath field may be expressed as $B_{SH} = \sqrt{4 B_{SW} B_{ST}}$, which implies that B_{SH} is equal to the geometric mean of the stagnation field strength B_{ST} and the shocked solar wind field, approximated by $4 B_{SW}$. For the usual spiral pattern of the solar wind field, B_{SH} on the duskside of the magnetopause is about 20% stronger than it is on the dawnside. No dependence of B_{SH} on the sign of the north-south component of the solar wind field is apparent.

3. Crooker, N. U., J. G. Luhmann, C. T. Russell, E. J. Smith, J. R. Spreiter, and S. S. Stahara, Magnetic field draping against the dayside magnetopause, J. Geophys. Res., **90**, 3505-3510, 1985.

This paper was presented in combination with Paper 8 at the Spring AGU Meeting, Cincinnati, May, 1984.

Abstract

Interplanetary magnetic fields observed upstream of Earth's magnetosphere at ISEE 3 form input for a gas dynamic model of magnetic field draping in the dayside magnetosheath. Model results near the magnetopause are compared with appropriately lagged observations at ISEE 1. In 16 of 24 cases the angle between the transverse component of the model and observed fields is less than 20° . The agreement is surprisingly good in view of the uncertainty introduced by the large distances between ISEE 1 and ISEE 3. The results indicate that magnetohydrodynamic and energy transfer processes at the magnetopause do not cause large distortions of the magnetosheath magnetic field. In addition, a comparison between observed and model field magnitudes indicates that immediately outside the magnetopause the observed field behaves like the model field at a distance of $\sim 0.5 R_E$ from the magnetopause, outside the region

- where magnetohydrodynamic effects make the gas dynamic model inapplicable. Patterns of model magnetic field orientation at the magnetopause are presented for practical application.

4. Crooker, N. U., G. L. Siscoe, T. E. Eastman, L. A. Frank, and R. D. Zwickl, Large-scale flow in the dayside magnetosheath, J. Geophys. Res., **89**, 9711-9719, 1984.

This paper was presented at the Fall AGU Meeting, San Francisco, December, 1983.

Abstract

The degree of control over plasma flow direction exerted by the compressed magnetic field in the dayside magnetosheath is examined by comparing ISEE 1 LEPDEA data with hydrodynamic and magnetohydrodynamic predictions. Measured flow directions projected toward the subsolar region pass within $\sim 1 R_E$ of the aberrated theoretical hydrodynamic stagnation point in 11 of 20 cases analyzed. The remaining nine cases pass within $\sim 2-3 R_E$ of the stagnation point. One case with large deflection has been studied in detail with high-time-resolution plasma and magnetic field data both from ISEE 1 and from ISEE 3, in the role of a solar wind monitor. The deflected flow is persistent over a period of 1 1/2 hours, and its direction is consistent with a stagnation point displacement resulting from increased, asymmetric magnetic field pressure contributions during periods of low Alfvén Mach number, as predicted by Russell et al. Of the other eight cases with large deflections, four are associated with flux transfer events identified independently by Berchem and Russell. The observed deflections in these cases are consistent with either the subsolar merging line or the antiparallel merging hypothesis, but not exclusively with one or the other. The results relating to the formation of a stagnation line rather than a stagnation point are inconclusive.

The prediction referenced above, in the abstract of Paper 4, was reported in the following paper, to which this grant contributed peripheral support:

5. Russell, C. T., H.-C. Zhuang and R. J. Walker, A note on the location of the stagnation point in the magnetosheath flow, Geophys. Res. Lett., **8**, 984-986, 1981.

Abstract

Observational and theoretical investigations indicate that the shape of the magnetosphere is nearly symmetric about the plane defined by the aberrated solar wind velocity and the earth's magnetic dipole axis. Nevertheless, many phenomena such as magnetic pulsations and geomagnetic activity seem to indicate that the effective solar wind arrival direction is perhaps 15° to the dawn side of noon. This apparent paradox may have a simple resolution since it can be shown that the location of the stagnation point in the magnetosheath flow is shifted towards dawn by MHD effects not included in the simple gasdynamic model of the solar wind interaction. The shape of the magnetosphere is little affected by the inclusion of these MHD effects. However, the size of the stagnation point shift is very sensitive to the Alfvén Mach number and can only account for the largest reported shifts ($\sim 15^\circ$) at low Mach numbers ($\lesssim 3.5$).

Magnetopause Merging Model

Research on modeling of dayside merging sites was based on the earlier antiparallel merging model [Crooker, 1979]. A follow-on paper to the earlier work was completed with support from this grant:

6. Crooker, N. U, The half-wave rectifier response of the magnetosphere and antiparallel merging, J. Geophys. Res., 85, 575-578, 1980.

Abstract

In some ways the magnetosphere behaves as if merging occurs only when the interplanetary magnetic field (IMF) is southward, and in other ways it behaves as if merging occurs for all IMF orientations. An explanation of this duality is offered in terms of a geometrical antiparallel merging model which predicts merging for all IMF orientations but magnetic flux transfer to the tail only for southward IMF. This is in contrast to previous models of component merging, where merging and flux transfer occur together for nearly all IMF orientations. That the problematic duality can be explained by the model is compelling evidence that antiparallel merging should be seriously considered in constructing theories of the merging process.

A realistic computer version of the model was developed by other researchers, with peripheral support from this grant:

7. Luhmann, J. G., R. J. Walker, C. T. Russell, N. U. Crooker, J. R. Spreiter, and S. S. Stahara, Patterns of potential magnetic field merging sites on the dayside magnetopause, J. Geophys. Res., 89, 1739-1742, 1984.

Abstract

Models of the magnetospheric and magnetosheath magnetic fields are used to determine the relative orientations of these fields at the dayside magnetopause in order to locate potential merging sites. Areas on the magnetopause with different fractional antiparallel components are displayed by contour diagrams for a variety of interplanetary field orientations. For interplanetary fields oriented perpendicular to the solar wind velocity the areas of nearly antiparallel field agree with those obtained by Crooker using simplified representations for the magnetic field geometry. Here, the application of more realistic models gives the locations of areas where any antiparallel component occurs. Potential merging sites for interplanetary fields with radial components are also illustrated. The results suggest that the topology of the magnetosheath and magnetospheric fields provides antiparallel components over a substantial fraction of the magnetopause for most interplanetary field orientations.

The computer model was then used to explore asymmetries in merging patterns:

8. Crooker, N. U., J. G. Luhmann, J. R. Spreiter, and S. S. Stahara, Magnetopause merging site asymmetries, J. Geophys. Res., 90, 341-346, 1985.

Abstract

Regions where a draped model magnetosheath magnetic field is nearly antiparallel to a model geomagnetic field are shown to be asymmetric for an interplanetary magnetic field (IMF) at the garden hose angle, as suggested by Heelis. When the IMF has a southward component, the asymmetry favors the dawn region for both IMF polarities. The dusk region is favored when the IMF has a northward component. If the regions of antiparallel fields are assumed to be sites of maximum magnetic merging, then the asymmetry is consistent with observed seasonal variations of geomagnetic activity and with dawn-displaced magnetospheric phenomena. In the alternate merging geometry of a merging line passing through the subsolar region, the asymmetry is predominantly north-south rather than dawn-dusk. The subsolar merging-line geometry is consistent with the seasonal variations but not with the dawn-displaced phenomena.

Statistical IMF Studies

Two papers address the question of how well the IMF near Earth can be predicted from upstream measurements at the sunward libration point:

9. Crooker, N. U., G. L. Siscoe, C. T. Russell, and E. J. Smith, Factors controlling degree of correlation between ISEE 1 and ISEE 3 interplanetary magnetic field measurements, J. Geophys. Res., 87, 2224-2230, 1982.

This paper was presented at the Fall AGU Meeting, San Francisco, December, 1980.

Abstract

The degree of correlation between ISEE 1 and ISEE 3 IMF measurements is highly variable. Approximately 200 two-hour periods when the correlation was good and 200 more when the correlation was poor are used to determine the relative control of several factors over the degree of correlation. Both IMF variance and spacecraft separation distance in the plane perpendicular to the earth-sun line exert substantial control. Good correlations are associated with high variance and distances less than $90 R_E$. During periods of highest variance, good correlations occur at distances beyond $90 R_E$ up to $120 R_E$, the maximum range of ISEE 1 - ISEE 3 separation. Thus it appears that the scale size of magnetic features is larger when the variance is high. Abrupt changes in the correlation coefficient from poor to good or good to poor in adjacent two-hour intervals appear to be governed by the sense of change of IMF variance: changes in correlation from poor to good correspond to increasing variance and vice versa. The IMF orientation also exerts control over the degree of correlation. During periods of low variance, good correlations are most likely to occur when the distance between ISEE 1 and ISEE 3 perpendicular to the IMF is less than $20 R_E$. This scale size expands to $\sim 50 R_E$ during periods of high variance. Solar wind speed shows little control over the degree of correlation in the speed range 300-500 km/s.

10. Kelly, T. J., N. U. Crooker, G. L. Siscoe, C. T. Russell, and E. J. Smith, On the use of a sunward-libration-point orbiting spacecraft as an IMF

monitor for magnetospheric studies, to be submitted to J. Geophys. Res., 1985.

This paper was presented at the Fall AGU Meeting, San Francisco, December, 1983.

Abstract

Magnetospheric studies often require knowledge of the orientation of the IMF. In order to test the accuracy of using magnetometer data from a spacecraft orbiting the sunward libration point for this purpose, the angle between the IMF at ISEE 3, when it was positioned around the libration point, and at ISEE 1, orbiting Earth, has been calculated for a data set of two-hour periods covering four months. For each period, a ten-minute average of ISEE 1 data is compared with ten-minute averages of ISEE 3 data at successively lagged intervals. At the lag time equal to the time required for the solar wind to convect from ISEE 3 to ISEE 1, the median angle between the IMF orientation at the two spacecraft is 20° , and 80% of the cases have angles less than 38° . The results for the angles projected on the y-z plane are essentially the same. The minimum angle between the IMF orientation at the two spacecraft has a median of 11° , with 80% less than 19° . These low values indicate little temporal or small scale variation between the spacecraft. The minimum angle generally occurs at a lag time different from the convection time. The sign of the difference depends on IMF orientation in the sense that magnetic features tend to arrive sooner when the IMF is directed along the line between the spacecraft. However, the difference between a lag time appropriate to this corotation geometry and the convection lag time is not large enough to produce a significant decrease in the angles between the IMF vectors at the two spacecraft. We conclude that the IMF at a libration-point-orbiting spacecraft, lagged by the time required for the solar wind to convect to the earth, is a good, convenient predictor of the IMF near the earth.

Reprints of Papers 1, 2, 3, 4, 6, 8, and 9, and a preprint of Paper 10 are appended to this report.

References

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- Russell, C. T., and R. C. Elphic, ISEE observations of flux transfer events at the dayside magnetopause, Geophys. Res. Lett., **6**, 33-36, 1979.