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Geosynchronous Orbit Magnetopause Crossings

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1. Introduction

The shape and location of the magnetopause, which bounds the magnetosphere, is controlled largely by the plasma and magnetic field properties of the onrushing solar wind [e.g., Fairfield, 1971; Formisano et al., 1979; Sibeck et al., 1991; Petrinec and Russell, 1993]. In these studies, the magnetopause shape was generally assumed to be a paraboloid of revolution about the Earth-Sun line. Only a very small asymmetry, consistent with that expected from aberration, due to the Earth's motion about the Sun, is found in this shape at typical subsolar standoff distances (~10 R_E). On rare occasions, magnetopause crossings have been observed as far inward as geosynchronous orbit (6.6 R_E) [Russell, 1976; Wrenn et al., 1981; Rufenach et al., 1989; McComas et al., 1993; 1994]. These crossings constitute a small but important subset of all magnetopause crossings, which are characteristic of unusual conditions when the magnetosphere is very highly compressed and/or eroded.

Three of these previous studies have found a substantial dawn-dusk asymmetry in the occurrence rates of geosynchronous magnetopause crossings, and hence, in the shape of the highly compressed magnetosphere. Wrenn et al. [1981] identified 15 magnetosheath intervals encountered by the GEOS spacecraft using low-energy (<500 eV) plasma observations. This rather limited data set indicated a mean crossing local time of ~10:00, two hours to the dawn side of local noon. Subsequently, Rufenach et al. [1989] examined 64 magnetosheath intervals, selected on the basis of magnetometer observations from GOES 2,5, and 6. These authors found a slight skewing of magnetopause crossings to the dawn side on average and a marked offset to this side for crossings that they associated with a substantial southward magnetic field component in the magnetosheath.

Recently, McComas et al. [1993] examined in detail three months of geosynchronous observations taken simultaneously at three widely spaced locations around geosynchronous orbit with the Los Alamos Magnetospheric Plasma Analyzer (MPA) instruments. These instruments measure, with high sensitivity, the 3-dimensional plasma electron and ion distributions at geosynchronous orbit from ~1 eV/q to ~40 keV/q [Bame et al., 1993; McComas et al., 1993]. McComas et al. [1993] documented a small set of encounters with the magnetosheath and/or low latitude boundary layer (LLBL) which again indicated the presence of a strong asymmetry to the pre-noon side.

In this study (and in McComas et al. [1994]) we extend the analysis of magnetopause crossings observed with MPA measurements to examine a much larger statistical data set. This study examines 39 magnetosheath/LLBL intervals from 79 spacecraft-months of observations; these observations were taken from a survey of data from the start of each spacecraft mission (March 1990 for S/C 1989-046; February 1991 for S/C 1990-095; and December 1991 for S/C 1991-080) and extending through March 1993. In contrast to the previous findings outlined above, we find no evidence for a significant dawn/dusk asymmetry in geosynchronous magnetopause crossings.

2. Observations

The MPA instrument provides an unambiguous identification of magnetosheath plasmas at geosynchronous orbit since it measures the entire energy range of plasma electrons and ions. Magnetosheath plasma distributions are readily identified in these data by very intense fluxes of electrons at several hundred eV and intense ion fluxes from several hundred eV to several keV, flowing away from the nose of the magnetosphere (see examples in McComas et al. [1993; 1994]). Unfortunately, the unique separation of magnetosheath from LLBL intervals is less straightforward. McComas et al. [1994] used the presence (LLBL) or absence (magnetosheath) of a superposed population of energetic electrons, with energies above several keV, as a rough indicator for separating these regions. This analysis indicated that both regions had statistically similar distributions. Here, we will treat all magnetosheath-like distributions, including LLBL, together and refer to them simply as "magnetosheath."

Our data set contains 916 5-minute samples of magnetosheath plasma distributions from 39-unique magnetosheath intervals. Using these intervals and the data coverage for our 79 spacecraft-months of data, we calculate that these geosynchronous spacecraft were in the magnetosheath 0.2% of the time. Figure 1a displays the local time distributions of the 916 5-minute samples in 15-minute local time bins. Note the large variability in the local time of the observations, including occurrences as much as ~6 hours both before and after local noon. In contrast to previous studies described above, no large asymmetry about local noon is indicated in these observations. In fact, the distributions of occurrence in this study have both mean and median local times of ~11:30.

Figure 2 shows an independent method for determining the nose or stagnation point of the magnetopause for the nine cases in our data set where one of the geosynchronous spacecraft observed a flow reversal while it was outside the magnetosphere, in the magnetosheath. This figure displays the dawn-dusk (Y) component of the magnetosheath flow velocity. The crossing times ($v_y = 0$) of linear fits to the data, all of which occur within one hour of local noon, are given along the right side of the plots. Non-radial solar wind flows [e.g., Hundhausen et al., 1970] undoubtedly account for some of the non-local noon flow reversals and magnetopause crossing asymmetries. We would expect the unusual circumstances associated with geosynchronous magnetopause encounters to be disproportionately associated with such non-radial flows. In addition, MHD effects in the magnetosheath flow can substantially move the flow reversal point to the dawn (dusk) side of local noon for a normal spiral (antispiral) IMF orientation [Russell et al., 1981; Crooker et al., 1984]. None-the-less, both the median and mean local times for these nine reversals are very nearly local noon with a standard deviation of about half an hour.

3. Discussion

The statistical observations of magnetopause crossings at geosynchronous orbit as well as flow reversal observations in the magnetosheath just upstream from the magnetopause indicate that, in contrast to previous studies, no strong asymmetry about local noon generally exists when the magnetopause crosses geosynchronous orbit. Instead, these results show that simple aberration caused by the motion of the Earth in its orbit is sufficient to account for the small asymmetry toward dawn-side magnetopause crossings. For a 400 km s^{-1} solar wind the aberration angle is ~5° which gives a magnetosphere aberrated around a local noon of ~11:40. Local time centroids between ~11:40 and 12:00 are well within the statistical uncertainty of our data set.

In addition to the statistical results shown here, McComas et al. [1994] examined the data set for instances where spatial and temporal effects could be separated using the simultaneous, multi-point aspects of the MPA observations. Of the 39 intervals described in this study, there were only four where the spacecraft were appropriately positioned to allow definitive testing of a dawn-dusk asymmetry. Only one of these four cases indicated any asymmetry about local noon whatsoever, and this one showed a magnetopause nose at ≤11:45 local time, again consistent with aberration of the overall magnetopause.

The observations shown here and by McComas et al. [1994] suggest that the location of a geosynchronous spacecraft when the magnetopause happens to be compressed, rather than the shape of the magnetosphere, is the single most important determinant of where it will observe the magnetopause. Statistical variations in the spacecraft location may explain why previous studies with appreciably smaller data sets [e.g., Wrenn et al., 1981; McComas et al., 1993]

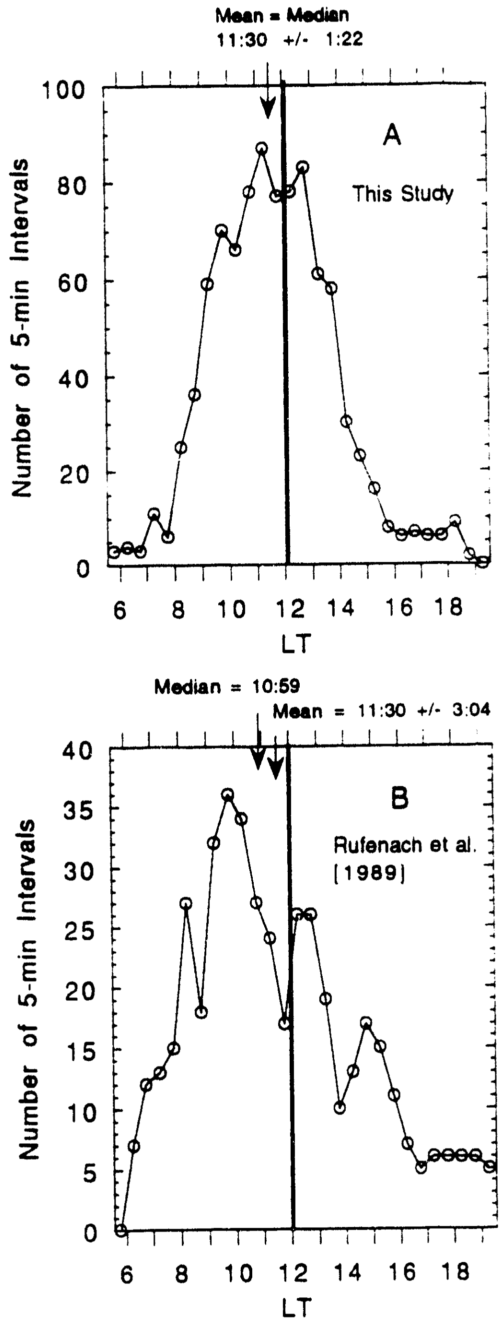

Figure 1. Local time occurrence of the 916 five-minute magnetosheath intervals (1a). The bottom panel (1b) shows a comparable plot for the observations of Rufenach et al. [1989].

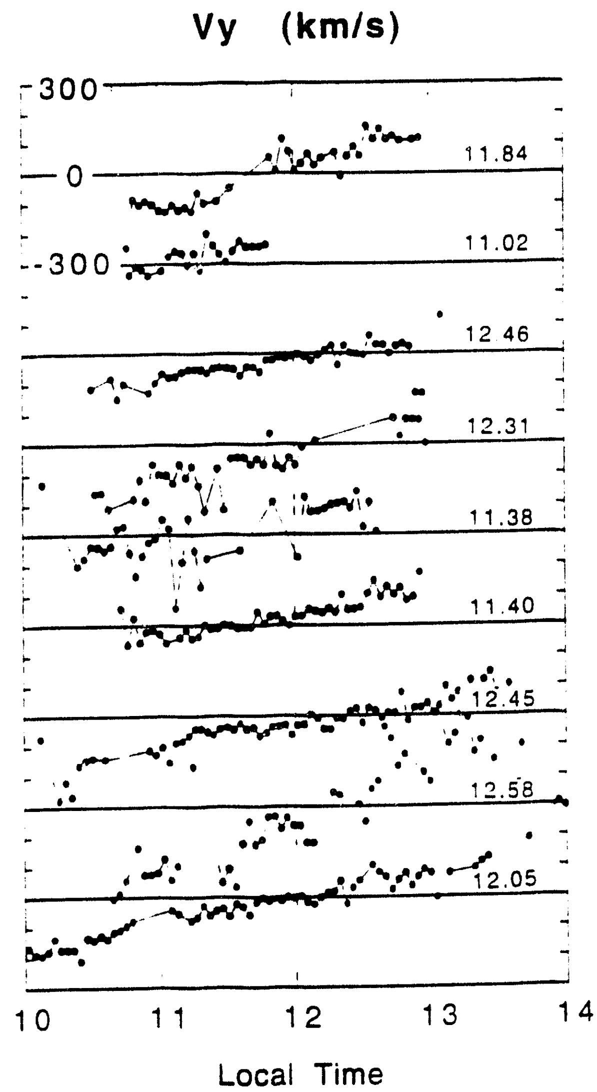

Figure 2. Dawn-dusk velocity in the magnetosheath, just upstream from the magnetopause, as a function of local time. The time of the flow reversal is determined from the zero crossing points of linear fits to the data. From McComas et al. [1994].

observed such pre-noon local times. We also find that our geosynchronous spacecraft spent 0.2% of the time in the magnetosheath. This is to be compared to 0.1% calculated from the only other large statistical study [Rufenach et al., 1989], which examined 64 magnetopause intervals consisting of 440 5-minute samples (about half as many as analyzed here). This difference might be attributable to the fact that magnetosheath intervals selected purely on the basis of magnetometer measurements can easily miss some crossings during times of northward IMF [McComas et al., 1993; 1994] and/or might represent a real difference between solar maximum conditions (this study) and the solar cycle averaged results of Rufenach et al.

Figure 1b displays the distribution of samples from Rufenach et al. [1989] in the same format as our observations (1a), but with a reduced scale. The apparent difference between these two studies may be simply attributable to statistical variations, however, it may also be that the somewhat larger pre/post-noon asymmetry shown by Rufenach et al. [1989] is real. If so, this difference is probably associated with the preference for selecting southward IMF magnetopause crossings with magnetometer data. One possibility is that there is a dawn-dusk asymmetry in the magnetopause position at times of southward B_Z because of an asymmetric inflation of the magnetosphere owing to the growth of the ring current [e.g., Cahill, 1966].

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