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EXTERNAL AND INTERNAL INFLUENCES ON THE SIZE OF THE DAYSIDE TERRESTRIAL MAGNETOSPHERE

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Abstract. ISEE-1 and -2 observations of the position of the magnetopause during solar cycle 21 are used to determine quantitatively the role of both internal and external influences. We find that the magnetopause is a function of the direction of the IMF and the magnitude of the solar wind momentum flux but depends only weakly on the ring current intensity. The magnetopause stand-off position is found to lie at a distance similar to that expected from theory for northward IMF, but is found to lie 0.5 Re closer to the Earth for southward IMF. When the position of the magnetopause is normalized for variations in the solar wind dynamic pressure, the magnetopause is found to move earthward 1 Earth radius for every 7.4 nT southward IMF, but remains at nearly a constant distance for northward IMF.

Introduction

In the three decades since the advent of the first high altitude spacecraft that probed the interface between the magnetosphere and the solar wind we have developed a good qualitative understanding of the physics of this interaction. The size of the magnetosphere is determined to first order by the dynamic pressure of the solar wind, and the southward component of the interplanetary magnetic field (IMF) in geocentric solar magnetospheric coordinates controls the transfer of magnetic flux to the magnetotail.

Because it controls the transfer of flux from the dayside to the nightside magnetosphere, the IMF has a role to play in the size of the dayside magnetosphere. Several authors have attempted to quantify these effects [Fairfield, 1971; Formisano et al., 1979; Petrinec et al., 1991; Sibeck et al., 1991]. However, we feel that it is necessary to extend those studies for several reasons. First, our modern understanding of the solar wind interaction with the magnetosphere together with improved magnetospheric models gives us more accurate theoretical models with which to compare. Secondly, the availability of an intercalibrated set of solar wind data comprising 4 different solar wind instruments provides a larger and more accurate solar wind database than previously available [Petrinec and Russell, in preparation, 1992]. Third, the previous studies did not test the suggestion of Cahill and Patel [1967] that the ring current enhancement associated with geomagnetic storms would lead to an inflated magnetosphere. It is the objective of this paper to test quantitatively our present theoretical understanding using our improved dataset and to examine the conjecture of Cahill and Patel.

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The crossing set used in this study has been carefully assembled from traversals of the magnetopause by the ISEE-1 and -2 spacecraft, from the years 1977-1987, cross checking with plasma data in ambiguous cases. In order to maximize the statistical validity of this data base and avoid orbital biases, several criteria are imposed on the entries in this data set. First, each orbital pass through the magnetopause is designated by a single point. Because of the long coherence time of the solar wind plasma, multiple crossings during a single pass are not independent events. In the case of multiple crossings of the magnetopause boundary during a single pass, the median crossing position and corresponding time are used. Each data point is then given equal weight. Second, the trajectory of the ISEE spacecraft places a constraint on the region over which the magnetopause can be sampled. Since the ISEE orbits had an apogee of only 22.5 Re, magnetopause crossings beyond x = -5 Re are not considered, because they may be biased toward large solar wind dynamic pressures and inward excursions of a fluctuating boundary.

In a previous paper we have discussed the shape of the magnetopause, the solar cycle variation of the size of the magnetopause and how the location of the magnetopause during solar cycle 21 compares with that seen in earlier solar cycles [Petrinec et al., 1991]. In this paper we show

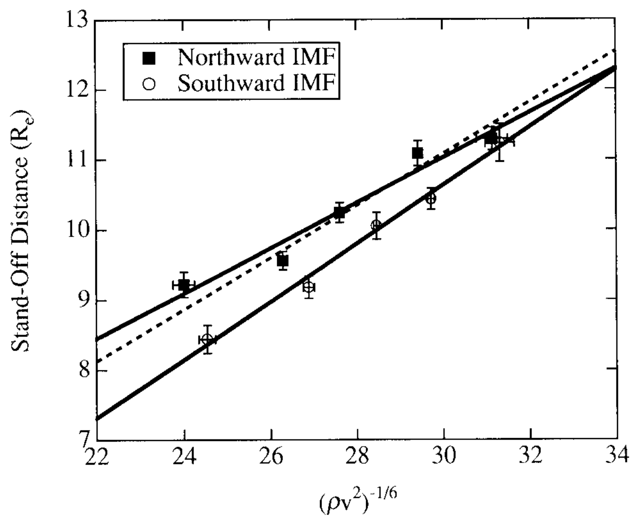

Fig. 1. Median stand-off position as a function of solar wind dynamic pressure measured by ISEE-3 and by IMP-8 normalized to a common calibration using ISEE-3 electron data for strongly northward and strongly southward IMF configurations. Solid line gives expected variation from equation (1). The error bars represent the standard error of the mean (147 crossings in the northward IMF crossing set and 150 for southward IMF). Medians are used throughout this work as they are less sensitive to outliers.

how the size of the magnetosphere is controlled by the solar wind dynamic pressure, the north-south component of the IMF, and the strength of the ring current.

Statistical Results

The magnetopause crossing set used in this study is the same as that presented in Petrinec et al. [1991]. The dayside magnetopause is assumed to be best represented as an ellipsoid with the Earth at one focus in the GSM coordinate system. We use the average shapes determined in our earlier study for northward and southward IMF to extrapolate each crossing to the subsolar point. We use solar wind observations from both IMP-8 and ISEE-3. These data have been intercalibrated and adjusted for ion velocity and temperature variations by referencing them to ISEE-3 electron data that should not have such sensitivity to the ion properties. The intercalibrated dataset has been tested and suffers none of the dependences outlined by Russell and Petrinec [1992].

Solar Wind Dynamic Pressure

To study the control by the solar wind dynamic pressure we have used data obtained by both ISEE-3 and IMP-8 suitably lagged to account for the solar wind convection time along the Earth-Sun line and intercalibrated as described above. As illustrated in Figure 1, the median stand-off position is determined to vary as expected with the solar wind momentum flux, and is larger for northward than for southward IMF (pressure bins are 2.5 $(\mathrm{Pa})^{-1/6}$, and are non-overlapping). We attribute the difference between the magnetopause position for northward and southward IMF to be due to the erosion of the magnetopause by reconnection as first noted by Aubry et al. [1970] and later confirmed by Fairfield [1971], Sibeck et al. [1991] and Petrinec et al. [1991]. The solid line represents the position of the subsolar point as a function of solar wind dynamic pressure as determined from:

$$\rho v^2 = K \frac{B_0^2}{2\mu_0 r_0^6} \quad (1)$$

where $B_o = 30574$ nT-Re^3, r_o is the stand-off distance in R_e, ρv^2 is in units of nPa, and $K = 6.77 \times 10^{-18}$. This value of K assumes that the intrinsic field of the Earth at the magnetopause nose is increased by a factor of 2.44 by the compression of the magnetospheric field by the solar wind, [Russell et al., 1992b and references therein] and a factor of 0.88 is included in order to account for the divergence of the stream lines about the magnetosphere [Spreiter et al., 1968]. Table 1 lists the slopes, intercepts, correlation coefficients and probable error in the slopes of straight line fits to the medians in Figure 1. We see that the correlation coefficient between the magnetopause position and the inverse sixth root of the solar wind dynamic pressure is very high ($\geq$ .95) and the slopes are similar to the theoretical slope, 0.369. The northward IMF fit is slightly more than one standard deviation of the mean less steep than expected and the southward IMF curve is about 2 standard deviations of the mean more steep. This latter difference could be due to a correlation of the B_z component with the dynamic pressure or the decreasing efficiency of reconnection with decreasing solar wind dynamic pressure [Scurry and Russell, 1991].

Dst index

The magnetosphere is not a vacuum, but contains energetic plasma. One region of the dayside magnetosphere which can contribute greatly to the energy density of the magnetosphere is the equatorial ring current. It might be expected that the more intense the ring current, the larger the magnetic field perturbation within the magnetosphere, which in turn would alter the size of the magnetosphere as has been suggested by Cahill and Patel [1967]. We can estimate the size of this effect by calculating the change in the magnetic moment of the Earth associated with a ring current flowing at 5 R_E causing a 100 nT depression at the surface of the Earth. We find that such a ring .current would cause the magnetopause to move outward by 0.25 R_E. The magnetopause stand-off distance, normalized to a solar wind dynamic pressure of 1.93 nPa., is plotted in Figure 2 as a function of the corrected Dst index corrected for the solar wind dynamic pressure [Burton et al., 1975; Russell et al., 1992]. This value, 1.93 nPa, is the median dynamic pressure measured for these magnetopause crossings. Median values of the stand-off distance are calculated for bins of Dst index (chosen such that an approximately equal number of points reside in each bin). As in the dynamic pressure study, the magnetopause crossings are separated by the direction of the z-component of the IMF. For northward IMF (panel a), there is a slightly linear trend that indicates that the dayside magnetosphere inflates as the ring current becomes more intense. Table 1 shows the fit to

TABLE 1. Linear Regressions for Fits in Figures

Figure	IMF Direction	Slope	Probable Error of Slope	Correlation Coefficient	Confidence Level	# in set
1	North	0.321	± .041	0.953	99%	147
1	South	0.414	± .023	0.990	99%	150
2a	North	-0.004	± .005	0.140	46%	147
2b	South	+0.013	± .007	0.552	85%	150
2c	Corrected	+0.004	± .004	0.281	64%	150
3	North	-0.041	± .026	0.375	80%	147
3	South	0.188	± .030	0.910	99%	150

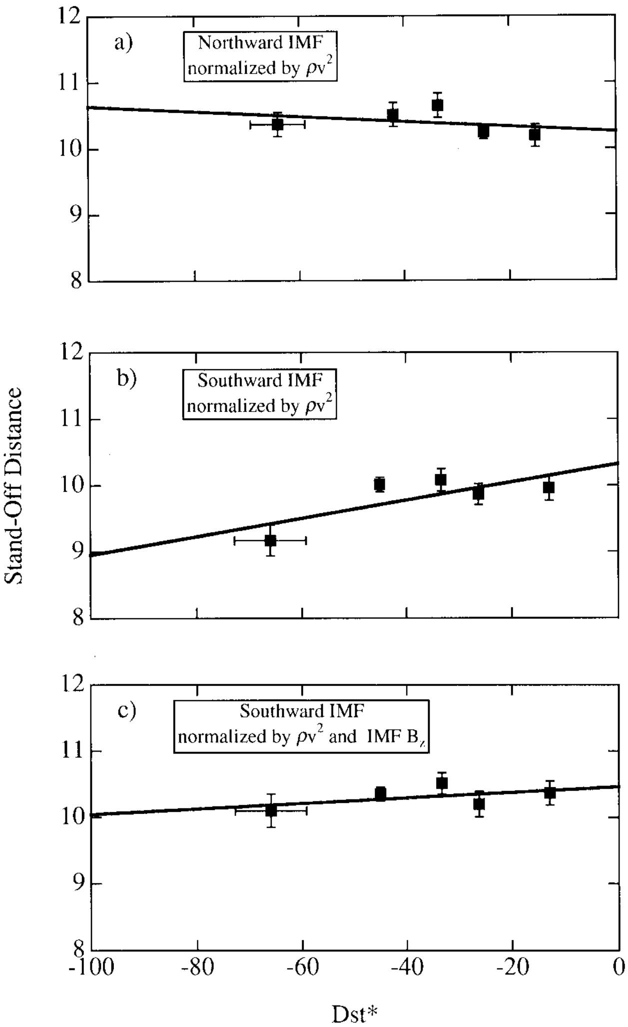

Fig. 2. Median normalized stand-off position as a function of ring current intensity, represented by the Dst index corrected for solar wind dynamic pressure using equation (1). Panel (a) shows the variation for periods when the IMF is northward. Panel (b) shows the variation when the IMF is southward. Panel (c) shows the variation of the magnetopause when the IMF is southward renormalized for the dependence of the magnetopause position on the southward IMF shown in Table 1 and Figure 3. The error bars represent the standard error of the mean. Intervals for medians are chosen to contain approximately equal numbers of crossings.

these points. The correlation is weak however, and the error in the slope is greater than the average slope.

For southward IMF, however, the trend is reversed. The slope is in the opposite direction. It is better correlated and the percent error in the slopes is smaller. However, this correlation is only slightly better and it is possible that this effect is due instead to the erosion during southward IMF which may be correlated with the strength of the ring current statistically (through the strength of the southward component of the IMF). In order to address this conjecture we need to examine more quantitatively the effect of the southward component of the IMF.

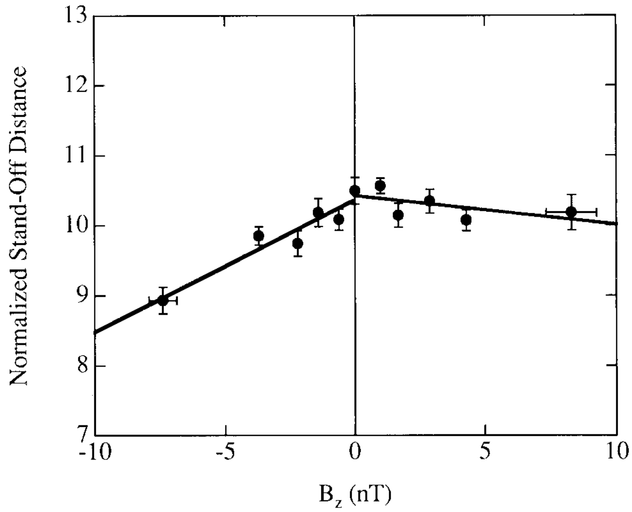

Fig. 3. Median location of the magnetopause for strongly northward IMF and strongly southward IMF crossings of the magnetopause. For these crossing |Bz| > |By/2| the Bz values are time-shifted by the solar wind convection time. These measurements are for passes through the magnetopause in which there was a well determined IMF value. Intervals for medians are chosen to contain approximately equal numbers of crossings.

Southward IMF

Even though we expect erosion to be an integrated effect, [e.g., Aubry et al., 1970] we can assess the effect of erosion by the IMF southward component by examining instantaneous values of B_z as a function of the normalized stand-off positions using equation (1), if we remember that this will be valid only in a statistical sense. There will be much variation of individual values. The normalized standoff positions using equation (1) are plotted as a function of Bz in Figure 3 again using medians with approximately an equal number of points in each bin. Only cases in which unambiguous IMF values can be assigned were used. As shown in Table 1, for southward IMF, the stand-off position, normalized by equation (1), is found to decrease with decreasing Bz with a correlation coefficient of 0.91, significant at a confidence level of 99%. This is in approximate agreement with the results obtained by Sibeck et al. [1991]. However, for the northward IMF cases, there is a weak decrease in position with increasing Bz, in contrast to the aforementioned study. This correlation is only weakly significant. It has a 20% chance of being consistent with the null hypothesis. One possible reason for this difference with the above mentioned study is that for the strongly northward IMF cases studied here, the IMF was northward as determined using 5 min averages for a long period of time (>1 hr.) before the magnetopause crossing for nearly every event. However, some of the northward IMF crossings in the Sibeck et al. study which used hourly averages may have had southward IMF for short periods of time before the magnetopause crossing, resulting in the observed increase of the stand-off position for increasingly positive Bz.

The single southward IMF crossings were then normalized for the effect of erosion by the linear regression shown in Figure 3, and plotted in panel (c) of Figure 2 as a function of the corrected Dst. The doubly normalized southward IMF magnetopause crossings now appear to be independent of Dst. This dependence is similar to that of the northward IMF crossings that were normalized by dynamic pressure. Moreover, the error in the magnetopause position associated with the error in the slope for panels (a), (b) and (c) is greater than our calculated effect. Thus, it appears that our data are still too noisy to determine an effect as small as that of the ring current. The greatest influences on magnetopause position are clearly the solar wind dynamic pressure and the southward component of the IMF.

Conclusions

The magnetopause position is influenced by the direction of the IMF, and the magnitude of the solar wind dynamic pressure, but very little by the intensity of the ring current within the magnetosphere. The stand-off position of the magnetopause is found to lie about 0.5 Re closer to the Earth for southward IMF than for northward IMF. The magnetopause position decreases significantly in proportion to the southward IMF, but no dependence appears for northward IMF crossings.

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