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THE STUDY OF MAGNETIC BARRIER PARAMETERS DEPENDENCE ON THE DIRECTION AND INTENSITY OF THE INTERPLANETARY MAGNETIC FIELD

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Abstract. The magnetic barrier is the region with enhanced magnetic field magnitude and depleted plasma. It is formed in the inner magnetosheath layer adjacent to the low-latitude dayside magnetopause. There is a general point of view now that a magnetic barrier can persist only for the northward direction of interplanetary magnetic field (IMF) while it is absent for the southward direction. We make a study to check appearance of magnetic barrier for different directions of IMF. To this end a data base consisting 63 events of low-latitude dayside magnetopause crossings by the THEMIS satellites was created and analyzed. In order to study the variations of key plasma parameters and the magnetic field near the magnetopause in a systematic way we used a superposed epoch analysis. It turns out that the magnetic barrier is the most pronounced for the northward IMF. For the southward IMF we still were able to find events with signatures of magnetic barrier. According to the theory magnetic barrier builds up more slowly than it collapses much more. Due to reconnection we find out that the magnetic barrier field at the dayside magnetopause is about 80% of the magnetospheric value for southward IMF cases with a minimum magnetopause reconnection rate. In other hand, previous statistical studies showed that for southward IMF the magnetic barrier field is no more than 50% of the magnetospheric value.

Introduction

The interaction between the solar wind (SW) and the geomagnetic field defines topology and properties of the magnetosphere and the surrounding areas. The magnetic barrier in front of the magnetosphere is one of the most important elements of this interaction. The magnetic barrier is the area of the transition layer adjacent to the magnetopause with an increased magnetic field intensity and decreased plasma density.

At the southern orientation of the interplanetary magnetic field (IMF) magnetopause reconnection destroys the magnetic barrier. The magnetic barrier is stronger in a case of northern IMF and completely absent while IMF is directed to the South, as it was showed by the superposed epoch analysis in [1]. This point of view is widespread in the scientific community. However, where does the energy required for magnetopause reconnection come from if IMF is oriented to the south?

In this regard, we set the following objectives: to compile a database with magnetopause crossings, to divide events into couple groups by IMF orientation and investigate them; to find the individual events with a southern IMF in which there is the magnetic barrier and compare them with the events in which the magnetic barrier is destroyed by the magnetopause reconnection.

Methods and materials

It was used data parameters from THEMIS-B and -C satellites for the period 2007-2009. The magnetic field and plasma parameters were measured with a spin-resolution of about 3s. Details are on the THEMIS website [2]. Solar wind data with a spin-resolution of 1 min have been taken from OMNI [3].

It was selected 74 low-latitude, dayside (10-14 LT) magnetopause crossings during the period from 2007 to 2009. It can be observed multiple magnetopause crossings in many events. To weed out the plasma parameters variations associated with the oscillatory motion of the magnetopause we chosen one of the magnetopause crossing for each event: the first crossing when a satellite had come into the magnetosphere and the last one otherwise. Additional selection criterion was the condition that the satellite crossed the magnetopause at an angle greater than 45^o.

Further we are going to use the term «magnetic shear». Magnetic shear is the angle between the magnetosheath magnetic field and the geomagnetic field. There were appropriated 74 magnetopause crossings: 25 events with low-shear magnetopauses (according to northern IMF) and 49 ones with high-shear magnetopauses (according to southern IMF).

To get an overall picture of changes in the magnetic field and plasma parameters we used the superposed epoch analysis following by [1]. At first, we determined the magnetopause crossing time which we took as the time T_0 (t = 0). The reference time T_0 was determined by the sharp leap in the density, temperature and particle spectrum. It's worth noting that our results do not strictly depend on the error of determining the magnetopause position since the considered area is much wider than the magnetopause itself. The analysis was performed for 20 min before the magnetopause crossing and 2 min after entering into the magnetosphere. For the outbound passes we changed the timeline to combine it with the timeline for inbound passes. There were 25 crossings with low-shear magnetopauses (magnetic shear ~ 0^o-40^o) and 49 with high-shear magnetopauses (magnetic shear ~ 80^o-180^o).

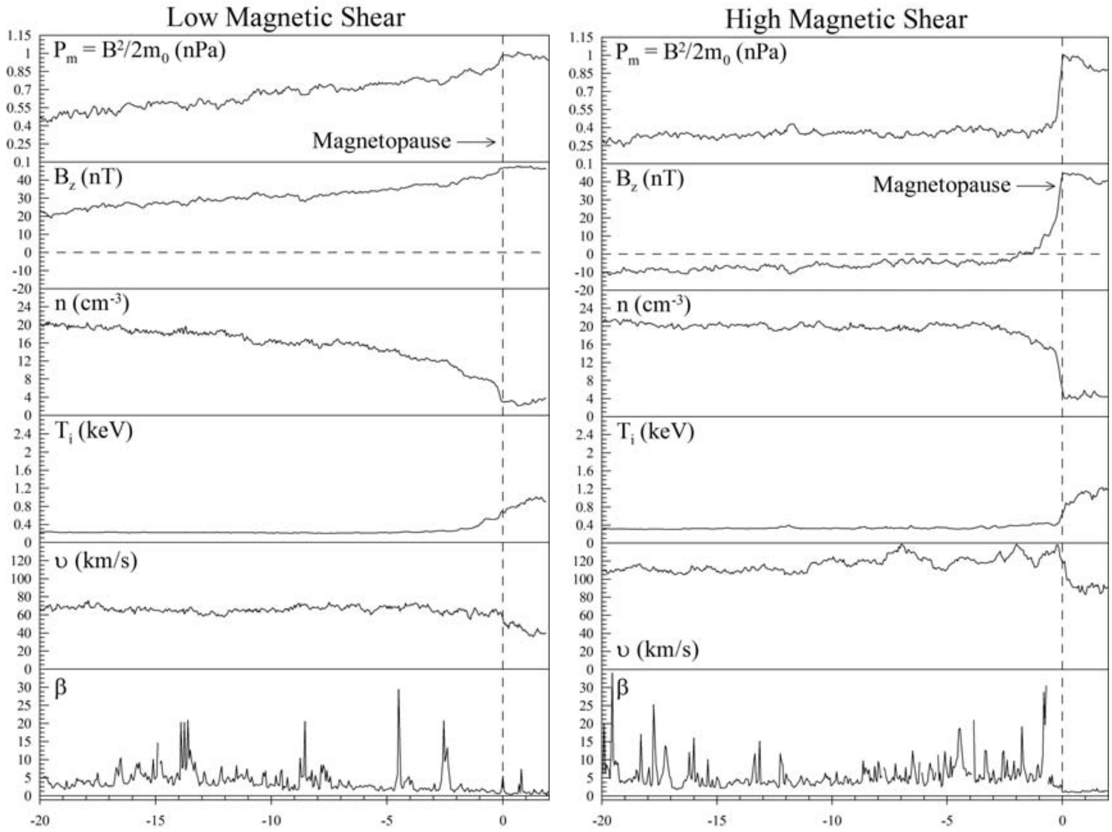

Fig. 1 Superposed epoch analysis for 25 low-shear magnetopause crossings (left column) and 49 high-shear magnetopause crossings (right column). Magnetosheath is before T_0, magnetosphere — after. From top to bottom: magnetic pressure (nPa), Z-component of the magnetic field in GSM (nT), proton density (cm^{-3}), temperature (keV), bulk velocity (km/sec), and plasma β.

Results and discussion

The result obtained by the superposed epoch analysis showed full compliance with the result of [1]. For low-shear events we could see signs of the magnetic barrier which were expressed in the magnetic flux piling up at the magnetopause, in the decrease of the density and plasma β. For high-shear events the magnetic barrier is absolutely absent. In this case there are a leap of the magnetic pressure, a slight decrease in the plasma density and the growth of the velocity fluctuations close to subsolar magnetopause. The features of high-shear magnetopause crossings (a sharp drop in the plasma density and a growth of the velocity fluctuations) indicated an effective process of the dayside reconnection because of which the magnetic barrier had disappeared.

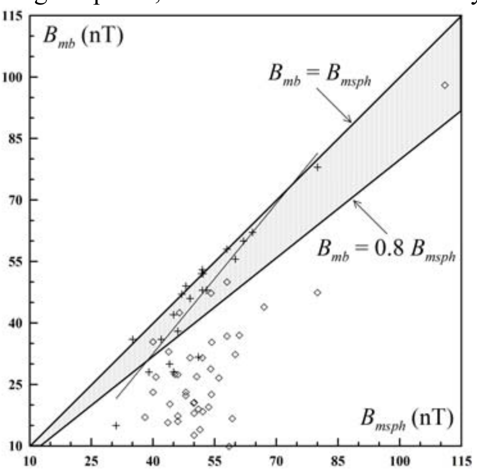

Fig. 2 The Figure shows the field magnitude in the magnetic barrier B_{mb} depending on the magnetic field inside the magnetosphere B_{msph}. The shaded area is bounded by two lines: $B_{mb} = B_{msph}$ — at the top and $B_{mb} = 0.8\ B_{msph}$ — at the bottom.

We compared the magnetic field magnitude in the magnetosheath and in the magnetosphere (Fig. 2). The lines limiting the shaded area correspond to 80% of the magnetospheric magnetic field. This level is determined by the minimum plasma inflow velocity into the reconnection area while IMF was oriented to the south. If the inflow velocity is at least 0.1 of the Alfvén speed (the minimum reconnection rate) the field magnitude in the magnetic barrier does not exceed 80% of the magnetospheric magnitude. Therefore, in cases when the magnetic field magnitude greater than 80% we could assume that there is no reconnection.

Almost all low-shear events (crosses in Fig. 2) are in the shaded area. There are clear signs of a magnetic barrier in these events. For the low-shear events the approximation line lies along the shaded area. It means the field magnitude inside the magnetic barrier is about magnetospheric magnitude. The events located near the diagonal line indicate the maximum of field magnitude in the magnetic barrier.

However, in this area we can see a few rhombs (high-shear magnetopause crossings) that correspond to the magnetic barrier presence for these events. As we can see in Fig. 2 such events are observed rarely.

The large group of rhombs is below the shaded area. These rhombs correspond to events without signs of a magnetic barrier. However, there are 5 high-shear events in the shaded area. This is because the magnetic barrier accumulation time (~10 min) several times longer its destruction (1-2 min) [4]. Thus, in the presence of the dayside reconnection the probability of observing the magnetic barrier is determined by the ratio of the two characteristic times that is about 10-20%.

Then we repeated the superposed epoch analysis for high-shear magnetopause events with signs of a magnetic barrier and without them. The results are shown in Fig. 3.

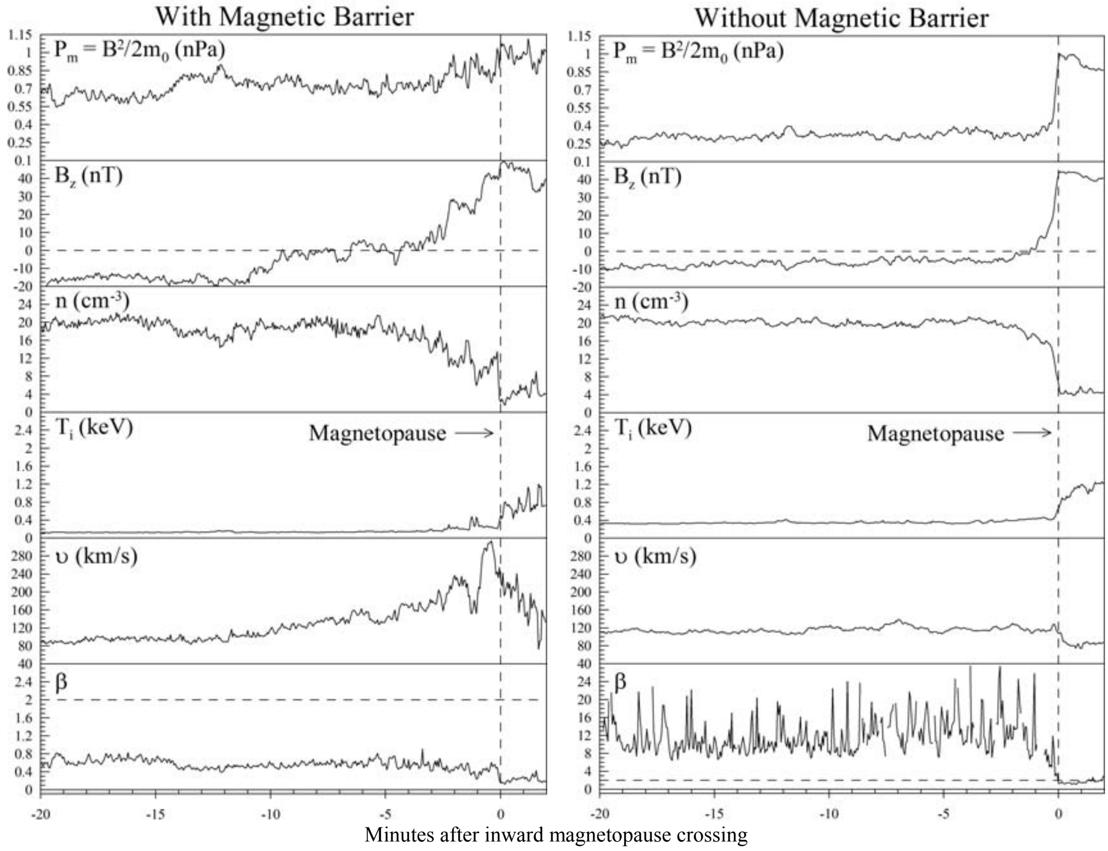

Fig. 3 Superposed epoch analysis for 4 high-shear magnetopauses with signs of a magnetic barrier (left column) and 45 high-shear magnetopauses without them (right column). The format is the same as in Fig. 1.

The magnetic pressure for the first subgroup increases while distance to the magnetopause decreases, there is also a layer with depleted plasma, low plasma β and increase of the plasma velocity in front of the magnetopause. The second subgroup is characterized by weaker magnetic pressure inside the transition layer and depleted plasma. These features indicate the absence of a magnetic barrier in front of the magnetopause.

From the above it follows that the superposed epoch analysis does not give a correct answer to the question of whether exist or not the magnetic barrier in a case of southern IMF but gives an overall picture. We can see that presence of high-shear magnetopause events with a magnetic barrier does not affect the picture obtained by the superposed epoch analysis.

After all we determined the reconnection rates at the magnetopause for each case with a destroyed magnetic barrier. The method from [5] was used to estimate the reconnection rates.

For each event we determined the angle λ. It is the angle between magnetopause reconnection line and axis Z at subsolar area. With that angle we calculated theoretical field magnitude B and density n in a magnetic barrier for different magnetopause reconnection rates g (0,1; 0,2; 0,3) by this formulas:

$$\lambda = \arcsin\left(\frac{(B_m - B_s\cos\theta)}{(B_m^2 + B_s^2 - 2B_mB_s\cos\theta)^{1/2}}\right), \qquad \xi = gM_A{}^2\sin(\theta-\lambda),$$

$$B = \left(4\pi n_0 u_0{}^2\right)^{1/2}\widetilde{B}(\xi), \qquad n = n_0\widetilde{n}(\xi).$$

In formulas B_m и B_s is magnetospheric field magnitude and field magnitude in a magnetic barrier correspondingly; the angle θ is the deviation of IMF vector from axis Z; n_0, u_0 и M_A is correspondingly plasma density, bulk velocity and the Alfven Mach number in the solar wind; $\widetilde{B}$ и $\widetilde{n}$ is the dimensionless functions from ξ parameter (they used in [5] for calculation of MGD parameters on a border of the reconnection area). Calculating ξ for different values of reconnection rate g we determined field magnitudes and densities and compared them to experimentally received values. In each case, for comparison with the experimental B_s and n_s we chose the similar of the three calculated values of B and n. Thus, we determined the reconnection rate corresponding to each event. As a result the histogram of events distribution on reconnection rates g was built. It turned out that the most likely g = 0.3. Thus selected pairs of B and n values are compared in Fig. 4(b-1, c-1). A similar comparison for the condition g = 0.3 in all the events is shown in the Fig 4(b-2, c-2).

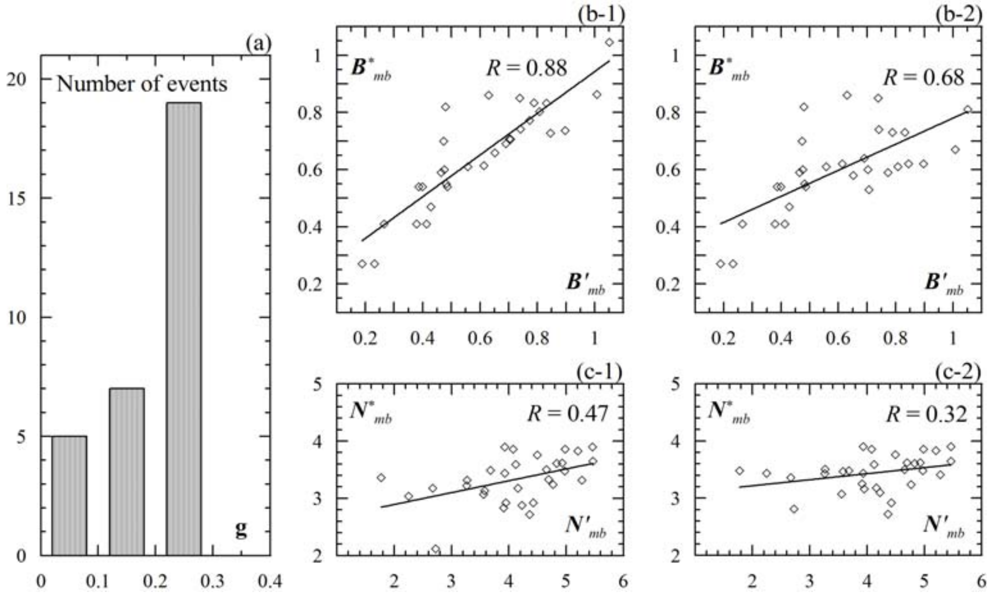

Fig. 4 Statistics for 31 events with destroyed magnetic barrier. The histogram of the events distribution with destroyed magnetic barrier by the magnetopause reconnection rate (a). In Figure theoretical (*) and experimental (') magnetic field (b) and plasma density (c) are presented in comparison with the solar wind parameters for rates of magnetopause reconnection g obtained by compare theoretical and experimental values (1) and for fixed g = 0.3 (2).

Conclusions

It was shown by the superposed epoch analysis that the features of the magnetic barrier (enhancement of the magnetic field and the decrease in the plasma density) were observed for northern IMF and not observed for the southern IMF. These are consistent with the results of [1]. For southern IMF the features of the magnetic barrier (increase magnetic field by more than 80% of the magnetospheric magnitude) are observed in 5 of the 49 events. This ratio corresponds to the magnetic barrier accumulation time (~10 min) several times longer its destruction (1-2 min). Thus, the magnetic barrier is formed for all IMF directions, including southern, however, it is unlikely to detect accumulated magnetic barrier for southern IMF. It was found (Fig. 4(b-1, c-1, b-2, c-2)) that the correlation between the calculated and experimantal values is better at choosing reconnection rate for each event. It follows that reconnection rate can vary in different events. This is reflected in the large scatter of points for the event (Fig. 2).

References

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