"Physics of Auroral Phenomena", Proc. XXXV Annual Seminar, Apatity, pp. 45 - 48, 2012

Polar Geophysical Institute

MAGNETIC FIELD PARAMETERS NEAR THE SUBSOLAR MAGNETOPAUSE IN ACCORDANCE WITH THEMIS DATA

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Abstract. We analyze the crossings of the magnetopause near the subsolar point using FGM and ESA devices of THEMIS mission. Variations of the magnetic field near magnetopause measured by one of THEMIS satellites are compared with simultaneous measurements in the solar wind by another THEMIS satellite. 30 and 90 s averaging of magnetic field in the magnetosheath is produced. The results of averaging are compared with the results of measurement just after the magnetopause crossing. It is shown, that *Bx* component of the magnetic field near magnetopause is near to zero, which supports the possibility to consider the magnetopause as the tangentional discontinuity. Comparatively good correlation of *By* component in the solar wind and near the magnetopause is observed. The correlation of *Bz* component near the magnetopause and IMF is practically absent. It is shown, that in many cases the sign of the *Bz* component of magnetic field near the subsolar point does not coincide with the sign of IMF *Bz* component. The results of the analysis create definite difficulties to simplified theories of magnetic reconnection of solar wind magnetic field at the magnetopause.

Introduction

The development of the solar wind-terrestrial interaction theory requires taking into account the existence of a high level of turbulence in the magnetosheath. Therefore, comparison of the magnetic field parameters directly in front of the magnetopause with the magnetic field in the solar wind (IMF) is of great interest. A large number of measurements of IMF were carried out in the libration point. The solar wind propagation time from the libration point to the Earth is about one hour. Solar wind is itself a turbulent medium (see *Riazantseva et al.* [2005, 2007] and references in these papers). Therefore, its parameters may change during the propagation to the Earth's orbit.

To assess the effect of magnetosheath turbulence on the magnetic field parameters changing during the propagation through the magnetosheath to the magnetopause these parameters should be compared directly in front of the shock wave and near the magnetopause. At the same time measuring of the solar wind should be carried out upstream the foreshock region which makes a strong disturbance in the solar wind prior to the shock front. The opportunity of such a comparison has appeared only with the start of the five-satellite THEMIS mission (*Angelopoulos,* [2008]; *Sibeck and Angelopoulos*, [2008]). One of THEMIS satellites during summer times performed measurements in the solar wind, while the other occasionally crossed the magnetopause on the dayside.

In this study, a comparison of the magnetic field parameters near the magnetopause measured every 3 seconds (spin resolution of the probe), 30 seconds (which is ~ the correlation time, in accordance with estimations of *Gutynska et al.* [2008]) and 90 seconds (~ three times greater than characteristic correlation time) with the same parameters before the bow shock is made. Average dependences of the magnetic field parameters near the magnetopause on the corresponding parameters in the solar wind at selected averaging intervals are obtained. It is shown that the orientation of the magnetic field at the magnetopause may differ significantly from the orientation in the solar wind including even change of sign.

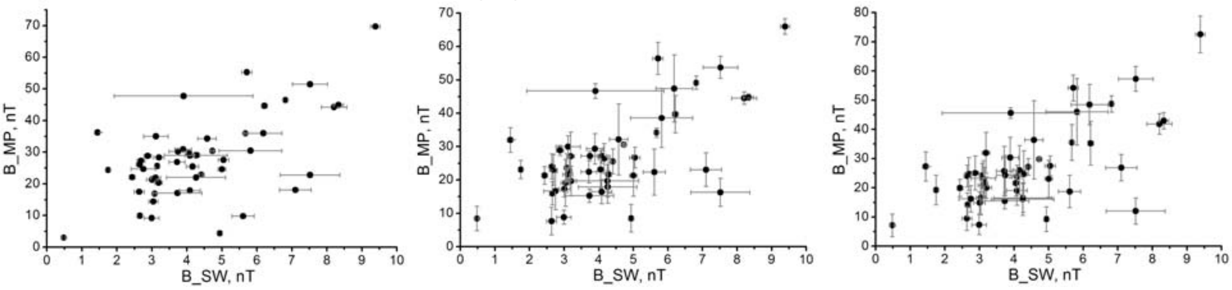
Method and results of data analysis

Data for analysis were taken from the website http://cdaweb.gsfc.nasa.gov/. In this paper we analyze THEMIS data for years 2008, 2009 when the orbits of spacecrafts deployed by the precession in such a way that their apogees were located close to the Earth-Sun line, i.e. the configuration convenient for studying the interactions on the dayside of the Earth's magnetosphere takes place. The intervals when one of the spacecrafts was located in the solar wind, and another crossed the magnetopause near the subsolar point were picked out. The events were selected when the deviation of the probe from the x-axis did not exceed 7 R_E. The moment of crossing of the magnetopause was fixed by the distinctive changes in plasma parameters and magnetic field, determined according to the Electrostatic Analyzer ESA and the Flux Gate Magnetometer FGM on the probe. Parameters of the interplanetary magnetic field (IMF) were determined according by FGM. The events in which the solar wind did not suffer significant variations were chosen. The value of the standard deviation of the absolute value of the magnetic field from the average for the selected periods does not exceed 2 nT, the flow velocity was no more than 650 km/sec.

The parameters of the magnetic field, measured by one of the spacecraft after crossing the magnetopause, were compared with the IMF parameters observed by another spacecraft. The time resolution of the measurements was 3 seconds which is equal to the spin resolution of the probe. The following quantities were used as analyzed parameters: the magnitude and the three components of the magnetic field and the IMF clock angle. The 'clock angle' was considered as the angle produced in the vertical plane from the vector addition of the B_y and B_z components of the IMF (in GSM coordinates). Mean value and dispersion were calculated for each variable.

The magnetic field parameters near the magnetopause were averaged over periods of 30 and 90 seconds after crossing the magnetopause (what was fixed simultaneously by changes in the parameters of plasma and magnetic field). The first point of the magnetosheath was taken as the last data point before or the first after the significant change in the parameter value. Values of the magnetic field, averaged over 3 s, i.e. field directly close to magnetopause was also analyzed. The solar wind parameters were averaged over a maximum period of 90 s taking into account the time shift of solar wind propagation from the spacecraft performing measurements in the solar wind to the magnetopause. The shift was calculated as the time of the solar wind passing the difference between x-coordinates of the spacecrafts in the approximation of the radial propagation of the solar wind. Solar wind velocity was determined from the data of THEMIS probe located in the solar wind. It was considered in the magnetosheath as reduced by about two times as a result of thermalization. The magnetosheath thickness was supposed to be approximately ~ 2 R_E. For each case the time shift was calculated individually for the specific spacecraft coordinates. Since the errors of the order of ten seconds are possible when calculating the time shift, the averaging of values in the solar wind was made for a maximum period of 90 seconds to minimize them. 50 events were analyzed, 25 of them with nortward magnetic field in solar wind and 25 with southward.

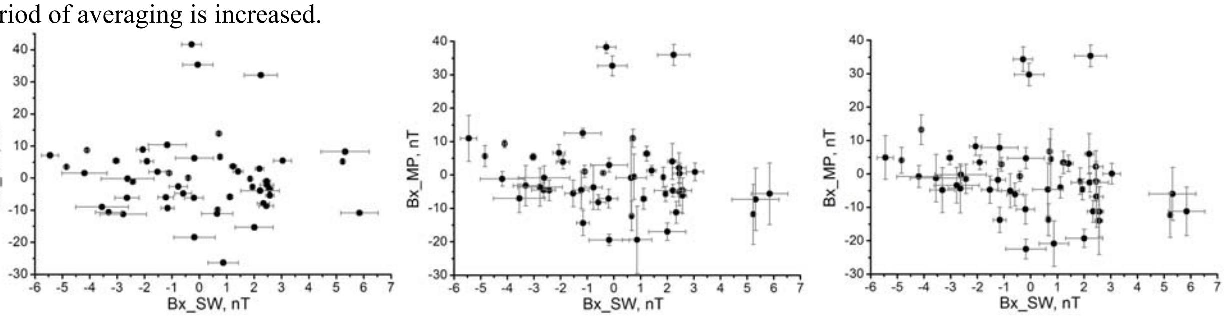
Figures 1 – 5 show the dependences of the magnetic field parameters near the magnetopause on the solar wind parameters. A set of three curves is given for each parameter. The first distribution is plotted for the instantaneous values (three second averaging) after crossing the magnetopause, the second – for the averaged over a 30-s interval after crossing, the third – for the averaged over a 90-s interval. Averaging in the solar wind is realized for a maximum period of 90 s (taking into account the time shift of the solar wind propagation to the magnetopause) in order to minimize errors due to deviation of the estimated solar wind delay from the real delay. For each point, an error calculated as the standard deviation over the averaging periods is also shown. In Figures for the instantaneous values the errors are shown only for the averaging in the solar wind.



a) b) c)

Fig. 1 The dependence of the magnetic field magnitude for the considered set of events a) over 3 seconds after crossing the magnetopause, b) averaged over a period of 30 seconds from the moment of crossing c) averaged over a period of 90 seconds – on the magnitude in the solar wind.

The values of the magnetic field magnitude (see Figure 1) at the magnetopause noticeably trend to increase when increasing magnitude in the solar winds. The form of the distribution remains essentially unchanged when the period of averaging is increased.

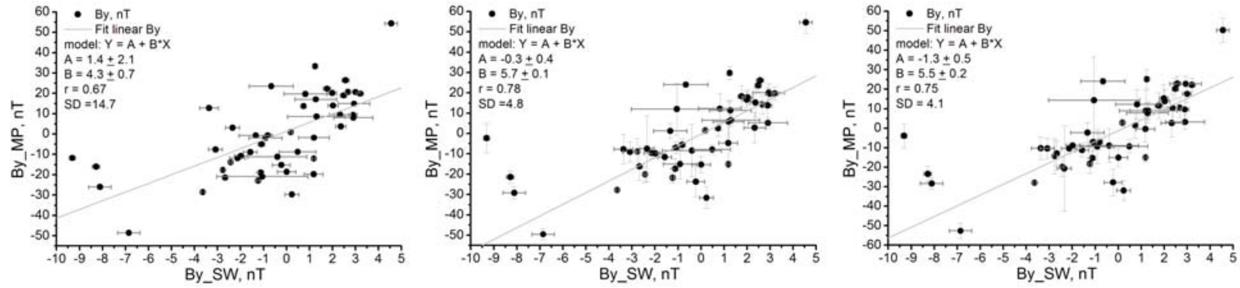


a) b) c)

Fig. 2 The dependence of the x-component of the magnetic field for the considered set of events a) over 3 seconds after crossing the magnetopause, b) averaged over a period of 30 seconds from the moment of crossing c) averaged over a period of 90 seconds – on the B_x in the solar wind.

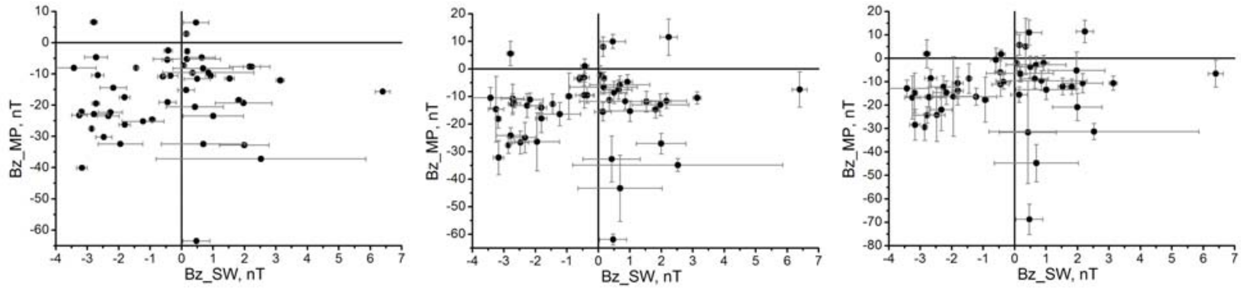
In accordance with Figure 2 the x-component of the magnetic field at the magnetopause does not depend on the corresponding value in the solar wind and fluctuates around zero, which is in accordance with the assumption of magnetopause as a tangential discontinuity. As well as for the field magnitude, the increase in averaging interval does not change the form of the distribution of points on the graph.

A comparatively good linear dependence of the y-component at the magnetopause (see Figure 3) on that in the solar wind is obtained. The correlation coefficient is better and the errors of the parameters of the approximation and standard deviations are lesser for averaged data. For instantaneous values after crossing the approximation with the model $By_{MP} = a + b \cdot By_{SW}$ gives the following values of parameters: a = 1.4 ± 2.1 nT, b = 4.3 ± 0.7, SD = 14.7 nT, correlation coefficient r = 0.67. For the 30s-averaged values: a = -0.3 ± 0.4 nT, b = 5.7 ± 0.1, SD = 4.8 nT, r = 0.78. For the 90s-averaged values: a = -1.3 ± 0.5 nT, b = 5.5 ± 0.2, SD = 4.1 nT, r = 0.75.



a) b) c)

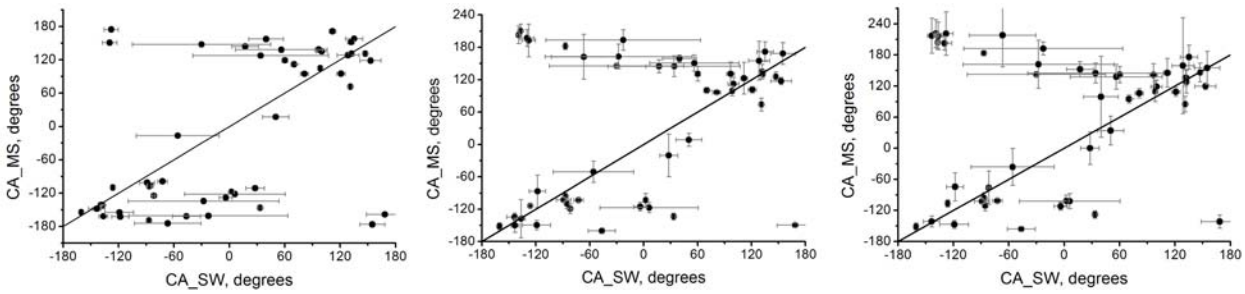
Fig. 3 The dependence of the y-component of the magnetic field for the considered set of events a) over 3 seconds after crossing the magnetopause, b) averaged over a period of 30 seconds from the moment of crossing c) averaged over a period of 90 seconds – on the B_y in the solar wind.



a) b) c)

Fig. 4 The dependence of the z-component of the magnetic field for the considered set of events a) over 3 seconds after crossing the magnetopause, b) averaged over a period of 30 seconds from the moment of crossing c) averaged over a period of 90 seconds – on the B_z in the solar wind.

The results obtained for the z-component of the magnetic field (see Figure 4) are of great interest. There is a vague tendency towards an increase in the value of this component with the increasing of corresponding value in the solar wind. However, almost a half of cases (25 out of 50 for the instantaneous and 30s-averaged values, and 24 out of 50 for the values averaged over a period of 90 seconds) show that the sign of the z-component at the magnetopause changes compared with the sign of B_z in the solar wind. The most common changes are from positive value (in the solar wind) to negative (at the magnetopause): 24 for instantaneous values, 23 for 30s-averaged and 22 for 90-s averaged values, and in a few cases (1 for the instantaneous and 2 for averaged over 30 and 90 seconds values) from negative to positive value. It should be noted that considered set of cases contains the equal number of events with positive and negative B_z in the solar wind.



a) b) c)

Fig. 5 The dependence of the magnetic field clock angle for the considered set of events a) 3 seconds after crossing the magnetopause, b) averaged over a period of 30 seconds, c) averaged over a period of 90 seconds – on that in the solar wind.

The dependencies of clock angle at the magnetopause on that in the solar wind have been obtained and are presented in Figure 5 and Table 1. For clarity, there are a line of equal values of clock angles in solar wind and near the magnetopause in each plot.

Table 1. The deviation of clock angles.

Number of cases with deviation more then	For instantaneous values	For 30s-averaged values	For 90s-averaged values
30 degrees	30 cases (60%)	28 cases (56%)	23 cases (46%)
60 degrees	16 cases (32%)	15 cases (30%)	14 cases (28%)
90 degrees	13 cases (26%)	14 cases (28%)	10 cases (20%)

Conclusions

The produced analysis of observations obtained during realization of THEMIS mission confirmed the existence of a high level of turbulence of the magnetic field in the magnetosheath. Unlike previous studies the magnetic field parameters in this research obtained directly in front of the subsolar magnetopause were compared with the IMF parameters measured upstream of the bow shock wave. It was shown that B_x-component at the magnetopause varies near zero regardless of the averaging interval that fit well with the existence of the tangential discontinuity at the magnetopause. B_y-component at the magnetopause is comparatively well correlated with IMF B_y. The increasing of the period of averaging leads to the increases of the correlation coefficient of IMF B_y and B_y at the magnetopause. The correlation of B_z component near the magnetopause and IMF B_z is practically absent. It was shown, that in ~50% for considered set of cases the sign of the B_z component of magnetic field near the subsolar point does not coincide with the sign of IMF B_z component. Events not conforming the assumption of equality of clock angles were observed (90-degree deviation was observed for no less then 20% of cases). Poor correlation between the magnetic field in the magnetosheath with the IMF had been noted earlier (see *Coleman* [2005], *Šafránková et al.* [2009] and references in these papers). The presented results imply that the poor correlation, even at a relatively long averaging interval of 90 s, comparable with the time of solar wind plasma propagation through the magnetosheath, is connected with the magnetosheath turbulence. In this study, due to a limited statistics (the limited number of magnetopause crossings by one of the spacecraft, when the other was located upstream the foreshock), we does not distinguish events with quasiperpendicular and quasiparallel shock waves. In accordance with the results of *Shevyrev and Zastenker* [2005] one can expect that the average level of fluctuations behind quasiperpendicular and quasiparallel shock waves will differ by about a factor of 2. IMF, especially its B_z-component, is the major factor controlling the geomagnetic activity. It is usually assumed that this control is performed due to the processes of reconnection of the IMF and the magnetic field on the magnetopause and inside the magnetosphere. Numerous studies of turbulence in the magnetosheath, including the above analysis, give reason to reconsider such suggestion. The high level of magnetic field fluctuations in the magnetosheath, even for the relatively large averaging intervals, indicate that at different points of the magnetopause the magnetic field has different orientations, poorly correlated with the orientation of the IMF. The ideas about the role of large-scale reconnection processes at the magnetopause and formation of large-scale neutral lines were involved for explaining a relatively good correlation of IMF and large-scale magnetospheric convection. The experimental evidences of the support of the field-aligned current system in the magnetosphere and large-scale convection by azimuthal pressure gradients of the magnetospheric plasma were accumulated (see *Antonova* [2004] and references therein). Therefore, it is possible to reanalyze the suggestion about the penetration of the solar wind electric field inside the magnetosphere as a result of large-scale reconnection.

Acknowledgments. The authors thank the group of developers of THEMIS mission and the support group of spacecraft data website http://www.nasa.gov/mission_pages/themis/. The work was supported by the grants of Russian Foundation for Basic Research 12-02-00217-a, 12-05-00984-a, 12-02-31224 мол_а

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