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# Comparison of the magnetic field before the subsolar magnetopause with the magnetic field in the solar wind before the bow shock

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**Abstract**

Crossings of the magnetopause near the subsolar point are analyzed using data of THEMIS mission. Variations of the magnetic field near magnetopause measured by one of THEMIS satellites are studied and compared with simultaneous measurements in the solar wind by another THEMIS satellite. The time delay of the solar wind arrival at the subsolar point of the magnetopause is taken into account. 30 and 90 s averaging of the magnetic field in the magnetosheath is produced. The results of averaging are compared with the results of measurements in the solar wind before the bow shock and foreshock. It is shown, that $B_x$ component of the magnetic field near magnetopause is near to zero, which supports the possibility to consider the magnetopause as the tangential discontinuity. Comparatively good correlation of $B_y$ component in the solar wind and near the magnetopause is observed. The correlation of $B_z$ component near the magnetopause and IMF is practically absent, the sign of the $B_z$ near the subsolar point does not coincide with the sign of IMF $B_z$ in ∼30% cases.
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*Keywords:* Magnetopause; Magnetosheath; THEMIS mission; Turbulence

## 1. Introduction

Measurements of the magnetic field (IMF) by the spacecraft in the solar wind (Wind, ACE etc.) are ordinarily used analyzing the interaction of the solar wind with the magnetosphere of the Earth. However, it is a magnetosheath plasma and magnetic field that come into a contact with the magnetopause. A characteristic feature of magnetosheath plasma is a high level of turbulent fluctuations (Schwartz et al., 1996; Shevyrev and Zastenker, 2005; Savin et al., 2005; Rossolenko et al., 2008; Antonova et al., 2012; Shue and Chao, 2013 and references therein). The most popular theories of the interaction of the solar wind with the magnetosphere suggest the existence of the laminar flow and the validity of the frozen-in condition destroyed only in reconnection points and lines. Estimates of the global plasma properties in the magnetosheath are predominantly based on the results of the gasdynamic model predictions of Spreiter et al. (1966) and Spreiter and Stahara (1980). Verification of the model made in the papers of Němeček et al. (2000) and Zastenker et al. (2002) showed that this model generally describes the properties of the flow although there may be significant deviations. Such deviations are especially noticeable in the

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behavior of the magnetic field. The numerical MHD models are usually unable to reproduce the magnetic field fluctuations in the magnetosheath (see, for example, Li et al., 2009). The correlation scale of fluctuations of module of the magnetic field in the magnetosheath in the dawn-dusk meridional plane according to CLUSTER data was determined in Gutynska et al. (2008, 2009). It was shown that the correlation length of magnetosheath magnetic field fluctuations varies from 0.5 to 1.5 $R_E$ and does not depend significantly on the magnetic field or plasma flow direction. The time of correlation length crossing by plasma flow is ~30 s when the plasma flow velocity in the magnetosheath is ~200 km/s. Gutynska et al. (2009) stressed that for a reliable determination of the magnetic field at the magnetopause, the monitor should be as close as ~1 $R_E$ from the investigated magnetopause point.

The development of the theory of the solar wind-magnetosphere interactions requires the knowledge of the properties of the turbulence in the magnetosheath. The turbulent solar wind, the foreshock region of the near-Earth shock wave, the shock wave itself and the development of instabilities in the magnetosheath and near the magnetopause are the sources of magnetic field fluctuations (Gutynska et al., 2012). Therefore, the comparison of the magnetic field parameters directly in front of the magnetopause with the magnetic field in the solar wind (IMF) represents the real 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 (Tu and Marsch, 1995) in which sharp parameter changes are observed (Riazantseva et al., 2005, 2007). Therefore, its parameters may change during the propagation to the Earth's orbit.

Šafránková et al. (2009) analyzed a probability of simultaneous observations of the same sign of the magnetic field $B_z$ component in the solar wind and magnetosheath. The analysis was based on 5 min data from four spacecrafts (Interball-1, IMP 8, Cluster and THEMIS) operating in the magnetosheath. Their measurements were compared with Wind, ACE, THEMIS-B interplanetary magnetic field (IMF) observations and OMNI database. They found that the probability of observations of the same $B_z$ sign in the solar wind and in the magnetosheath is close to 0.5 (random coincidence) for IMF $|B_z| < 1$ nT, and it is a rising function of the $B_z$ value. They noted that their study did not cover the subsolar region ($x_{GSE} > 9\ R_E$) and other components of IMF.

It was stressed by Šafránková et al. (2009) that their research does not cover the near-dayside region, where the magnetosheath is very thin and the creation of a sufficient set of observations is more difficult. They noted that the subsolar magnetopause would be especially sensitive to the $B_z$ sign. Therefore it was necessary to continue such studies concentrating attention on the subsolar observations. However the 5 min interval of averaging is too large for the subsolar magnetosheath (the distance ~3 $R_E$ is crossed with the typical magnetosheath velocity 200 km/s for 90 s). That is why it is necessary to select shorter than 5 min periods of averaging. It is also necessary to mention that Šafránková et al. (2009) did not analyzed $B_y$ and $B_x$ components of the magnetic field but stressed the necessity of such study.

To assess the effect of magnetosheath turbulence on the changing of magnetic field parameters during the propagation through the magnetosheath to the magnetopause these parameters should be compared directly in front of the bow shock 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 (see Gutynska et al., 2012 and references therein). The opportunity of such a comparison has appeared only with the start of the five-satellite THEMIS mission (Angelopoulos, 2008; Sibeck and Angelopoulos, 2008).

It is necessary also to take into account that in accordance with Balogh et al. (2005) the level of fluctuations of the plasma parameters and magnetic field in the magnetosheath is strongly depends on the angle between the direction of the interplanetary magnetic field (IMF) and the normal to the bow shock $\Theta_{Bn}$ at the point where considered plasma volume entered the magnetosheath. The fluctuation level in accordance with Shevyrev and Zastenker (2005) is reduced in the transition from quasiparallel ($\Theta_{Bn}$ is close to zero) to the quasiperpendicular ($\Theta_{Bn}$ tends to 90 degrees) shock wave.

The analysis of the dependence of the magnetic field near the magnetopause on the magnetic field in the solar wind can be made only during summer time when one or two of THEMIS satellites performed measurements in the solar wind, while the others occasionally crossed the magnetopause on the dayside. Pulinets et al. (2012) analyzed a number of events when one of THEMIS satellites crossed the magnetopause and measured the magnetic field parameters before it and the other THEMIS satellite produce the magnetic field measurements before the bow shock and foreshock in the solar wind. However only 23 events were analyzed. The selection on the value of the angle $\Theta_{Bn}$ was not made. The time of the magnetosheath correlation length (~1 $R_E$ in accordance with (Gutynska et al., 2008, 2009)) crossing with the typical magnetosheath velocity (~200 km/s) constitute ~30 s. Maximal time of the averaging can not be larger than the subsolar magnetosheath thickness crossed with the velocity ~200 km/s. The distance ~3 $R_E$ is crossed with this velocity for ~90 s.

In this study, a comparison of the magnetic field parameters near the magnetopause measured every 3 s (spin resolution of the probe), 30 s and 90 s with the same parameters before the bow shock averaged for 90 s interval is made. Events with sharp changes of solar wind parameters of types analyzed by Riazantseva et al. (2005, 2007) are excluded from the analysis as such events are the special class of phenomena which requires more careful analysis. All events were marked according to the value of the angle $\Theta_{Bn}$. Average dependences of the magnetic field parameters

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