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Correlation level between solar wind and magnetosheath plasma and magnetic field parameters

L. Rakhmanova[a,*], M. Riazantseva[a,b], G. Zastenker[a]

[a] *Space Research Institute of Russian Academy of Sciences, 84/32 Profsoyuznaya Street, Moscow 117997, Russian Federation*
[b] *Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, 1(2) Leninskie Gory, Moscow 119991, Russian Federation*

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Abstract

We conduct a statistical study of the correlation coefficients between solar wind and magnetosheath parameters using plasma and magnetic field data from THEMIS satellites. Correlation coefficients for high temporal resolution data are less than 0.5 in 70–80% of cases and remain the same for 30–40% of cases for 100-s smoothed data. The solar wind and magnetosheath parameters correlate better for larger solar wind density and interplanetary magnetic field magnitude values and for larger relative standard deviations of their parameters. Correlation level is higher in cases of quasi-perpendicular bow shock versus quasiparallel one. We consider correlation changes while magnetosheath satellite approaches the magnetopause and do not find correlation dependence on the satellite position inside the magnetosheath.

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1. Introduction

The interaction between supersonic solar wind (SW) flow and the Earth's magnetosphere leads to the bow shock (BS) formation in front of the magnetopause (MP). The region between the BS and the MP is called magnetosheath (MSH). It is the magnetosheath plasma and magnetic field (MF) that interact with the magnetosphere, not the undisturbed SW.

Plasma decelerates and changes its direction inside the MSH, with temperature and density increasing. In general the MSH plasma flow was well described by the MHD model of Spreiter et al. (1966). Later models (e.g., Southwood and Kivelson, 1992, 1995; Zwan and Wolf, 1976) are more complicated, and able only to present average values of plasma and magnetic field parameters but not their variations. Safrankova et al. (2009) analyzed the probability of interplanetary magnetic field (IMF) B_z component to have the same sign in the SW and inside the MSH. The authors pointed out that for the $|B_z|$ value below 1 nT the probability is close to 0.5, that corresponds to a random coincidence. For larger $|B_z|$ values the probability increases but not always reaches the unity even for $|B_z|$ values exceeding 9 nT. Pulinets et al. (2014) presented a comparison of the IMF direction in front of the bow shock with the direction of the field in the magnetopause vicinity inside the MSH. They showed that the B_z component sign differs from the SW one in 30% of cases. Thus, parameters' fluctuations inside the MSH must be taken into account. Both B_z component value and SW dynamic pressure are usually (see Shue et al., 1997 and references therein) supposed to be the key parameters controlling the magnetopause form and dynamics. So the question how plasma and magnetic field change inside the MSH is the challenging one.

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[*] Corresponding author. Tel.: +7 4953331388.
E-mail address: rakhlud@gmail.com (L. Rakhmanova).

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The MSH is known to be highly turbulent region with parameters fluctuating in a wide frequency range. The nature and the origin of the MSH fluctuations are widely discussed in the literature. Various wave modes (e.g., Schwartz et al., 1996), foreshock fluctuations convected to the MSH (e.g., Blanco-Cano et al., 2006; Engebretson et al., 1991; Nemecek et al., 2002), oscillations of the MSH profile itself (Sibeck and Gosling, 1996) are the probable sources of the MSH fluctuations. To date only few models appear to be able to simulate those turbulent fluctuations (e.g., Karimabadi et al., 2014). The number of papers distinguishes the angle between IMF and the bow shock normal as the main factor that control fluctuation level of the MSH parameters (e.g., Shevyrev et al., 2003; Shevyrev and Zastenker, 2005). The authors showed the MSH parameters fluctuation level behind the quasi-parallel bow shock to be twice as large as it behind the quasi-perpendicular one. That result is well consistent with the results of modeling presented in Karimabadi et al. (2014).

Gutynska et al. (2008) showed that the correlation length of the MSH magnetic field fluctuations is equal to $\sim 1\,R_E$ for frequencies ranging from 0.001 to 0.125 Hz and does not depend significantly on the flow direction with respect to the field direction. Gutynska et al. (2009) confirmed the results of Gutynska et al. (2008) and added that the correlation length increases for larger values of SW velocity, interplanetary magnetic field strength and amplitudes of fluctuations. The number of studies dealt with the problem of SW plasma and magnetic field structures modification in the MSH. Case studies of interplanetary shocks propagation through the MSH are carefully discussed in the literature (e.g., Koval et al., 2006; Safrankova et al., 2007). Rakhmanova et al. (2012) showed that the amplitude and the duration of ion density and MF magnitude abrupt (by 20% of amplitude or larger during several seconds) changes of are usually increased in the MSH versus the SW.

Another method to explore the SW structures during transition through the Earth's bow shock and the MSH is correlation analysis. It provides larger statistics and information on typical behavior of the structures on various spatial and temporal scales in MSH. Gutynska et al. (2012) prepared multispacecraft complex study of the MSH fluctuations using distant (WIND) and close (Geotail) SW monitors and two pairs of the MSH satellites at both dawn (THEMIS-B/-C) and dusk (CLUSTER-2/-3) flanks. The authors revealed that the low-frequency (10^{-4}–10^{-3} Hz) MSH variations of magnetic field magnitude are of the SW origin, whereas the variations with higher frequencies (up to 0.1 Hz) originate locally inside the MSH. The authors suggested processes near the magnetopause to be a probable source of those variations. Rakhmanova et al. (2013, 2015) prepared the correlation analysis of simultaneous plasma and magnetic field measurements in the SW and MSH using several intervals (altogether 89 h of measurements) of the THEMIS-mission data. The study predominantly includes cases of the MSH measurements behind quasi-perpendicular bow shock, with the foreshock measurements avoided. The authors found out that the plasma and magnetic field low frequency (below 0.01 Hz) fluctuations, observed in the MSH, are mainly of the SW origin, whereas the variations with higher frequencies (up to 0.3 Hz) are created by the BS and MSH. The analysis preliminarily showed parameters that influence correlation level; higher correlation level is usually characterized by higher values of SW ion density, IMF magnitude and amplitude of the SW structures.

The most common models of the Sun–Earth interaction calculate magnetospheric parameters on the base of solar wind measurements. The studies mentioned above indicate magnetosheath as a turbulent region, with processes difficult to describe and simulate. Thus one needs a statistical description of the ways this turbulent region modifies the solar wind structures. Moreover one should find key parameters responsible for the level of structure modification in the MSH; doing this one can understand if it is possible to use solar wind data for a particular case. Present study provides a statistical investigation of the solar wind structures modification in the turbulent magnetosheath.

In comparison with Rakhmanova et al. (2013, 2015) present study deals with the notably extended statistics. Moreover we select all the measurements during appropriate spacecraft locations without avoiding the foreshock measurements. The number of intervals with the MSH behind the quasi-parallel bow shock is considerably enlarged. That allows us to see clear dependencies of the correlation level on every particular parameter. Following Gutynska et al. (2012) we consider the correlation value for different distances between the magnetopause and the point of measurements in the MSH that was not presented in our previous studies.

2. Data

For the study we used THEMIS mission (Angelopoulos, 2008; Sibeck and Angelopoulos, 2008) measurements during the period May–October 2008. Within that period spacecraft orbits configuration was suitable for finding intervals when one spacecraft was located in the MSH and another one was monitoring SW. We successively selected every interval with the duration exceeding 3 h for the further analysis. We used 3-s ion number density and MF magnitude measurements from ESA (McFadden et al., 2008) and FGM (Auster et al., 2008) devices respectively. During the period SW density did not exceed 12 cm^{-3}, velocity did not exceed 700 km/s and IMF magnitudes were within 16 nT. Therefore, we predominantly dealt with the quiet solar wind conditions.

Altogether we managed to obtain 300 h of measurements. Spacecraft positions for every interval used are shown in Fig. 1. The black lines present spacecraft scanning the SW and the grey present spacecraft crossing the MSH. The dotted curves show the mean position of the BS and MP. However these positions do not always represent the real observed boundaries position. Nearly

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