MAGNETOSHEATH TURBULENCE AND THE LOW LATITUDE BOUNDARY LAYER FORMATION

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Abstract. Results of the study of low latitude boundary layer (LLBL) properties are presented. Data, obtained on high apogee satellites, are used. Intervals of multi satellite observations are selected when one satellite was inside the magnetosheath and the other crossed magnetopause and measured plasma parameters in LLBL. Amplitudes of magnetic field fluctuations in the magnetosheath are compared with the values of magnetic field inside the magnetosphere. Such values are determined for case studies using observations inside the magnetosphere and results of model calculations. It is shown, that amplitudes of magnetosheath magnetic field fluctuations are comparable with the values of magnetic field inside the magnetosphere in the near cusp regions. The role of magnetosheath turbulence in LLBL formation is discussed. It is shown that it is difficult to select the dependence of LLBL thickness on the angle between the interplanetary magnetic field and the normal to the bow shock.

1. Introduction

The low latitude boundary layer (LLBL) is the region just earthward of the magnetopause where the magnetosheath-like and magnetosphere-like plasmas coexist. The solution of the problem of LLBL formation is connected with the study of mass, momentum and energy transfer between the magnetosheath and the magnetosphere. LLBL is formed due to process of interaction between the turbulent solar wind and the Earth’s magnetic field. The condition of stress balance on the magnetopause is not properly studied until now. Therefore, the problem of the magnetosheath plasma penetration through the magnetopause has no definite solution. Changes in the observed LLBL properties are commonly explained as a result of changes in the conditions of magnetosheath plasma penetration through the magnetopause when the interplanetary magnetic field (IMF) has different values and orientations. However, the processes inside the magnetosphere can also influence the LLBL properties observed (Antonova, 2005).

In this paper we examine the results of simultaneous THEMIS satellites observations of LLBL, solar wind and magnetosheath plasma for the event 8 November 2008 and try to show that fluctuations of magnetic field in the magnetosheath can be the important factor of magnetosheath plasma penetration inside the magnetosphere. We also analyze the dependence of LLBL thickness on the angle between the interplanetary magnetic field vector and the normal to the bow shock on the base of INTERBALL/Tail satellite observations.

2. Results of THEMIS observations

We use data obtained by the THEMIS multi satellite experiment. The plasma spectrograms for ions and electrons are computed on the basis of the Electrostatic Analyzers (ESA) measurements (http://cdaweb.gsfc.nasa.gov/). ESA measure the flux of thermal particles in a 360° field of view over the energy range from ~3 eV to 30 keV. The magnetic field data are obtained from the Flux Gate Magnetometer (FGM). Fig.1 shows the coordinates of THEMIS satellites A, B and C. The satellite A crossed the magnetosheath, LLBL and entered the magnetosphere at 00.06 UT on 8 November 2008. The satellite B was in the solar wind, the satellite C crossed the magnetosheath.

The electron ESA spectrograms from A (panel 1), B (panel 2) and C (panel 3)-satellites for the discussed period of time are presented on Fig.2.

Fig.3 presents the results of ESA observations on the THEMIS-A satellite. The upper panel shows the ion spectrogram. Next panel shows the electron spectrogram. The intensity of the colors on the spectrograms is color-coded according to the logarithm of the measured count rate per sample as shown by the color bar on the
right of the figures. Satellite THEMIS-A crossed the magnetosheath, LLBL and then plasma sheet from 01.00 till 03.00 UT on 28 November 2008. Satellite was in magnetosheath till 01.45 UT, from 01.10 till 01.37 UT and from 01.45 till 01.57 UT it crossed LLBL. The analysis of distribution functions shows the simultaneous presence of magnetosheath and plasma sheet particles from 01.15 till 01.27 UT and at 01.48-01.57 UT at $Z \approx 3 R_E$ which means low latitude boundary layer crossing. The satellite entered the magnetosphere, crossing the magnetopause several times during mentioned time intervals. The analysis of LLBL crossing gives the possibility to select particle jet structures.

![Final orbits: THEMIS-P5 (A) THEMIS-P1 (B) THEMIS-P2 (C)](image)

*Figure 1. A, B, C THEMIS satellite coordinates for the event 8 November 2008.*

Fig. 4 shows THEMIS-B measurements of the IMF $B_X$, $B_Y$ and $B_Z$ components in GSM coordinate system 8 November 2008. Solar wind magnetic field was oriented northward till 01.50 UT. Then IMF $B_Z$ changed its orientation to southward with the value $\sim -2$ nT.

Fig. 5 shows the results of THEMIS-C observations of magnetic field components $B_X$, $B_Y$, $B_Z$ in GSM coordinate system. It is possible to see typical for the magnetosheath magnetic field fluctuations.

We can see analyzing Fig. 4 that solar wind conditions are comparatively stable: fluctuations of magnetic field do not exceed 4 nT. Simultaneous variations of magnetosheath magnetic field are $\sim 20$ nT (see Fig.5).
3. Results of the analysis

Fig. 6 shows magnetic field line configuration in the plane $Y=0$ determined in accordance with Ts-96 model (Tsyganenko, 1995) for solar wind parameters corresponding to the results of THEMIS measurements ($B_Y=1$ nT, $B_Z=1$ nT, $n_{sw}=13$ cm$^{-3}$, $V_{sw}=305$ km/s). Magnetic field distribution along magnetic field line has minima positioned far from the equatorial plane. Values of magnetic field in minima constitute from 4.3 till 32.5 nT. Such values of magnetic field in the near cusp regions take place during modeling using different models of magnetic field in the magnetosphere and well corresponds to the data of observations.

It is possible to see comparing values of magnetic field in the magnetosheath in accordance with the results of conducted analysis and taking into account data of multiple magnetic field measurements inside the magnetosphere near cusp, that the amplitudes of magnetic field fluctuations in the magnetosheath can be larger than values of magnetic field in the near cusp regions and in LLBL on the magnetospheric flanks.
Magnetopause position as it is well known is determined by the condition of plasma and magnetic field pressure balance. Magnetic field in the magnetosheath and its fluctuations obviously is the important factor determining the conditions of plasma penetration inside the magnetosphere when the value of magnetic field under the magnetopause is comparable with the value of magnetic field in the magnetosheath.

**Figure 5.** Magnetosheath plasma parameters in accordance with THEMIS-C data

**Figure 6.** Magnetic field line configuration in the day-night plane in accordance with Tsyganenko-96 model under solar wind parameters $B_Y = 1 \text{ nT, } B_Z = 1 \text{ nT, } n_{sw} = 13 \text{ cm}^{-3}, V_{sw} = 305 \text{ km/s}$
4. Bow shock types and the $\Theta_{Bn}$ angle

To clarify the role of magnetic field fluctuations of the magnetosheath in LLBL formation we analyze the dependence of LLBL thickness on the angle between the interplanetary magnetic field vector and the normal to the bow shock $\Theta_{Bn}$ as the properties of magnetosheath magnetic field fluctuations is determined by this angle. $\Theta_{Bn}$ determines the conditions of solar wind particle motion through the bow shock and the magnetic field variations in the magnetosheath. The reflected from the bow shock front solar wind particles and the high energy magnetosphere and magnetosheath particles, leaked through the bow shock reel in the magnetic field lines and can flow far with the solar wind flow if the bow shock orientation is quasiparallel ($\Theta_{Bn} < 45^\circ$) (Fuselier, 1994). The reflected particles, rotating around the magnetic field lines, have no possibility to leave the front, the oscillations are generated on the bow shock surface or behind it if the bow shock orientation is quasiperpendicular ($\Theta_{Bn} > 45^\circ$) and the magnetic field is oriented nearly tangent to the bow shock.

![Figure 7. The dependence of time in LLBL crossing on the $\Theta_{Bn}$ angle.](image)

Variations of the ion flow and the magnetic field in magnetosheath decrease with the growth of the $\Theta_{Bn}$ angle at the nearby bow shock (see, for example, Shevyrev et al., 2005). The fluctuations of plasma and magnetic field parameters in magnetosheath behind the quasiparallel bow shock exceed the fluctuations behind the quasiperpendicular bow shock. We supposed that the pressure balance at the magnetopause should be more often disturbed behind the quasiparallel bow shock because of the high level of plasma parameters and magnetic field fluctuations. These conditions can lead to LLBL plasma jets formation. We have made an assumption that the LLBL thickness increases if the bow shock is quasiparallel ($\Theta_{Bn} < 45^\circ$).

We have estimated the $\Theta_{Bn}$ angle during several LLBL INTERBALL/Tail intersections (Yermolaev et al., 1997; Klimov et al., 1997; Sauvaud et al., 1997). The plasma flow lines was found for each case. The plasma flow lines distribution was evaluated using Spriter magnetosheath model. The found plasma flow line was prolonged to the bow shock where the position of the normal to the bow shock and the $\Theta_{Bn}$ angle were estimated, using the IMF orientation and the time of plasma flow from the bow shock to the satellite position. Mitchell et al. (1987) show that LLBL thickness can be estimated using the time of LLBL crossing by satellite. The time of LLBL crossing was estimated for a number of cases. Fig. 7 presents the dependence of time of LLBL crossing from the $\Theta_{Bn}$ angle. Pink colored points are the LLBL tail intersections and the black points – the dayside LLBL intersections. The dayside LLBL is usually thinner than LLBL in the tail region, what is possible to see analysing Fig. 7. We take into account the difference between the tail and dayside LLBL thickness. Analysis of Fig. 7 shows that no dependence of LLBL thickness on the $\Theta_{Bn}$ angle cannot be selected.
5. Discussion

The absence of the dependence of LLBL thickness on the $\Theta_{bn}$ angle can be explained with the separation of the processes responding to the plasma penetration and LLBL formation. The LLBL is formed due to the magnetosheath particle penetration inside the magnetosphere in the near cusp regions where the level of fluctuations of plasma parameters and magnetic field is high (Rossolenko et al., 2007). At the same time the thickness of the LLBL can be determined by the processes inside the magnetosphere such as particle flow in $Y_{GSM}$ direction (Antonova E.E., 2005) in the conditions of pressure balance. Such processes can dominate in LLBL thickness formation which explain the absence of finite dependence on Fig. 7. It is necessary to mention that the processes of plasma structure motion in the magnetosheath and the plasma penetration inside the LLBL are not well studied till now. We have to note that the number of analyzed cases is not big enough to make any final conclusions.

6. Conclusions

The conducted analysis of the results of simultaneous observations on satellites of THEMIS-project supports the results obtained earlier on the existence of high level of fluctuations of parameters of plasma and magnetic field in the magnetosheath under comparatively stable solar wind conditions. This finding requires the creation of a new models of LLBL formation. The amplitude of magnetic field fluctuations in the magnetosheath can exceed the value of the magnetic field under magnetopause in the near cusp region. That is why the existence of such fluctuations is necessary to take into account in the analysis of the processes of magnetopause formation and particle penetration through the magnetopause.

The investigation of the dependence of LLBL thickness on the $\Theta_{bn}$ angle on the base of INTERBAL/Tail data push to the assumption that the formation of the LLBL thickness doesn’t depend on the processes in magnetosheath in the near cusp region. The processes inside the magnetosphere can determine the formation of the thick LLBL.

References


