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The dependence of the LLBL thickness on IMF B_z and B_y components

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Abstract

The thickness of the low latitude boundary layer (LLBL) is studied as a function of interplanetary magnetic field (IMF) using the data of THEMIS mission. The data from intersections of LLBL by Themis-A and -C satellites are analyzed. Solar wind parameters are provided by Themis-B satellite located before the bow shock. We use earlier developed method of LLBL thickness determination based on the analysis of the variation of plasma velocity in the layer perpendicular to the magnetopause. The database for the present analysis consists of 109 single satellite LLBL crossings where the values of LLBL thickness are obtained. The time shift of solar wind propagation from the spacecraft performing measurements outside the bow shock to the LLBL is taken into account. We analyze the dependence of LLBL thickness on IMF B_z and B_y using data of IMF measurements with 3 s resolution and produce the 180 s averaging of these data. Large scattering of the values of LLBL thickness and the weak dependence on IMF is demonstrated. Dawn–dusk asymmetry of LLBL thickness is not observed. The dependence of LLBL thickness on IMF clock angle is discussed.

Keywords: Low latitude boundary layer (LLBL); Magnetosheath; Plasma mixing; Magnetopause

1. Introduction

The low latitude boundary layer (LLBL) is one of the least studied regions of the magnetosphere. The LLBL formation is a result of the magnetosheath plasma penetration inside the magnetosphere and its mixing with magnetospheric plasma population. The analysis of this process is important for understanding the problem of mass, energy and impulse transfer through the magnetopause. The LLBL structure and its formation still causes some questions despite the long time elapsed since Eastman et al. discovered the LLBL in 1976 (see the review Antonova et al. (2012), and references therein). The values of plasma density and velocity in LLBL are transitional between the values inside the magnetosphere and in the magnetosheath. The ion and electron spectra in the LLBL and adjacent magnetosheath are similar. It was shown on the base of Prognoz and Prognoz-2-6 spacecraft observations (Kotova, 1984). The plasma parameters in the LLBL are the external boundary conditions in the modeling of the inner magnetospheric plasma dynamic.

The structure of the LLBL has been studied in detail as a function of the interplanetary magnetic field (IMF) in Němeček et al. (2015). The authors distinguish two parts of the layer: the inner and the outer, using the temperature vs density diagrams for ions and electrons. The case and statistical analysis leads to the conclusion that the outer LLBL is rather poorly presented under southward IMF conditions. They have assumed that the most probable mechanism that controls the dayside LLBL formation is low-latitude reconnection for southward and cusp reconnection for northward IMF.

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The LLBL thickness is one of the characteristics, significant for understanding the LLBL role in the inner magnetospheric dynamics. It characterizes the size of the magnetosphere region where the plasma flow has predominantly antiearthward direction. Such flow is considered to be the source of the dayside field-aligned currents (see, for example, Sonnerup and Siebert, 2003; Troshichev et al., 2003). The theories of the formation of such currents include the LLBL thickness as one of the main parameter. The LLBL thickness dependence on the solar wind and IMF parameters may be essential for the problem of the magnetosheath plasma penetration inside the magnetosphere. The evaluation of the rate of turbulent plasma transport inside the magnetosphere is another important aspect of this problem (see Antonova, 2005, 2006; Wang et al., 2010).

A systematic study of the LLBL thickness requires analysis of the measurements at low latitudes. The first systematic results were obtained by Haerendel et al. (1978) using data of HEOS-2 satellite and Eastman and Hones (1979) using data of IMP-6 satellite. Haerendel et al. (1978) used the time of the satellite crossing of the layer, the magnetopause motions were not considered. The dependences of LLBL thickness on IMF and solar wind parameters were studied in this paper. It was marked that LLBL thickness has a weak anti-correlation with IMF B_z at the dayside magnetosphere. Eastman and Hones (1979) evaluated the nominal thickness of the LLBL by projecting the spacecraft trajectory in each boundary layer segment onto a local normal to the magnetopause surface based on the model developed by Howe and Binsack (1972). Eastman and Hones (1979) used the set of 90 IMP-6 LLBL crossings to evaluate the nominal boundary layer thickness and found no statistically significant correlation between its value and geomagnetic activity and IMF parameters.

Mitchell et al. (1987) calculated LLBL thickness analyzing LLBL crossings by ISEE-1 satellite at the tail and dayside magnetopause. The LLBL thickness (crossing time) dependence on the value and orientation of magnetic field was obtained. The results of this investigation were:

- LLBL thickness increases from dayside to tail;
- both thick and thin LLBL are observed under southward IMF conditions in the tail and only the thick one – when IMF is northward;
- on average, LLBL is thicker under northward IMF conditions.

The high level of turbulent fluctuations in the magnetosheath/LLBL and fast magnetopause motions lead to certain difficulties in LLBL thickness evaluation. Therefore the multisatellite determination of LLBL thickness is required to obtain the reliable results (see Šafránková et al. (2007), Tkachenko et al. (2010), Znatkova et al. (2013), and references therein). However, the statistically significant results are difficult to obtain even using the data provided by the modern multisatellite projects. Taking into account these difficulties we developed a method of LLBL thickness evaluation based on the analysis of the value of the perpendicular to the magnetopause plasma velocity (see Znatkova et al., 2013). The values of LLBL thickness obtained by this method were compared with the results of more accurate determination using the multisatellite observations. It was shown that the developed method provides the accuracy of LLBL thickness determination of about 10%.

This work is devoted to the LLBL thickness determination for the database, consisting of 109 intersections by THEMIS satellites, and to the analysis of the dependences of LLBL thickness on the IMF B_z, B_y and clock angle. The choice of these IMF parameters is connected with the results obtained by Pulinets et al. (2012, 2014). They show the existence of the comparatively good correlation of IMF B_y and B_y component of the magnetic field in the magnetosheath just before the magnetopause and the increase of the correlation coefficient with increasing period of averaging. No correlations were found for IMF B_x and comparatively week correlation for IMF B_z component. However, the correlation of geomagnetic activity and IMF B_z is well known. So IMF B_z can also be considered as a parameter determining LLBL thickness.

Part 2 of the paper contains the description of the used method of LLBL thickness determination. We describe used instrumentation and cases location in part 3. Part 4 contains the results of the analysis and part 5 conclusions and discussion.

2. Method of LLBL thickness determination

Znatkova et al. (2013) determined the LLBL thickness analyzing the component of the plasma velocity vector perpendicular to the magnetopause during time interval of the satellite being inside the LLBL. It was assumed, that the main contribution to the averaged plasma velocity measured on the satellite is made by the layer motion as a whole relative to the satellite (in accordance with the results presented in Hapgood and Bryant (1992), Vaisberg et al. (1998), Nikolaeva et al. (1998) and Dušik et al. (2007)), i.e. velocity variations inside the LLBL region are not taken into account. The plasma velocity component perpendicular to the magnetopause needs to be determined for the layer thickness calculation based on the single satellite measurements. The method of minimum variance based on the results of magnetic measurements is usually applied for the determination of the normal to the magnetopause in such cases. However, the high level of turbulent fluctuations of the magnetic field in the magnetosheath and in the LLBL region complicates the determination of the direction of the vector perpendicular to the magnetopause based on the results of magnetic measurements. Such determination is possible only for rather quiet LLBL crossings (see the discussion in Rossolenko et al. (2006, 2008a,b)). Therefore, the use of one of the developed models of the