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ScienceDirect
Planetary and Space Science 55 (2007) 2286–2294
Planetary and Space Science
www.elsevier.com/locate/pss

Interball contribution to the high-altitude cusp observations

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Accepted 9 May 2007
Available online 10 August 2007

Abstract

The polar cusps have traditionally been described as narrow funnel-shaped regions of magnetospheric magnetic field lines directly connected to magnetosheath, allowing the magnetosheath plasma to precipitate into the ionosphere. However, recent observations and theoretical considerations revealed that the formation of the cusp cannot be treated separately from the processes along the whole dayside magnetopause and that the plasma in regions like cleft or low-latitude boundary layer is of the same origin. Our review of statistical results as well as numerous case studies identified the anti-parallel merging at the magnetopause as the principal source of the magnetosheath plasma in all altitudes. Since effective merging requires a low plasma speed at the reconnection spot, we have found that the magnetopause shape and especially its indentation at the outer cusp is a very important part of the whole process. The plasma is slowed down in this indentation and arising multiscale turbulent processes enhance the reconnection rate.

PACS: 94.30.Va; 94.30.Di

Keywords: Cusp; Plasma mantle; Magnetopause; Magnetosheath; Magnetic reconnection; Low-latitude boundary layer

1. Introduction

Although the low- and mid-altitude cusp precipitations were intensively investigated in course of last three decades, our knowledge on a structure of the cusp region in high altitudes is still under discussion. The Interball-1/Magion-4 satellite pair, called Interball-Tail project, was launched onto a highly elliptical orbit with 63° inclination, with apogee at 200 000 km or 31 R_E and perigee at 750 km. During 2 years, both satellites performed two-point measurements in the high-altitude cusp reaching altitudes above those of the apogee of Polar (9 R_E). Two closely separated satellites could remain in the cusp region for periods of more than 2 h and scanned the vertical profile of the cusp from altitude $\sim 3R_E$ up to the magnetosheath. Their simultaneous measurements are suitable for a study of the topology and dynamics of the high-altitude cusp and surrounding magnetosheath regions under various IMF orientations and solar wind conditions. The illustration in Fig. 1 presents projections of a part of the Magion-4 satellite trajectory onto GSM (geocentric solar magnetic) planes complemented with magnetic lines computed according to the Tsyganenko and Stern (1996) model and demonstrates the trajectory advantage. The abscissas show the 5-min averages of running magnetic field vectors as measured by Magion-4. One can note a good agreement of model and measured magnetic field directions in low latitudes. On the other hand, the model should be taken with care in high altitudes where the difference between measured and model magnetic field directions is notable. The cusp-like plasma was observed continuously nearly along the depicted orbit as can be seen from Fig. 2, and thus we can point out that the high-altitude cusp is far away from the general understanding of cusp as a narrow funnel-shaped region.

The ion energy spectrograms recorded by three channels of the MPS/SPS device (Magion-4) are shown in three bottom panels of Fig. 2. The ion fluxes derived from Faraday cups onboard Interball-1 and Magion-4 are given

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doi:10.1016/j.pss.2007.05.021

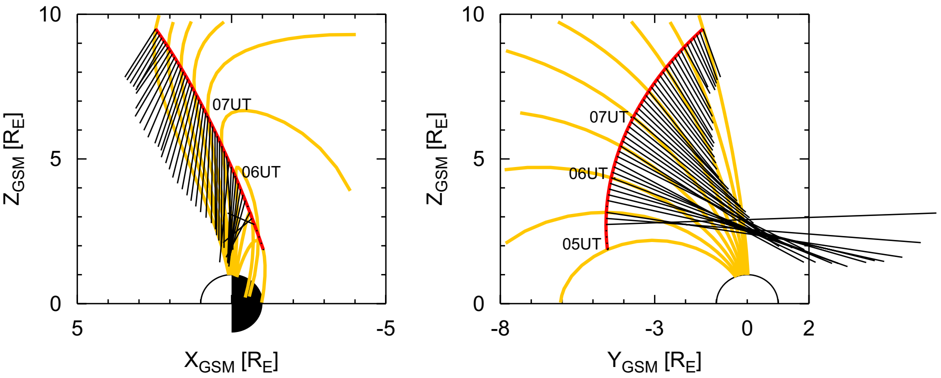

Fig. 1. Projections of the Magion-4 orbit onto the X–Z (left part) and Y–Z (right part) planes according to the Tsyganenko and Stern (1996) model. The abscissas show the magnetic field vector as measured by Magion-4 each 5 min. Adapted from Němeček et al. (2004).

in two top panels for reference. Ion flux profiles measured by two spacecrafts moving along the same orbit (Interball-1 advanced Magion-4 by 70 min) exhibit some simultaneous changes as increase in the ion flux at ~0747 or 0815 UT which can be attributed to the changes of the magnetosheath density above the cusp. However, these changes are small and do not mask the similarity of overall profiles. This similarity suggests that Magion-4 crossed a steady region and we can believe that the observed changes are of a spatial nature. The determination of the magnetopause crossing is very difficult but the most probable candidate is the change of the magnetic field (third and fourth panels in Fig. 2) accompanied with an increase of the ion flux at ~0827 UT. Moreover, these changes correlate with changes in ion energy spectra shown in the last three panels. The spectra were recorded by the analyzers with different view angles. The I0 channel registers tailward streaming ions, whereas I180 channel (bottom panel) measures ions proceeding toward the Sun. These two analyzers are oriented roughly along the satellite spin axis and thus their data do not exhibit any distinct spin modulation. On the other hand, the I90 analyzer is oriented nearly perpendicularly to the spin axis and scans a broad range of pitch angles during one satellite revolution. The classifications of visited regions is given below the figure for the sake of reference only because we will discuss their definition in the next section.

The analysis of the set of cusp observations during the years 1995–1997 presented in many related papers has shown that the cusp is well defined and persistent at altitudes of $4-13\ R_E$ (Sandahl et al., 1997, 2000; Sandahl, 2002). Nevertheless, the region above $8-10\ R_E$ is a highly turbulent (Savin et al., 1998, 2001, 2002; Měrka et al., 2000, 2002) and the cusp plasma is mixed with the magnetosheath population (Savin et al., 2004) at these altitudes. Thus, the dimensions of the cusp region are variable and controlled mainly by the interplanetary (magnetosheath) magnetic field orientation. In this overview of Interball project observations, the survey of some results regarding the high-altitude cusp region is presented. Our attention was predominantly concentrated on following topics: (1) definition of the high-altitude cusp and related regions, (2) average location of the cusp, (3) influence of the tilt angle of the Earth's dipole, and (4) the magnetopause in the cusp region. The limited extend of the paper cannot touch all peculiarities of the cusp formation and thus it is concentrated on the cusp geometry. The cusp in a broader sense and influence of the cusp processes on the morphology of the whole magnetosphere and its formation are treated in Němeček and Šafránková (2007).

2. Cusp definition

The traditional image of the cusp is a narrow region where magnetosheath plasma can directly enter into the magnetosphere and the dayside ionosphere (Haerendel et al., 1978; Smith and Lockwood, 1996). The particle composition and charge are the same as those found in the solar wind. Over a decade after initial cusp observation, the precise definition of this region was developed from observations of low-altitude ion and electron precipitations (Newell and Meng, 1988). These investigations have been extensively provided by the Defense Meteorological Satellite Program (DMSP) and using ~12,000 crossings, Newell and Meng (1988) developed a simple and practical definition of the cusp and cleft/low-latitude boundary layer (LLBL) regions. If $E_e < 200\,\mathrm{eV}$, $E_i < 2700\,\mathrm{eV}$, $j_i > 10^{10}\,\mathrm{eV/cm^2.s.sr}$, and $j_e > 6 \times 10^{10}\,\mathrm{eV/cm^2.s.sr}$, the region is called the cusp (E_i and E_e are the average ion and electron energies, j_i and j_e are the energy fluxes of ions and electrons, respectively). If either $3000\,\mathrm{eV} < E_i < 6000\,\mathrm{eV}$ or $220\,\mathrm{eV} < E_e < 600\,\mathrm{eV}$, the region was identified as cleft/LLBL. The cusp (or cusp proper) and the cleft/LLBL were distinguished later from the mantle (Newell et al., 1991a, b). The identification of the mantle at low altitudes is based on the following criteria (Newell et al., 1991a): (1) location—immediately poleward of the dayside oval; and (2) the associated soft spectra of the ions which have densities from a few times 10^{-2} to a few times $10^{-1}\,\mathrm{cm^{-3}}$, and a temperature range from a few tens of eV to about 200 eV.