Planetary and Space Science 115 (2015) 19–26

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

Transient events at the magnetopause and bipolar magnetic signatures

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ARTICLE INFO

Article history:
Received 21 July 2014
Received in revised form
3 February 2015
Accepted 11 February 2015
Available online 21 February 2015

PACS:
94.30.cj
94.30.ch
94.30.cp
96.50.Ci

Keywords:
Flux transfer events
Magnetopause deformation
Magnetosheath
Fluctuations
Magnetic reconnection
Foreshock bubbles

ABSTRACT

Bipolar signatures in the magnetic field component perpendicular to a nominal magnetopause surface accompanied with an increase of the magnetic field strength are regularly attributed to flux transfer events (FTEs) crossing the spacecraft. The detailed analysis of one such event shows that the magnetic signatures are consistent with the FTE but the timing of multipoint observations and the interpretation of changes of plasma parameters in terms of FTEs requires additional assumptions. We argue that although the event exhibits clear FTE signatures, an explanation of the observations as a local magnetopause surface deformation associated with a change of the magnetosheath density better fits to the data. The deformation caused by this density depression at the magnetopause is associated with a rotation of the magnetosheath magnetic field.

1. Introduction

Plasma structures at the magnetopause are often interpreted as signatures of flux transfer events (FTEs) (Russell and Elphic, 1978; Haerendel et al., 1978; Russell and Elphic, 1979). They are characterized by a bipolar oscillation of the magnetic field boundary normal component, B_N, mixtures of magnetosheath and magnetospheric plasmas, and either enhancements or crater-like variations of the magnetic field strength at the event center. Statistical surveys showed that FTEs are observed predominantly when the magnetosheath or interplanetary magnetic field (IMF) points southward (e.g., Berchem and Russell, 1984; Rijnbeek et al., 1984; Southwood et al., 1986; Kuo et al., 1995), strongly suggesting an association with time-dependent magnetic reconnection that was proposed as the fundamental process to the coupling of mass and energy between the solar wind and magnetosphere (Dungey, 1961).

The structure and properties of FTEs have been a subject of many studies in the last years, however, a significant progress started with new spacecraft missions as Cluster and THEMIS. For example, Cluster contributed: (1) to discussion of differences in the signatures between closely separated (≈ 600 km) spacecraft that indicated the substructure of the FTE on this scale (Owen et al., 2001); (2) to a better understanding of the FTE formation and to determine the cross-sectional profiles (Sonnerup et al., 2004; Fuselier et al., 2005), and (3) to studies of the diffusion region of magnetic reconnection at the magnetopause (Vaivads et al., 2004; Retino et al., 2006).

Owen et al. (2008) concentrated on the temporal nature of crater-like FTEs at the dayside high-latitude magnetopause. The authors have reported Cluster observations of signatures that have previously been the source of debate as to whether they are caused by pressure-induced waves on the magnetopause (e.g., Sibeck, 1990) or whether they are the results of encounters with various reconnection boundary layers (Smith and Owen, 1992). They argued that their observations are consistent with reconnected flux tubes created by a transient and localized patch of reconnection nearer to the subsolar point that moves northward and duskward. The FTE signatures arise from this transient inward motion of reconnection-associated boundary layers over the spacecraft.

On the other hand, Sibeck (1992) analyzed a train of transients observed by the IRM spacecraft at the dayside magnetopause and they have found that, in spite of bipolar magnetic signatures, the transients are correlated with the variations of the upstream pressure and should be interpreted as a small-scale magnetopause deformation.

Multipoint measurements by THEMIS allowed the identification of FTEs, investigations of their properties, and their comparison

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http://dx.doi.org/10.1016/j.pss.2015.02.008
0032-0633/

with simulations as it was shown in first papers from this mission (Angelopoulos et al., 2008; Sibeck et al., 2008; Liu et al., 2008; Lui et al., 2008; Zhang et al., 2008). However, their generation mechanism is not fully clear yet (e.g., Fear et al., 2009; Hasegawa et al., 2010).

To contribute to this investigation, we analyze one FTE-like event observed by THEMIS during the magnetopause crossing on August 26, 2007. We would like to point out that this multiple magnetopause crossing already attracted the attention of many investigators because the location and separation of the spacecraft and quiet upstream conditions were favorable for a study of the magnetopause structure. Tkachenko et al. (2011) analyzed a series of magnetopause transients and argued that a part of these transients is correlated with, and probably caused by the changes of the magnetosheath magnetic field direction. Zhang et al. (2012) studied a last part of the observed series of magnetopause crossings and they have shown that this particular crossing clearly reveals a structure of the magnetopause consisting of a relatively thick LLBL, magnetopause current sheet, and magnetosheath reconnection layer. We should point out that this crossing occurred under northward and westward IMF and that the same magnetic field orientation was monitored in the magnetosheath.

In this paper, we have chosen one event from a train of transients observed in course of the mentioned long series of magnetopause crossings. The changes of the magnetic field along the normal to nominal magnetopause surface suggest an FTE origin of the analyzed event as it was denoted by Zhang et al. (2012) (but with the deep analysis of a particular event). For this reason, we start the interpretation of the data in terms of FTEs. However, we show that plasma measurements do not fully agree with such explanation, thus we search for another possible mechanism.

2. Event overview

We analyze observations of the THEMIS spacecraft (Auster et al., 2008; McFadden et al., 2008; Angelopoulos, 2008) at the low-latitude dayside magnetopause on August 26, 2007 around 0750 UT. The spacecraft moved outward in a string-of-pearl configuration led by THB (9.9; -7.4; -3.7) R_E that was followed by shortly separated THC (9.5; -7.4; -3.6), THD (9.4; -7.5; -3.6) R_E, and THE (9.4; -7.3; -3.6) R_E (in GSE coordinates). The trailing spacecraft, THA (7.9; -7.5; -3.2) R_E, was in the magnetosphere during the event and it did not observe any change. Consequently, we will only examine THB–THE data but the information that the changes occurred in a layer less than 2 R_E thick is important for an interpretation of observations of all spacecraft.

THEMIS measurements within the magnetopause boundary layers were supported by two upstream monitors, ACE and Wind, as it can be seen in the top panel of Fig. 1. Wind was too far from the Sun–Earth's line, thus we use ACE observations as a proxy of solar wind conditions. The ACE data were lagged on a propagation time calculated as a two-step approximation. In the first step, we expected the solar wind speed to be 400 km/s and estimated the delay. The speed measured at the corresponding time was used for the lag calculation in the second step. This procedure provides the time lag of ≈ 3980 s for the analyzed event. Note that coordinates of the spacecraft in the top panel are in the GSE system, whereas two bottom panels show the precise locations of THEMIS in GSM coordinates, more appropriate for the magnetopause study.

The event was observed on the outbound part of the THEMIS orbit (the green dot on the THEMIS orbit in the top panel) near the geomagnetic equator. Both bottom panels show the situation at

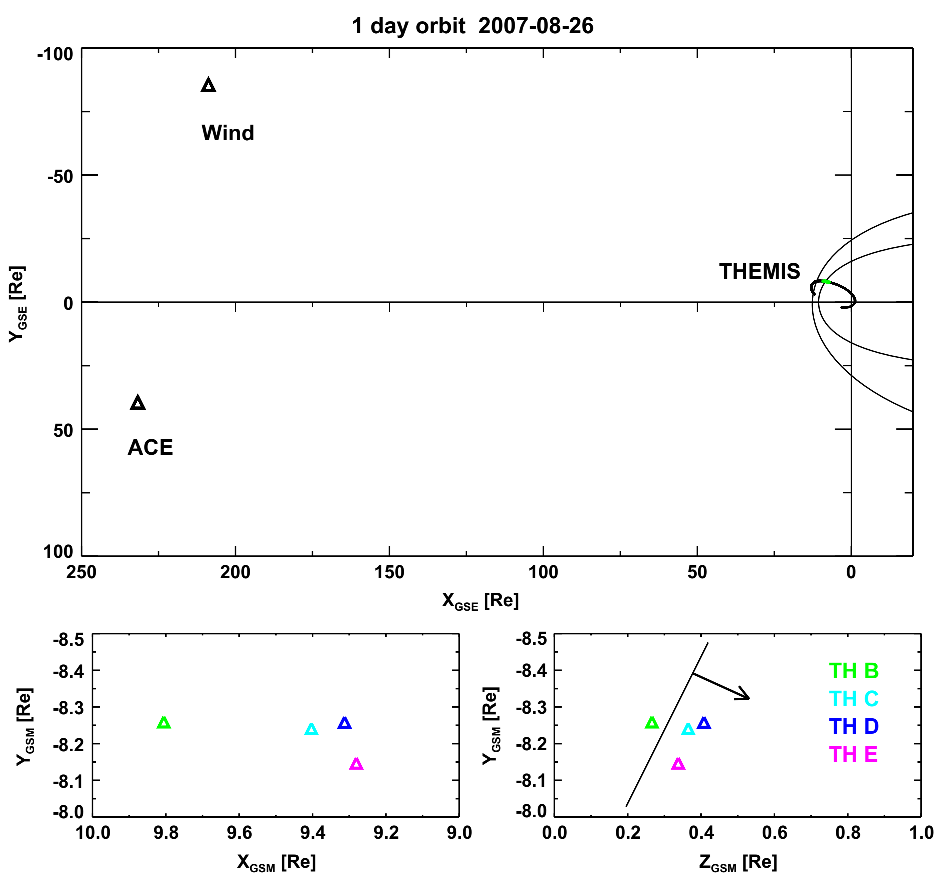

Fig. 1. Projections of ACE, Wind, and THEMIS orbits onto the equatorial plane with nominal locations of the bow shock (Jeřáb et al., 2005) and the magnetopause (Shue et al., 1998) – top part; a detailed projection of four THEMIS spacecraft onto the XY_{GSM} and YZ_{GSM} planes-bottom part. The heavy arrow indicates an estimated direction of the structure motion. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)