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On the large-scale structure of the tail current as measured by THEMIS

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Abstract

The magnetic field structure and the spatial characteristics of the large-scale currents in the magnetospheric tail were studied during quiet and moderately disturbed geomagnetic conditions in 2009. The magnetic field of the currents other than the tail current was calculated in terms of a paraboloid model of the Earth's magnetosphere, A2000, and was subtracted from measurements. It was found on the base of obtained tail current magnetic field radial distribution that the inner edge of the tail current sheet is located in the night side magnetosphere, at distances of about 10 R_E and of about 7 R_E during quiet and disturbed periods respectively. During the disturbance of February 14, 2009 ($Dst_{\min} \sim -35$ nT), the B_x and the B_z component of the tail current magnetic field near its inner edge were about 60 nT, and -60 nT that means that strong cross-tail current have been developed. The tail current parameters at different time moments during February 14, 2009 have been estimated. Solar wind conditions during this event were consistent with those during moderate magnetic storms with minimum *Dst* of about -100 nT. However, the magnetospheric current systems (magnetopause and cross-tail currents) were located at larger geocentric distances than typical during the 2009 extremely quiet epoch and did not provide the expected *Dst* magnitude. Very small disturbance on the Earth's surface was detected consistent with an "inflated" magnetosphere.

Keywords: Magnetospheric current systems; Geomagnetic tail; Magnetic storm

1. Introduction

The magnetospheric tail is developed due to interaction between solar wind plasma and geomagnetic field. As result, dipole-like magnetic field structure observed in the near-Earth's space is changed to tail-like structure in the night side magnetosphere. Electric currents flowing across the tail and closure currents through the magnetopause form the "comet-like" structure of the magnetosphere with magnetic field in the night side directed along the tail, to and from the Earth in the northern and southern lobes, respectively (Ness, 1965). Electric currents across the geomagnetic tail are controlled by the solar wind and cause geomagnetic variations, measured in the inner magnetosphere (radial distances < 8 R_E). In response to solar wind variations the tail current (like all other magnetospheric current systems) changes its shape, dimensions and intensity (Kaufmann, 1987; Lui and Hamilton, 1992; Sergeev et al., 1993; Pulkkinen et al., 1993; Runov et al., 2003; Ganushkina et al., 2010).

Previous studies have provided information on the average geotail magnetic field strength (Fairfield, 1980; Fairfield and Jones, 1996) and its variations due to interplanetary magnetic field (IMF) and solar wind pressure changes (Tsyganenko and Fairfield, 2004; Tanskanen et al., 2005; Zhou et al., 2013). The magnetotail current sheet shape, location, spatial properties such as position of the region between dipole-like and tail-like magnetic field structures and their dynamical behavior have also been studied as function on geomagnetic dipole tilt angle, IMF and solar wind pressure. These studies were

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statistical, based on magnetic field data measured by individual (typically single) spacecraft located in different regions of space.

The main problem, however, in magnetospheric studies is spatial–temporal uncertainty arising from single point observations in space. Ambiguity in the interpretation of the magnetic field variations can be caused not only by external factors like solar wind changes or inner-magnetosphere dynamics but also by spacecraft motion. Multi-satellite measurements obtained from missions like cluster or THEMIS can help resolve this problem.

This paper addresses this deficiency for the geomagnetic tail using coordinated THEMIS (Time History of Events and Macroscale Interactions during Substorms) satellite measurements, which provide the opportunity for detailed studies of the large scale structure of geomagnetic tail (Angelopoulos, 2008) with identically-instrumented spacecraft on resonant orbits, such that at least 4 out of 5 spacecraft were aligned once every 4 days in the winters of 2008 and 2009. Simultaneous measurements in different areas of the magnetotail allow direct investigations of spatial profiles without the immediate need for large ensemble averaging under similar external conditions.

The magnetic field in the magnetosphere results from currents flowing in the Earth's core (the internal current system) and joint action of large-scale magnetospheric current systems (the external current systems). The latter are under continuous external driving and are responsible for magnetospheric dynamics during quiet and disturbed conditions (Alexeev et al., 1996). Each current system develops independently at different time scales and their joint asynchronous development produces the complicated dynamics of total magnetic field. The structure and extent of the tail current cannot be established precisely in a routine fashion because typically we cannot separate its effects from those of the ring current or the magnetopause currents on the locally measured magnetic field. To better understand the magnetic field variations we need proper identification of the different current systems, their location and intensity.

In this study we will use 2009 tail THEMIS measurements to explain better the tail current dynamics during quiet and disturbed periods. Below, we first discuss the method of tail current magnetic field reconstruction from measurement data and modeling. Magnetospheric models (Alexeev et al., 1996; Tsyganenko, 2002; Ganushkina et al., 2004; Kubyshkina et al., 2009) can be used to study the magnetospheric magnetic field structure. We use the A2000 paraboloid model (Alexeev et al., 1996; Alexeev et al., 2001) to isolate the tail current contribution from that of the other large-scale magnetospheric current systems under various external conditions. After subtracting from the measurements the internal current magnetic field as well as A2000 model estimates of the magnetic field of the other external currents we then study the tail current system spatial structure, properties and evolution. We perform this study during quiet-time conditions on 4 April 2009 and during disturbed conditions on 14 February 2009. We also analyze the specific aspects of the geomagnetic disturbances during the prolonged minimum of solar activity in 2009.

2. Approach

During 2009 the five identical THEMIS spacecraft on resonant orbits, P1 through P5, aligned near apogee with each other and with the magnetotail axis approximately once every four days. Their configuration allows us to study the processes taking place at Earth's magnetotail during quiet and moderately disturbed periods. Based on satellite measurements (see mission description in Angelopoulos (2008)) we will try to determine the location of the inner edge of the magnetotail current, the tail current maximum intensity, radial distribution and dynamics. The magnetospheric magnetic field is the result of several external current systems, and the tail current effect is "masked" by the other magnetic field sources that cannot be split by measurements alone but require modeling. Typical magnetic field measurements along THEMIS P5 orbit during 14.02.2009 are presented in Fig. 1. B_x and B_z components in GSM-coordinates are shown. At apogee the field is determined by Earth's internal sources, but the tail current reveals itself near the apogee, near 10:00 UT in this figure, where significant variations in all three components take place. Ring current and Chapman-Ferraro magnetopause current effects also exist, in addition to tail current effects, in the magnetic field variations measured by satellite.

To estimate the contribution to the magnetic field from the tail current we subtract the effect of the other sources. Because we cannot estimate these other sources directly from observations, we use magnetic field models. IGRF10 is used for the contribution from internal currents. This is an expansion by spherical functions with coefficients approved by IAGA and valid till 2010–2015 epoch. The magnetic field of the large-scale magnetospheric currents can be calculated by modern dynamical models like T01 (Tsyganenko, 2002) or A2000 (Alexeev et al., 2001), or by event-oriented models like (Ganushkina et al., 2004). Taking solar wind data as input one can estimate variations of the magnetic field from the large scale current systems in response to external driving.

A paraboloid model of Earth's magnetosphere, A2000 (Alexeev et al., 1996, 2001, 2003), determines the magnetospheric magnetic field from each large scale current system as an analytical solution of the Laplace equation inside the fixed shape magnetopause (paraboloid of revolution). The magnetic field component normal to magnetopause is assumed to be zero. The model represents the magnetic field inside the magnetosphere as a superposition of the magnetic fields from the ring current, B_r, the tail current including the closure currents on the magnetopause, B_t, the Region 1 field-aligned currents, B_{fac}, the magnetopause currents screening the dipole field, B_{sd}, and the magnetopause currents screening the ring current magnetic field, B_{sr}: