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Subsolar magnetopause and cusp positions: comparison of MHD and empirical models

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Abstract

We simulate temporal variations of the subsolar magnetopause and cusp positions using global magnetohydrodynamic (MHD) models and compare predictions with the corresponding empirical models. In the second part, we calculate X-ray images from the MHD simulations. Results of this work can be used in preparation to the forthcoming SMILE mission.

1. Introduction

Global MHD models have been successfully used in different areas of space and planetary physics, including propagation of transient solar wind structures in the inner heliosphere [1], interaction of the solar wind with the interstellar medium, interaction of the solar wind with the Earth's magnetosphere [2] as well as with other planetary magnetospheres and even moons [3]. The latter paper illustrates that MHD models can be coupled with kinetic models in the regions where kinetic physics is essential for large scale dynamics.

MHD simulations help in studying the magnetospheric response to solar wind variations. Results of MHD models have been often compared with in-situ measurements [e.g., 4] or alternatively with empirical statistical models [5,6]. In particular, empirical magnetopause models [7,8] based on large databases of magnetopause crossings specify magnetopause shape with analytical functions and deduce relations between solar wind parameters (in [8] also taking into account the dipole tilt) and parameters that characterize the magnetopause shape. In general, global MHD models are in reasonably good agreement with empirical magnetopause models, except that some empirical models predict much stronger variations of magnetopause positions with solar wind parameters and dipole tilt than others [6].

Three stationary solutions were simulated in [6] to compare predictions of the magnetopause positions at subsolar point and in terminator plane. We extend this approach here by simulating an 8-hours solar wind interval on 2 November 2009 and comparing predictions of empirical and MHD models. Moreover, we have studied temporal variations of cusp latitudes in dependence on solar wind conditions.

2. Magnetopause and cusp positions

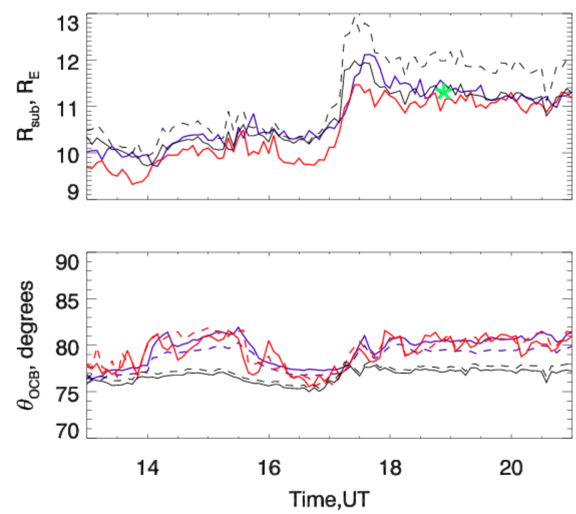

Figure 1: Top: variations of the subsolar magnetopause with time. Blue and red lines correspond to BATSRUS [2] and LFM [9] MHD models respectively, black solid line – Shue et al.'s model [7], black dashed line – Lin et al.'s model [8], green star indicates a THEMIS magnetopause crossing. Bottom: variations of the open-closed boundary (OCB) latitudes with time. Blue and red lines – results of BATSRUS [2] and LFM [9] models, black lines – OCB latitude in empirical models (subsolar point obtained by Shue et al.'s model was traced along field lines by Tsyganenko (T01) magnetospheric model. Solid and dashed lines correspond to the north and south cusps.

Fig. 1 compares the results of MHD simulations with predictions of empirical models. We note a good agreement in predictions of the subsolar magnetopause distance between both MHD models and the empirical Shue et al.'s model, while the Lin et al.'s model predicts a slightly larger magnetopause distance. The predictions of MHD and Shue et al.'s models well agree with the THEMIS magnetopause crossing indicated by the green star. Both MHD models yield quantitatively and qualitatively similar variations in the OCB latitude which corresponds to the south edge of the cusp.

3. X-ray images in MHD simulation

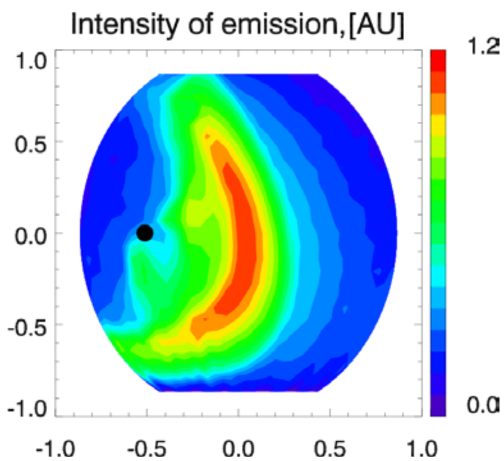

Figure 2. Simulated intensity of X-ray emission at the supposed apogee of SMILE at (6.8, 7.7, 17.1) R_E in GSM coordinates. The center of the image is at the subsolar magnetopause ~10.0 R_E.

Global MHD models predict the spatial distribution of the fluid density and velocity, as well as the position of the magnetopause in any particular time. The intensity of X-ray emission integrated along the line of sight can be calculated as shown below [10]:

$I \approx \int N_{SW} N_H V_{rel} dl$, where N_{SW} – the solar wind ion density, N_H – the exospheric neutral density [11], and V_{rel} – the relative velocity between two species which depends on the solar wind bulk velocity and thermal speed. An example of such calculation is shown in Fig. 2.

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