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Magnetospheric Response to the Mother's Day Weekend Geomagnetic Storm Observations from Geostationary Satellites

Sheng Li 李晟, Gilbert Pi, Zdeněk Němeček, and Jana Šafránková
Faculty of Mathematics and Physics, Charles University
sheng.li@matfyz.cuni.cz

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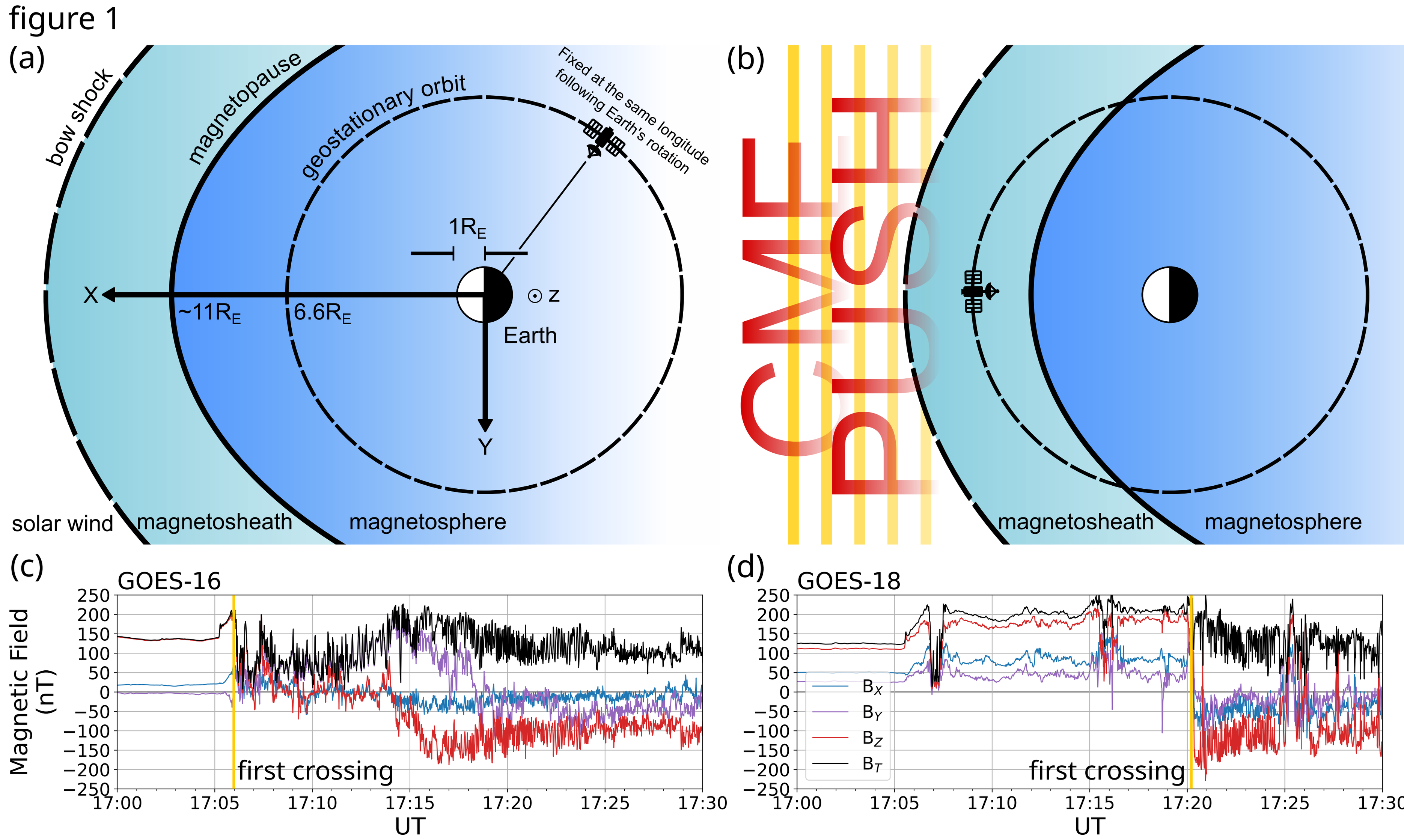
Introduction

On 10–11 May 2024, a geomagnetic storm, triggered by at least two interplanetary coronal mass ejections (ICMEs), marked one of the most intense events in recent decades. These ICMEs merged, driving a shock to hit the Earth's magnetosphere on 10 May at 17:05 UT. The shock compressed the magnetopause to below 6.6 R_E, smaller than the geostationary orbit radius. The GOES-16 satellite, located near the Sun-Earth line (11:50 MLT), observed a sustained southward interplanetary magnetic field, indicating that GOES-16 exited the Earth's magnetic field and entered the magnetosheath. Approximately 15 minutes later (17:20 UT), the GOES-18 satellite, positioned on the dawnside (08:10 MLT), also detected a sustained southward interplanetary magnetic field. Both GOES satellites were thus situated in the magnetosheath. This event provides a valuable opportunity to study the magnetospheric response under extreme solar wind conditions and to evaluate the performance of various empirical magnetopause models in simulating magnetopause crossings at geostationary orbit.

figure 1

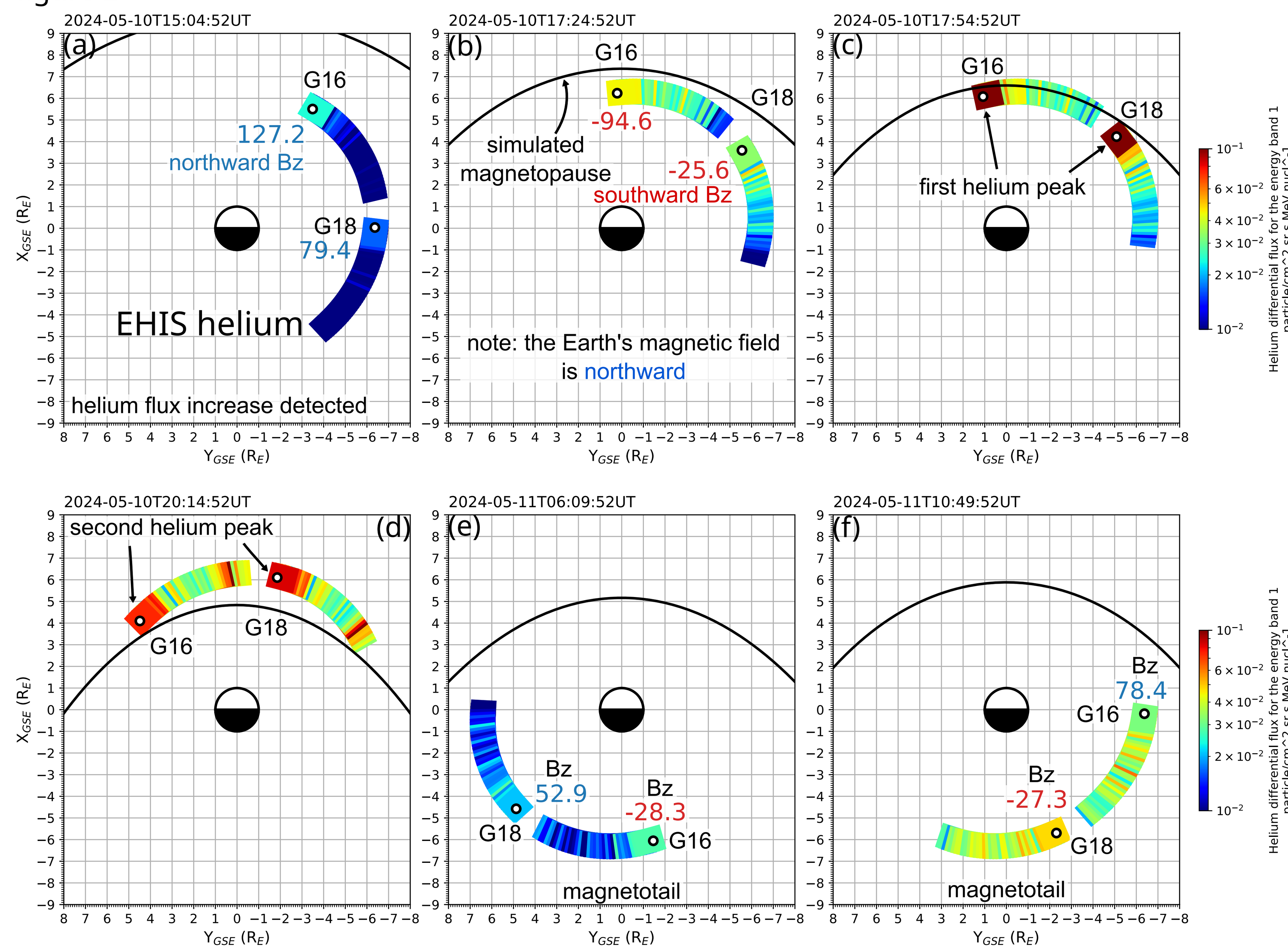


Data and Method

This study uses magnetometer and EHIS (Energetic Heavy Ion Sensor) data from GOES-16/18, and magnetometer data from FengYun-4B (风云-4B), all in geostationary orbit at 75.2°W, 137°W, and 105°E, respectively. THEMIS-A/D/E data (magnetometer and ESA) were used to identify magnetopause crossings during 10–11 May. GOES data are available at NOAA, FengYun-4B data at NSMC (National Satellite Meteorological Center), and THEMIS data from OMNIWeb. MHD simulations were performed using the SWMF and compared with nightside GOES observations; simulation data are from CCMC. Magnetopause crossings were also modeled using four empirical models: Petrinec & Russell (1996), Shue et al. (1998), Lin et al. (2010), and Li et al. (2023).

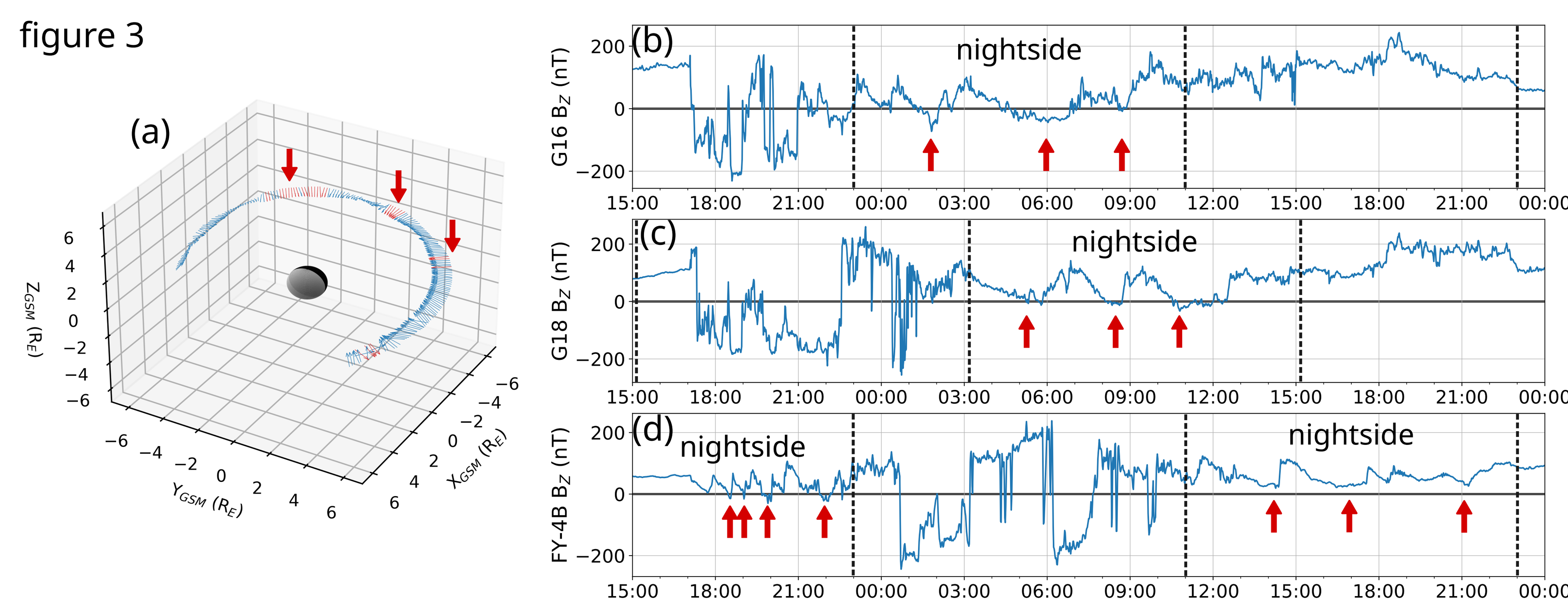
Results

figure 2



(a) Approximately 2 hours before the shock arrival, the EHIS instruments on both GOES satellites detected enhanced helium flux. (b) At 17:24 UT, both GOES satellites measured a southward magnetic field, indicating they were in the magnetosheath. The Shue et al. (1998) model overestimated the radial distance of the magnetopause. (c) and (d) Both GOES satellites observed two peaks of helium flux. The two peaks might suggest the structure of the ICME. (e) and (f) The two GOES satellites, located on the nightside, detected southward magnetic fields.

figure 3

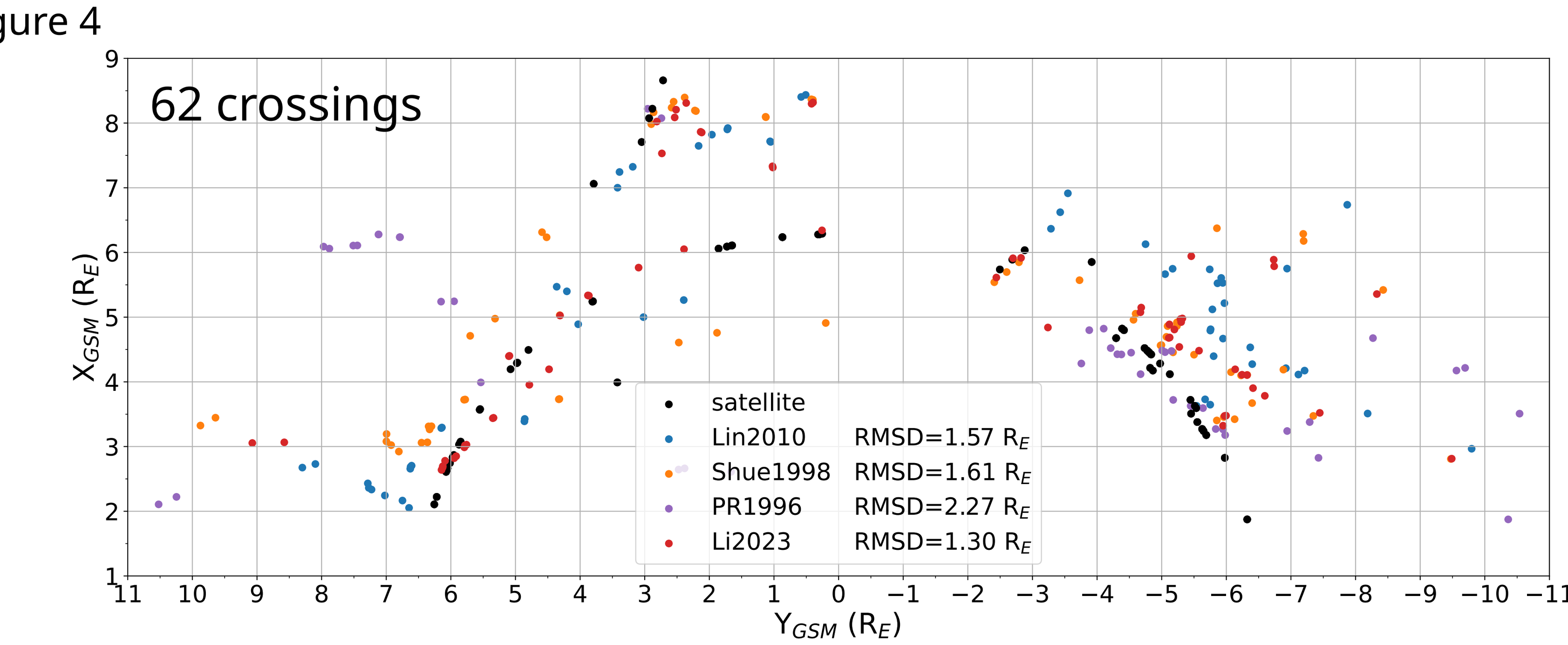


(a) The magnetic field measured by GOES-16. Noted that three intervals of the southward magnetic field were observed when it was on the nightside.

(b) and (c) The Bz component observed by GOES-16 and GOES-18. When both satellites were on the nightside, three intervals of southward magnetic field were detected. (d) The Bz component measured by FengYun-4B. At the time of the event (17:05 UT), FengYun-4B was located in the geostationary orbit on the nightside. A southward magnetic field was already observed at this time. When FengYun-4B was again positioned on the nightside, three intervals of decreasing Bz were observed.

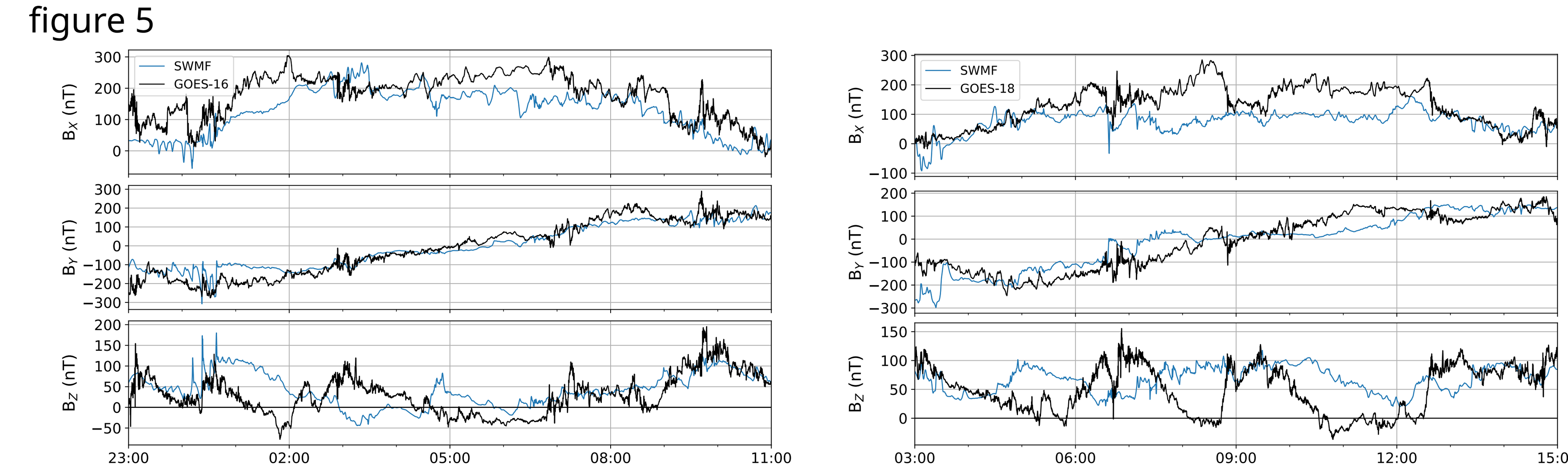
Discussion

figure 4



This study uses data from the THEMIS-A/D/E and GOES-16/18 satellites to identify 62 dayside magnetopause crossing events during 10–11 May. A comparison of four magnetopause models is shown in the figure. The Li2023 model is an open-source, interpretable machine-learning model, with code and data publicly available for download and retraining (https://zenodo.org/records/7436675).

figure 5



A comparison between satellite-observed magnetic fields and those simulated by the SWMF model is presented. The physical mechanisms behind the southward magnetic field on the nightside require further investigation.

Summary

During this event, GOES-16/18 crossed the magnetopause multiple times into the magnetosheath. At 15:04 UT, two hours before the shock arrival, enhanced helium flux was observed inside the magnetosphere. Both FengYun-4B and GOES detected southward magnetic fields on the nightside. Among the four magnetopause models compared, the Li2023 model showed the lowest RMSD (1.30 R_E). The nightside southward magnetic field mechanism requires further investigation.