Modelling the near-Earth magnetospheric field asymmetries

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Introduction

Data-based modeling of the near-Earth magnetospheric field is challenging due to the highly dynamical nature of magnetospheric currents and to the sparse available data. One important characteristic of this field is the so-called local time asymmetry, which can be clearly observed during the main phase of geomagnetic storms. Modeling this asymmetry requires a dataset with a good spatial coverage at a high time resolution. The network of ground magnetic observatories provides the only magnetic data that meet these criteria. In this study, we present a data-based model of the near-Earth magnetic field produced by electric currents in the inner magnetosphere.

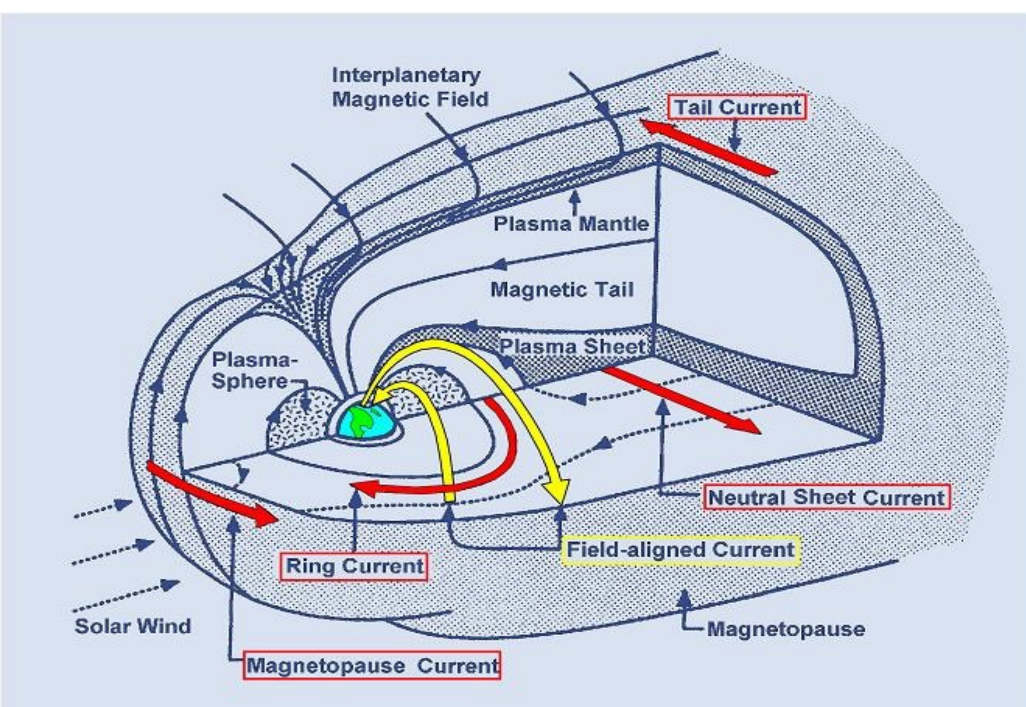

Figure 1: sketch of magnetospheric currents

Data preprocessing

We use ground observatory hourly magnetic field data from the World Data Center database between 5° and 55° of quasi dipole latitude from 1997 to 2021. The data are corrected from the following fields:

- Main field using the CHAOS 7.13 model[3]
- Crustal biases from Califf et al. (2022)
- E-region mid- and low-latitude ionospheric field using the DIFI model[2]
- Static GSM magnetospheric field using using the CHAOS 7.13 model[3]

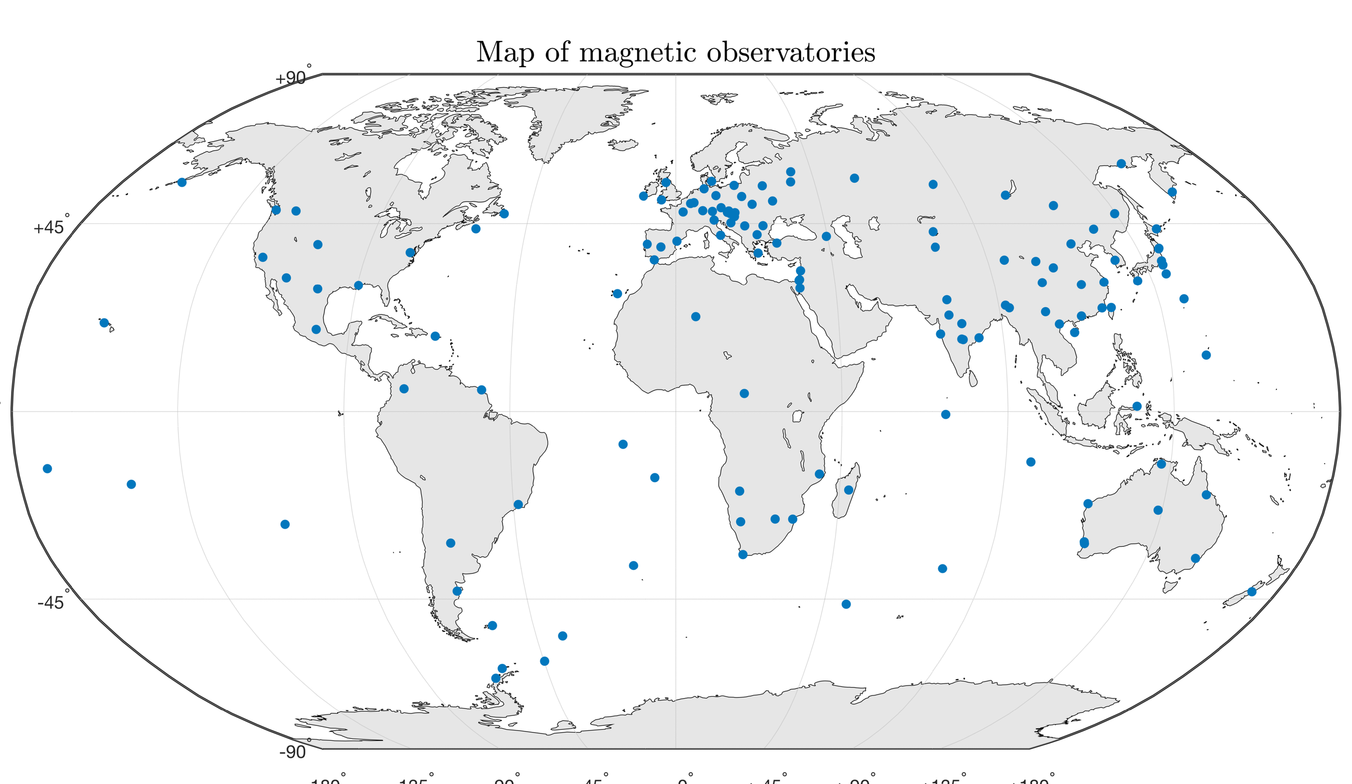

Figure 2: Position of geomagnetic observatories providing data used in this study.

Methodology: We derive a global static spherical harmonics model every one-hour timestamp:

- Select all available data for one timestamp
- Solve an inverse problem to find the best static spherical harmonics model in dipole magnetic coordinates
- The spherical harmonics coefficients are separated in their external an induced parts using an approach developed by Kruglyakov et al. (2022)
- Repeat process for next timestamp

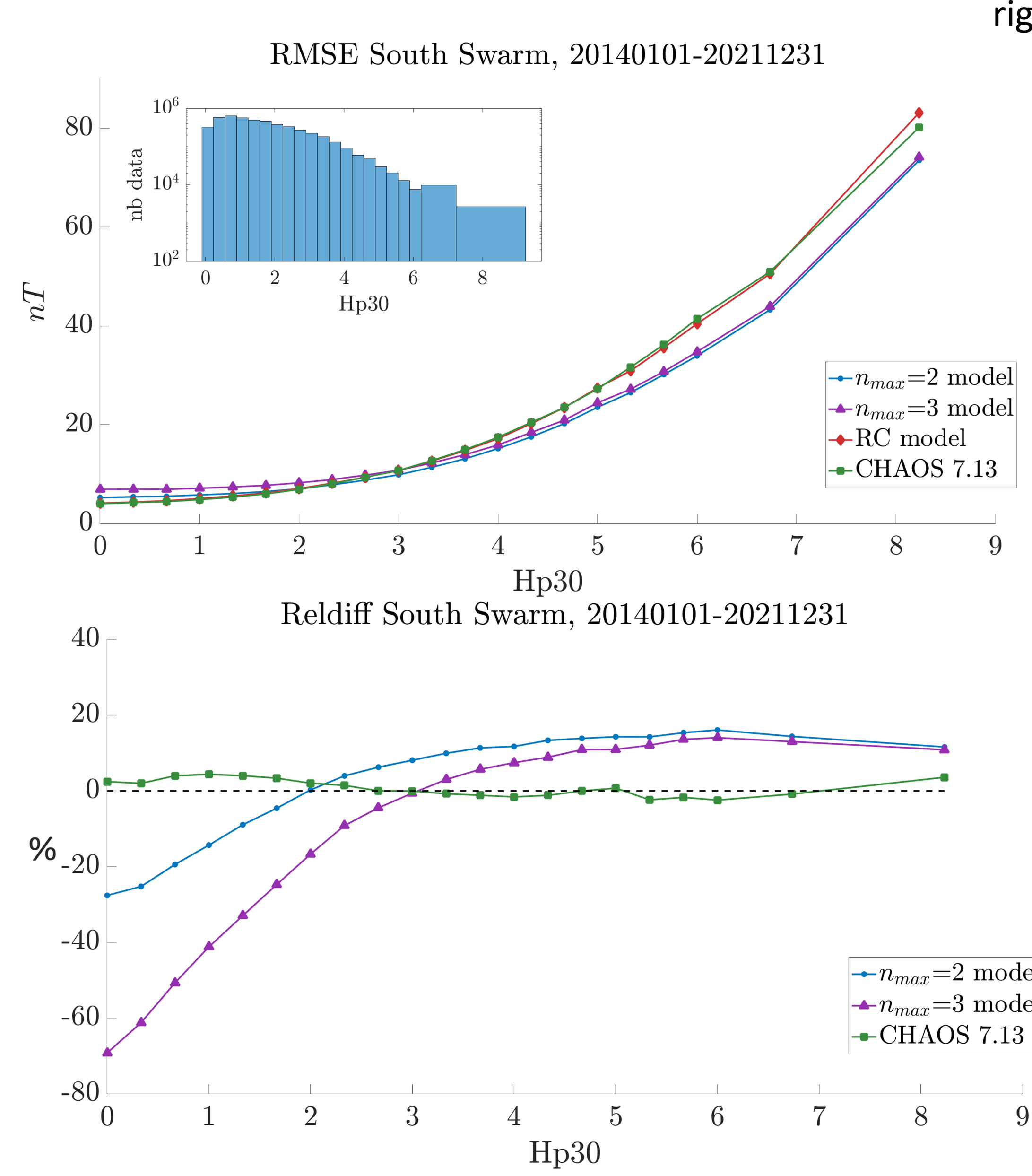

Figure 4: (Upper) Root Mean Square Error (RMSE) between the time series of the South component of the Swarm satellite vector data and the corresponding time series of the South component of the model prediction as a function of the Hp30 index[6] for a degree 2 model (blue), a degree 3 model (purple), a modified CHAOS 7.13 model with an in-house implementation of the RC index (red), and the official CHAOS 7.13 index (green). (Bottom) Relative difference between the RMSE of the modified CHAOS 7.13 model and of the RMSE of the degree 2 model (blue), of the degree 3 model (purple) and of the official CHAOS 7.13 (green).

$$\text{Reldiff} = \frac{\text{RMSE}_{\text{RC}} - \text{RMSE}}{\text{RMSE}_{\text{RC}}}$$

Observation: Degree 2 and 3 models improve fit to Swarm data in comparison to the CHAOS 7.13 model on the South component above Hp30=2.

Methodology and results

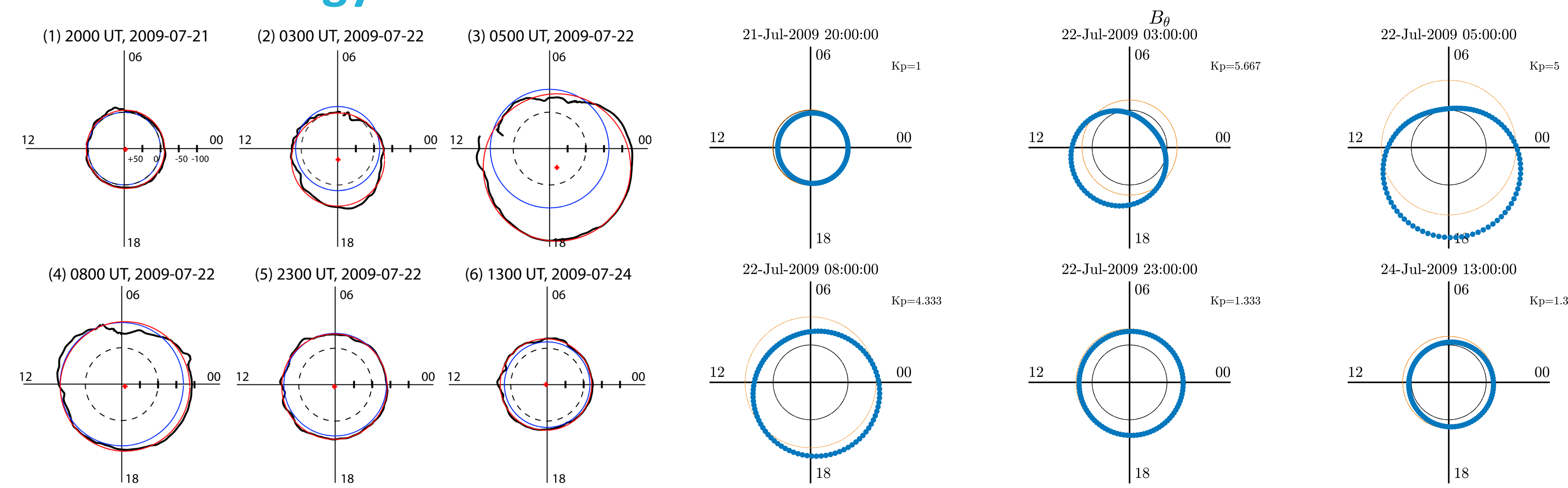

Figure 3: Comparison between results obtained in a study of Le et al. (2011) using data from the C/NOFS satellite (6 panels on the left) and results obtained using our spherical harmonics model (6 panels on the right) for the geomagnetic storm of July 2009. Each panel corresponds to one timestep. The angle shows the local time and the radial distance from the dashed black circle (left) or the black plain circle (right) the magnitude of the magnetic signal in nT. The Dst index – constant through all local times – is shown with a blue circle (left) or an orange circle (right).

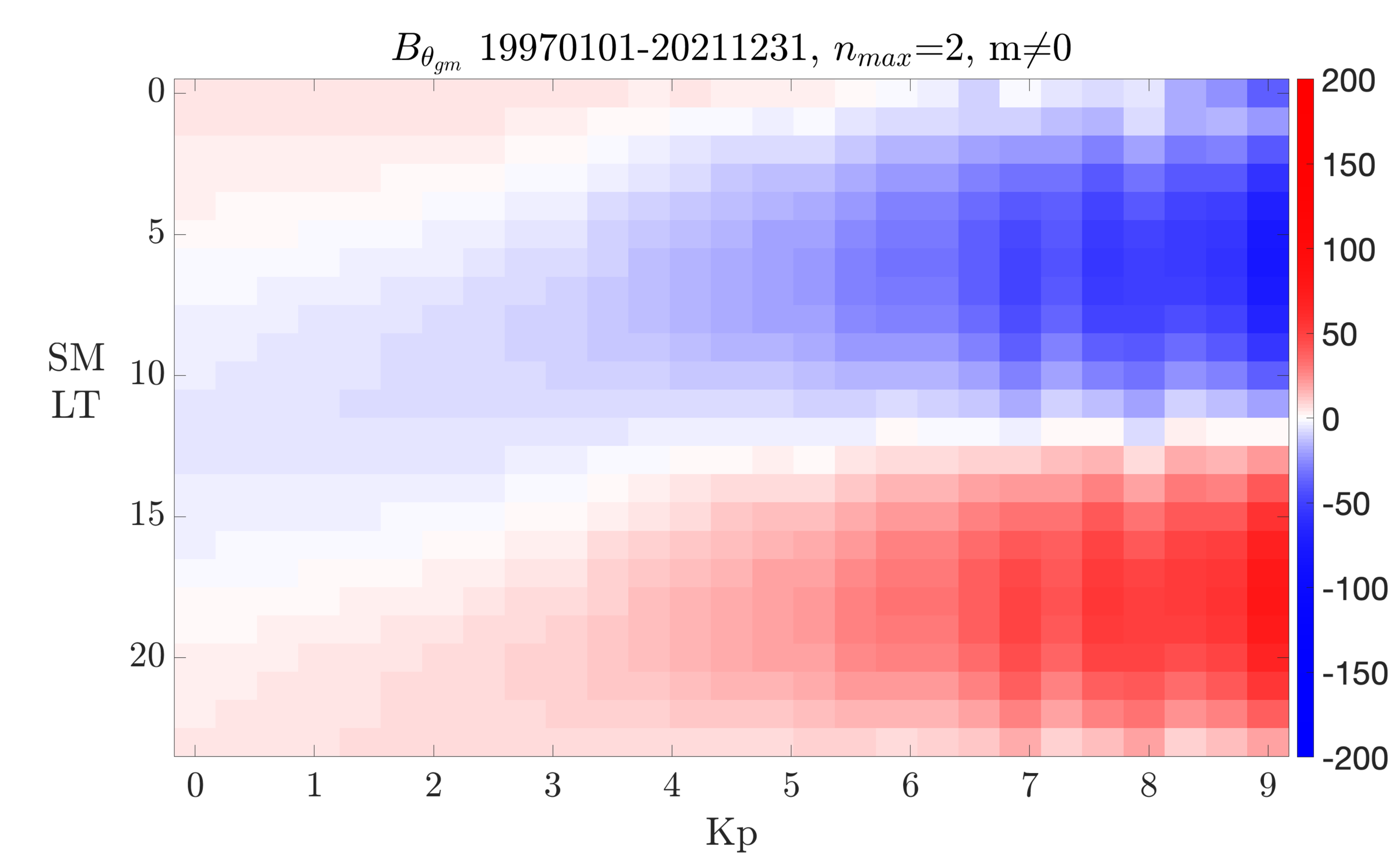

Figure 5: Average south component - in dipole magnetic coordinate – over 24 years predicted by the non-zonal terms of the spherical harmonics expansions - corresponding to the asymmetric part of the magnetospheric field - at the the magnetic equator, and as a function of the Kp index and local time.

Observation: Figure 5 shows a relatively strong dawn-dusk asymmetry for Kp above 3 and a weaker noon-midnight asymmetry for Kp below 2.

[1]Califf, Samuel, Patrick Alken, Arnaud Chulliat, Brian Anderson, Kenneth Rock, Sarah Vines, Robin Barnes, and Kan Liou. "Investigation of Geomagnetic Reference Models Based on the Iridium constellation." *Earth, Planets and Space* 74, no. 1 (February 25, 2022): 37. https://doi.org/10.1186/s40623-022-01574-w.

[2]Chulliat, A., P. Vigneron, and G. Hulot. "First Results from the Swarm Dedicated Ionospheric Field Inversion Chain." *Earth, Planets and Space* 68, no. 1 (December 2016): 104. https://doi.org/10.1186/s40623-016-0481-6.

[3]Finlay, Christopher C., Clemens Kloss, Nils Olsen, Magnus D. Hammer, Lars Tøffner-Clausen, Alexander Grayver, and Alexey Kuvshinov. "The CHAOS-7 Geomagnetic Field Model and Observed Changes in the South Atlantic Anomaly." *Earth, Planets and Space* 72, no. 1 (December 2020): 156. https://doi.org/10.1186/s40623-020-01252-9.

[4]Kruglyakov, Mikhail, Alexey Kuvshinov, and Manoj C. Nair. "A Proper Use of the Adjacent Land-Based Observatory Magnetic Field Data to Account for the Geomagnetic Disturbances during Offshore Directional Drilling." Earth and Space Science Open Archive, October 13, 2022. World. https://doi.org/10.1002/essoar.10512088.2.

[5]Le, Guan, William J. Burke, Robert F. Pfaff, Henry Freudenreich, Stefan Maus, and Hermann Lühr. "C/NOFS Measurements of Magnetic Perturbations in the Low-Latitude Ionosphere during Magnetic Storms." *Journal of Geophysical Research: Space Physics* 116, no. A12 (2011). https://doi.org/10.1029/2011JA017026.

[6]Yamazaki, Y., Matzka, J., Stolle, C., Kervalishvili, G., Rauberg, J., Bronkalla, O., Morschhauser, A., Bruinsma, S., Shprits, Y. Y., & Jackson, D. R. (2022). Geomagnetic Activity Index Hpo. *Geophysical Research Letters*, *49*(10), e2022GL098860. https://doi.org/10.1029/2022GL098860

Conclusions

To first order, the magnetospheric local time asymmetry can be represented by a degree 2 spherical harmonics external potential field model. This approach can be used for at least two distinct purposes:

- Provide a better correction of the magnetospheric field for core field modelling
- Provide constraints for the study of geomagnetic storms and substorms

In the future, the model will be improved by developing an algorithm to minimize contamination from the ionospheric field and to balance potential artefacts associated with the heterogeneous geographic data coverage.