Exploring near-Earth magnetospheric field asymmetries

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Introduction

The Earth's magnetic field is the sum of magnetic fields produced by several sources. It can be measured at the Earth's surface, in the geomagnetic observatories, or on board of satellites. Whether to build models or to study individual sources and their environment, one of today's main challenge is to separate the signals from the different sources in the magnetic measurements. The magnetospheric field, produced by the electric currents that flow in the magnetosphere, is particularly challenging. This field is well known to vary rapidly with time. It is also highly asymmetric with local time, in particular for high geomagnetic activity. This asymmetry is not taken into account in current geomagnetic field models. We propose to study this asymmetry using ground magnetic observatories and two different approaches: building a local time dependent magnetospheric index and using a global spherical harmonics representation. We discuss the possible uses of these two approaches.

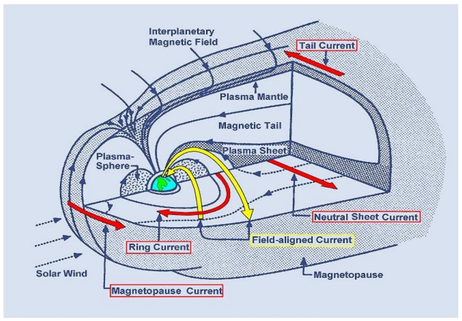

Figure 1: sketch of magnetospheric currents

Data preprocessing

We use hourly magnetic field data from the World Data Center database provided by ground observatory located between 10° and 40° of quasi dipole latitude. The data are corrected from the following fields:

- Main field using the CHAOS 7.9 model[3]
- Crustal biases from Califf et al. (2022)
- E-region mid- and low-latitude ionospheric field using the DIFI model[2]
- Static SM and GSM magnetospheric field using using the CHAOS 7.9 model[3]

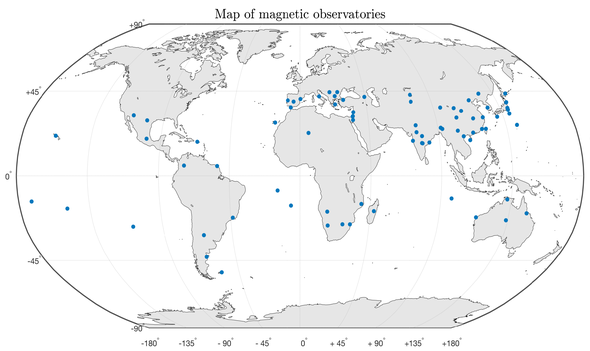

Figure 2: Position of geomagnetic observatories providing data used in this study

Local time dependent magnetospheric index

Methodology: The index is derived by computing the best dipole that fits the data in a 6h sliding local time window. The steps are :

- Select all available data in a 6h local time window
- Solve an inverse problem to find the best degree 1 spherical harmonics model
- Slide window by one hour and repeat process

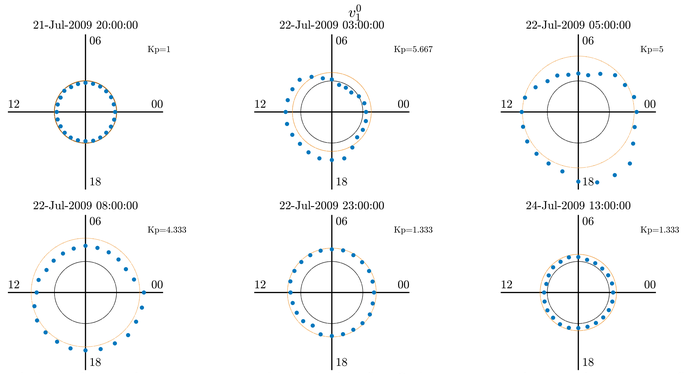

Figure 3: Local time dependent magnetospheric index for 6 timestamps during the storm of July 2009. The black circle is the 0 nT baseline. The angle gives the local time and the radial distance from the black circle the index value in nT. The Dst index is shown in orange. Positive and negative values are respectively inside and outside the black circle.

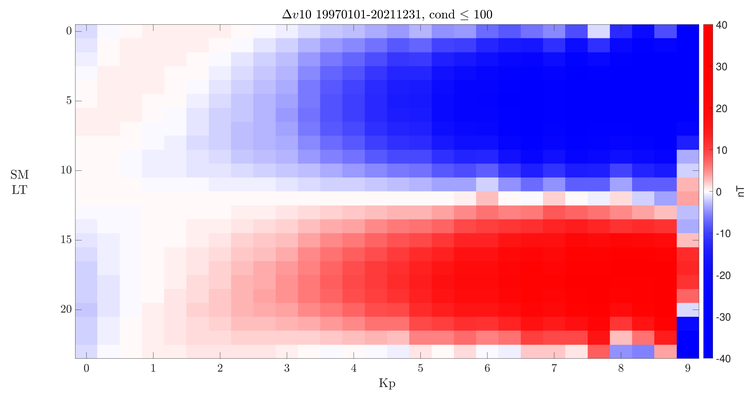

Figure 4: Average difference between the local time dependent magnetospheric index and a global magnetospheric index - computed with nighttime data - over 21 years as a function of the Kp index and the Solar Magnetic local time (SM LT).

Results: We observe a clear local time asymmetry both on some specific events and on global statistics. This asymmetry strongly depends on the geomagnetic activity. According to figure 4, it is minimum in the morning sector and maximum in the evening sector for almost all Kp values, with an exception for Kp=0 where the sign is reversed.

References

[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$$^{\circledR }$$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.

Global spherical harmonics representation

Methodology: We derive a global degree 2 static spherical harmonics model at each timestamp using all available data. The steps are :

- Select all available data for one timestamp
- Solve an inverse problem to find the best degree 2 static spherical harmonics model
- Repeat process for next timestamp

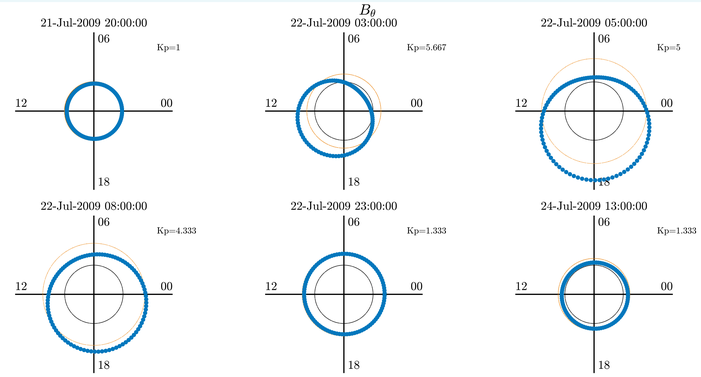

Figure 5: Local time variations of the Solar Magnetic South component model prediction at the Solar Magnetic equator for 6 timestamps during the storm of July 2009.

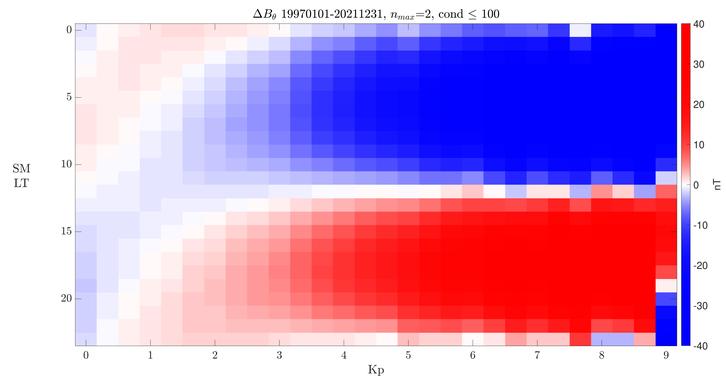

Figure 6: Average difference between the Solar Magnetic South component model prediction at the Solar Magnetic equator and a global magnetospheric index - computed with nighttime data - over 21 years as a function of Kp index and Solar Magnetic local time (SM LT).

Results: The results are consistent with results obtained using the local time dependent magnetospheric index. They show that the magnetospheric local time asymmetry can be modelled with a degree 2 spherical harmonics model.

Conclusions

The magnetospheric local time asymmetry can be represented both by a local time dependent magnetospheric index and degree 2 spherical harmonics model. These approaches can be used for two distinct purposes:

- The local time dependent magnetospheric index can be used to better characterize the storm time magnetospheric field for multiple applications.
- The degree 2 model will be used to parametrize a global magnetospheric field model that would better represent the local time asymmetry.

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