Enhanced Swarm-Based Climatological Models of the Non-Polar Geomagnetic Daily Variations

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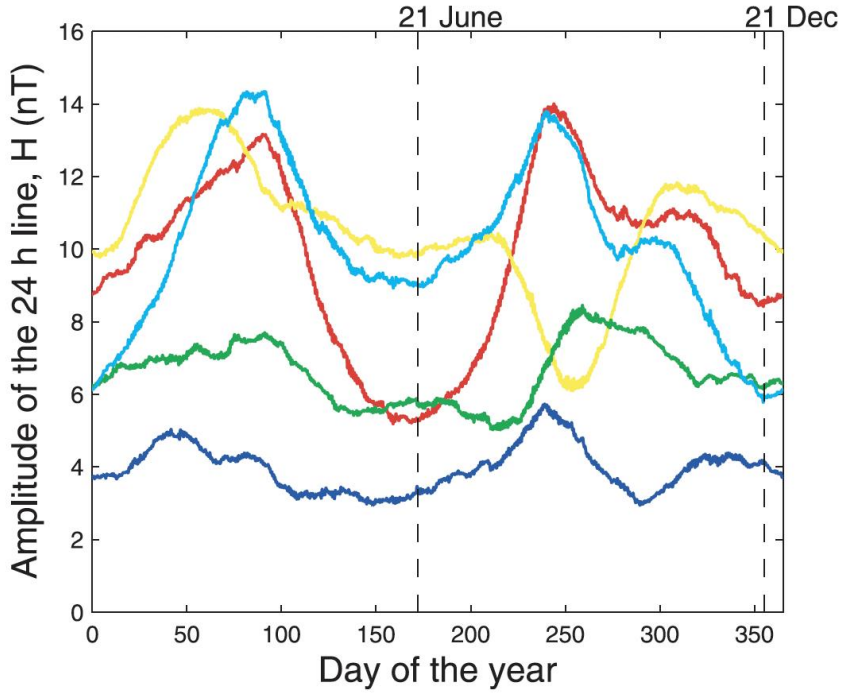
Background & Motivation (1)

- Non-polar geomagnetic daily variations are present in all geomagnetic field recordings, on ground and in low-Earth orbit (LEO).
- They are caused by electric currents in the ionospheric E-region on the day side (ionospheric wind dynamo), and by induced electric currents in the Earth's mantle.
- The amplitudes and phases of the diurnal variation and its harmonics vary as a function of location, season, solar cycle and geomagnetic activity.
- They are also affected by the day-to-day variability of thermospheric winds and tides.



BOU (red), HON (yellow), KAK (blue), TUC (green), VIC (cyan). Figure from Chulliat *et al*.(2005)

Background & Motivation (2)

- Physics-based models often focus on investigating the dynamics of the ionosphere-thermosphere rather than accurately predicting geomagnetic variations for practical applications.
- Empirical equivalent current models based on ground-based data generally lack truly global coverage (in longitude) and do not separate primary and induced magnetic fields.

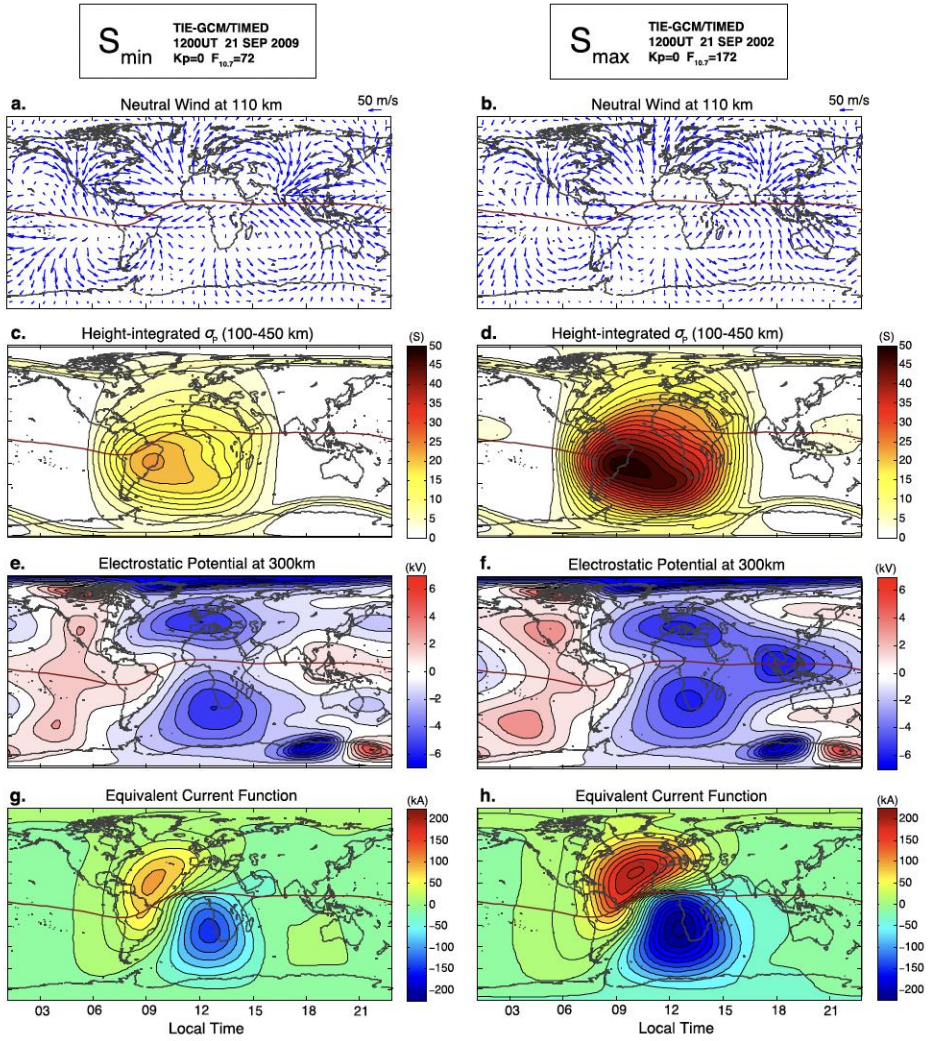


Figure from Yamazaki & Maute (2017)

Global Modeling of the Sq (and EEJ) Fields

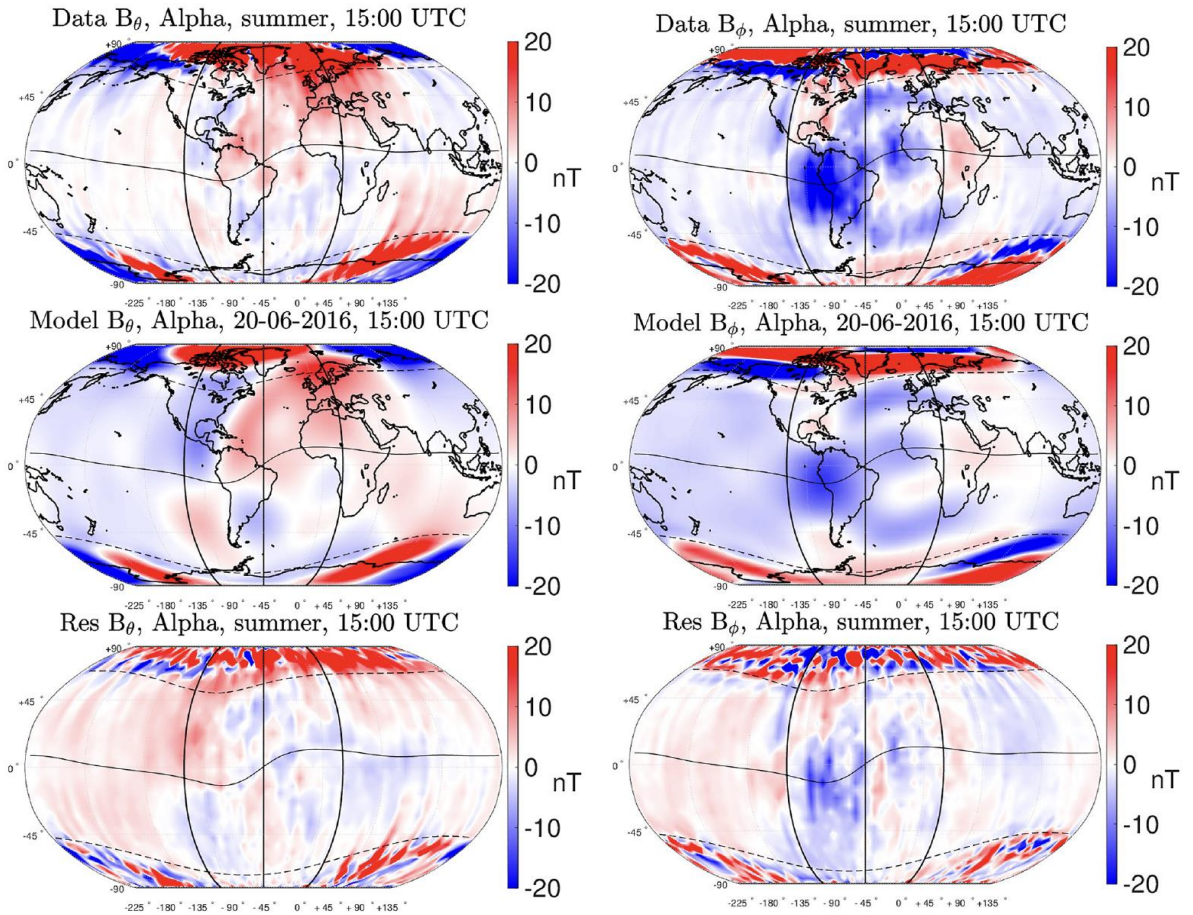
- An empirical modeling approach incorporating LEO satellite data was pioneered as part of the Comprehensive Model 20+ years ago (Sabaka *et al.*, 2003).
  - CM3 used a limited number of satellite data with insufficient LT coverage.
- It was decided during the Swarm mission preparation to develop two independent processing chains for non-polar geomagnetic daily variations: the CM and the Dedicated Ionospheric Field Inversion (DIFI).
- ”Dedicated” modeling allows for more frequent updates and a wider variety of data correction methods, and provides an independent validation.
- DIFI models provide global representations of the quiet-time, climatological, non-polar daily variations at ground and in LEO during the Swarm mission. They separate primary and induced fields.
- Seven DIFI models have been released so far; DIFI-8 to be released later this year.

DIFI Methodology

- Swarm Alpha & Bravo vector data and observatory hourly mean values (from the "SW_OPER_AUX_OBS" product developed by BGS)
  - Extended DIFI ("xDIFI"): adding CHAMP data
- Quiet-time data only: Kp < 2o, |Dst| < 20 nT, |IMF By| < 8 nT, -2 nT < IMF Bz < 6 nT
- Data corrections using the latest CHAOS (core and magnetospheric field) and MF7 (crustal)
- Additional track-by-track corrections and filtering to remove unmodelled magnetospheric field variations and high-latitude ionospheric fields in satellite data
- Inversion in Quasi-Dipole (QD) coordinates until degree 45 and order 5 (11,875 coefficients),
- Model released in dipole coordinates (degree 60 and order 12)
- Regularization minimizing the horizontal gradient of the current density at all local times

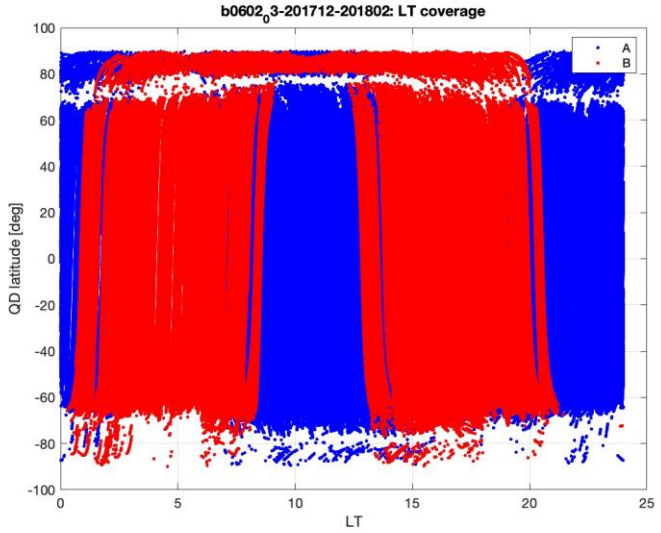
Toroidal Fields Corrections

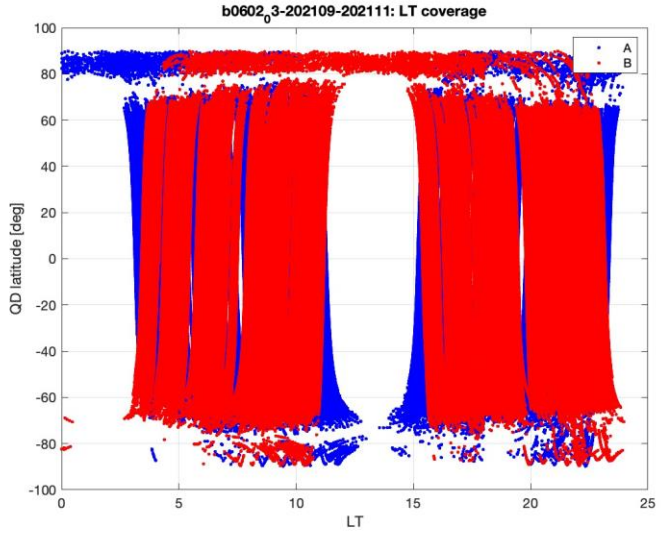
- Climatological model of non-polar F-region ionospheric currents developed by Fillion et al. (2023)
- Model predicts toroidal magnetic fields (B_θ, B_φ) at Swarm Alpha and B altitudes
- See Martin Fillion's talk in this session

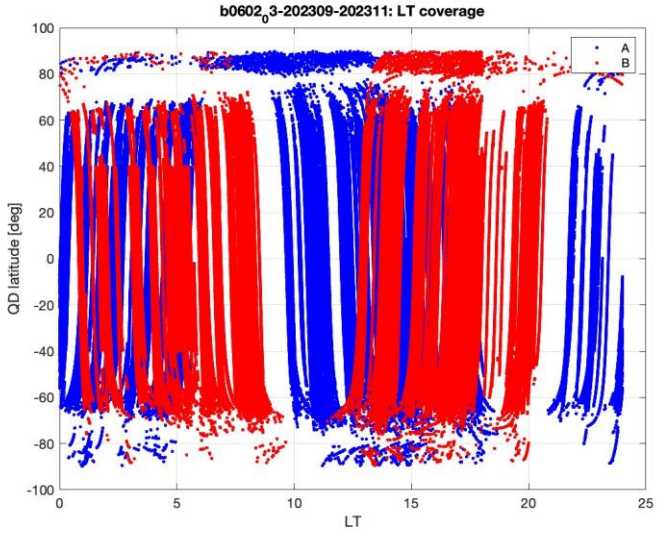


Data

Data	Baseline	Start Date	End Date	# of Data
Swarm A & B	0602/0603	Jan 1, 2014	Dec 31, 2023	~ 2.5 M
Observatories	Definitive and QD	Jan 1, 2014	Dec 31, 2023	~ 2.5 M







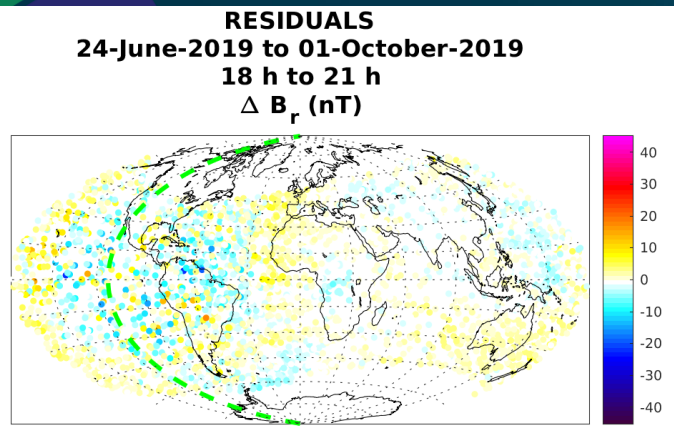
Data Residuals

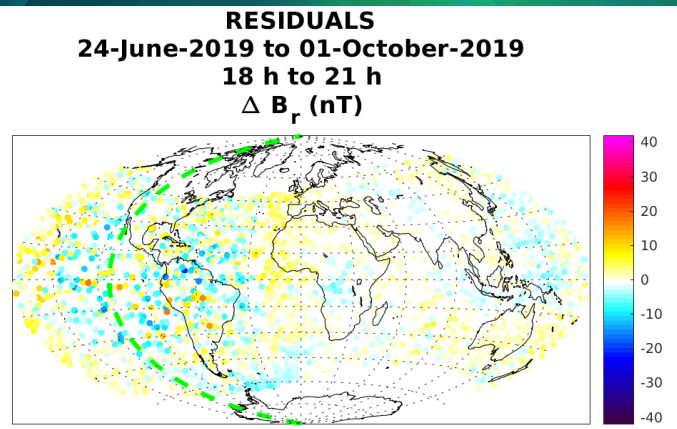
Satellite data (area of validity)

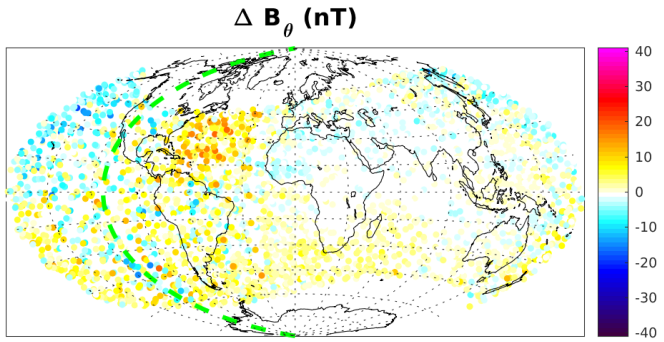
	No TF correction	TF Correction
Mean B_r (nT)	-0.01	-0.01
Std B_r (nT)	3.47	3.49
Mean B_θ (nT)	0.42	-0.17
Std B_θ (nT)	4.65	4.29
Mean B_ϕ (nT)	-0.20	-0.16
Std B_ϕ (nT)	8.77	7.00

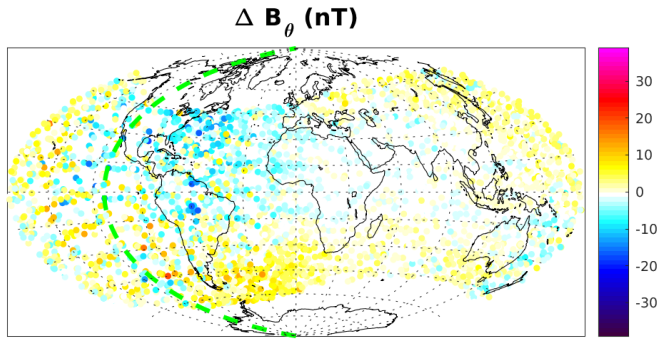
Observatory data (area of validity)

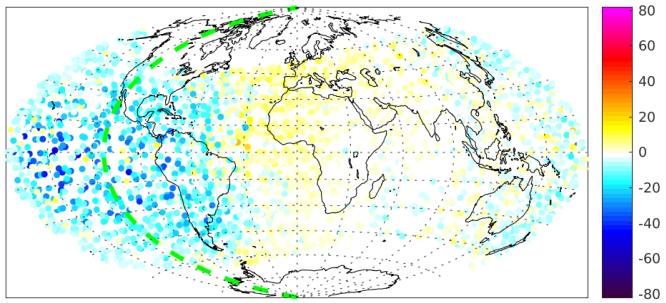
	No TF correction	TF Correction
Mean B_r (nT)	-0.15	-0.14
Std B_r (nT)	4.53	4.53
Mean B_θ (nT)	0.28	0.20
Std B_θ (nT)	6.34	6.34
Mean B_ϕ (nT)	-0.07	-0.08
Std B_ϕ (nT)	5.85	5.86

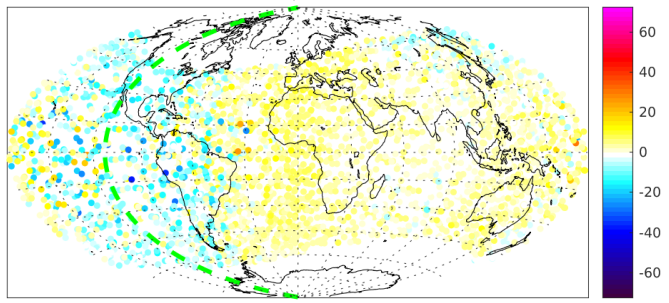




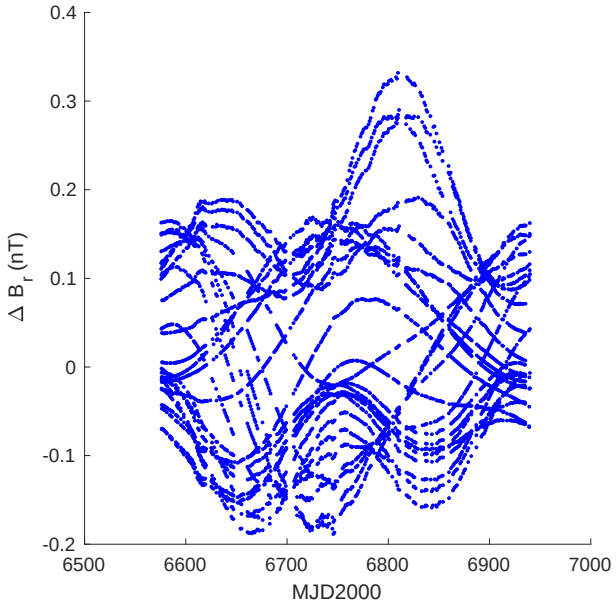






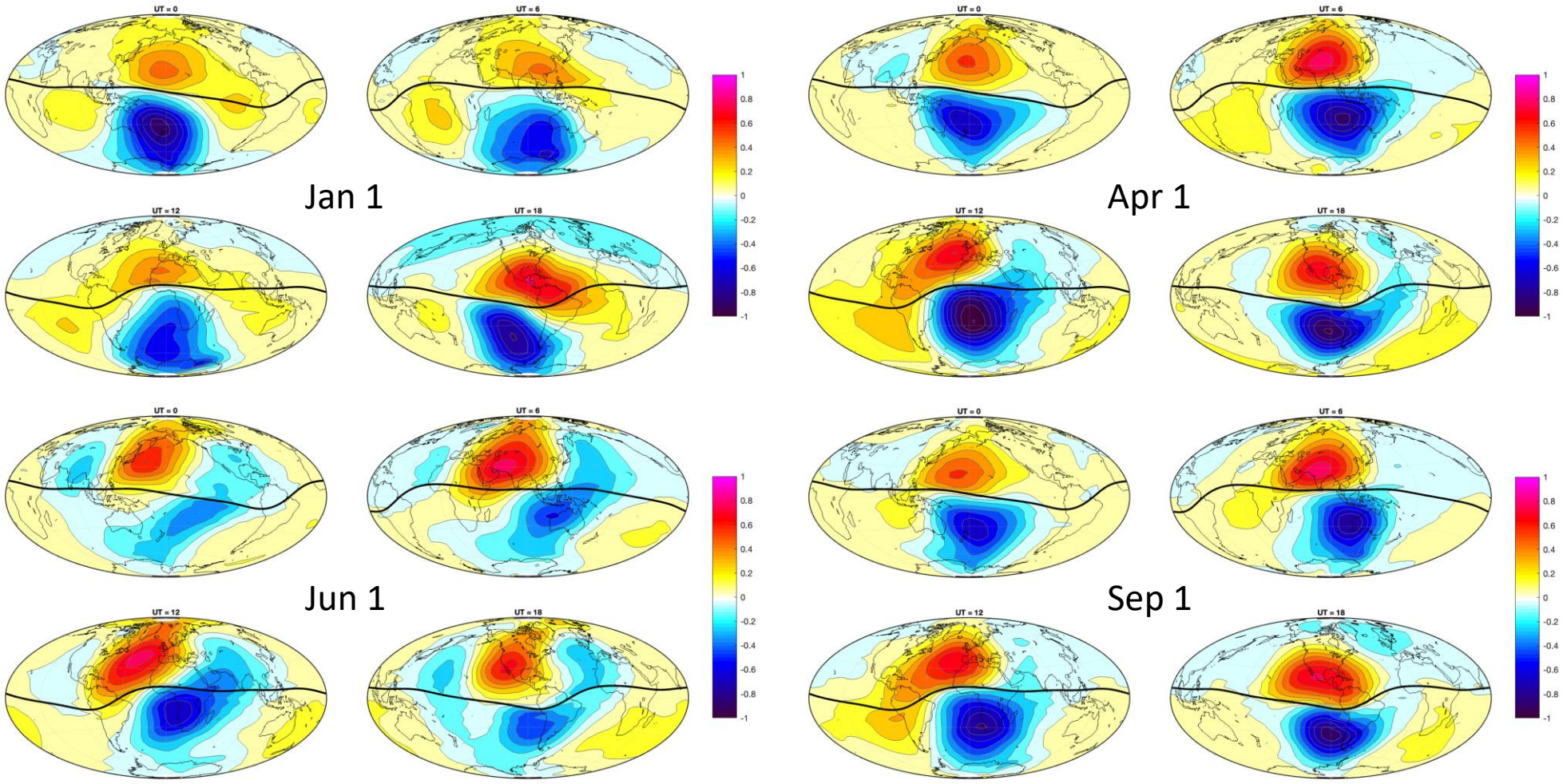


CLF observatory

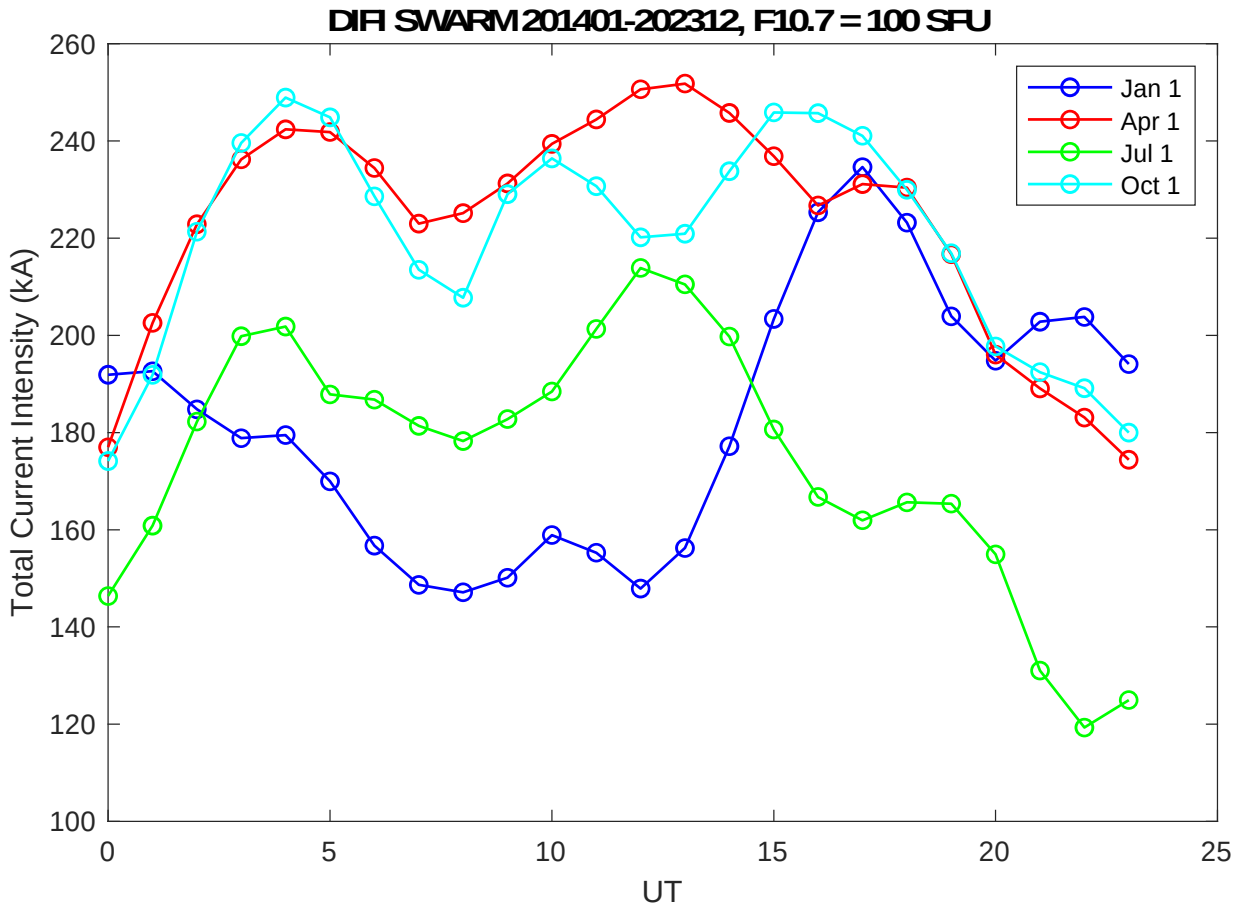


enhagen, Denmark

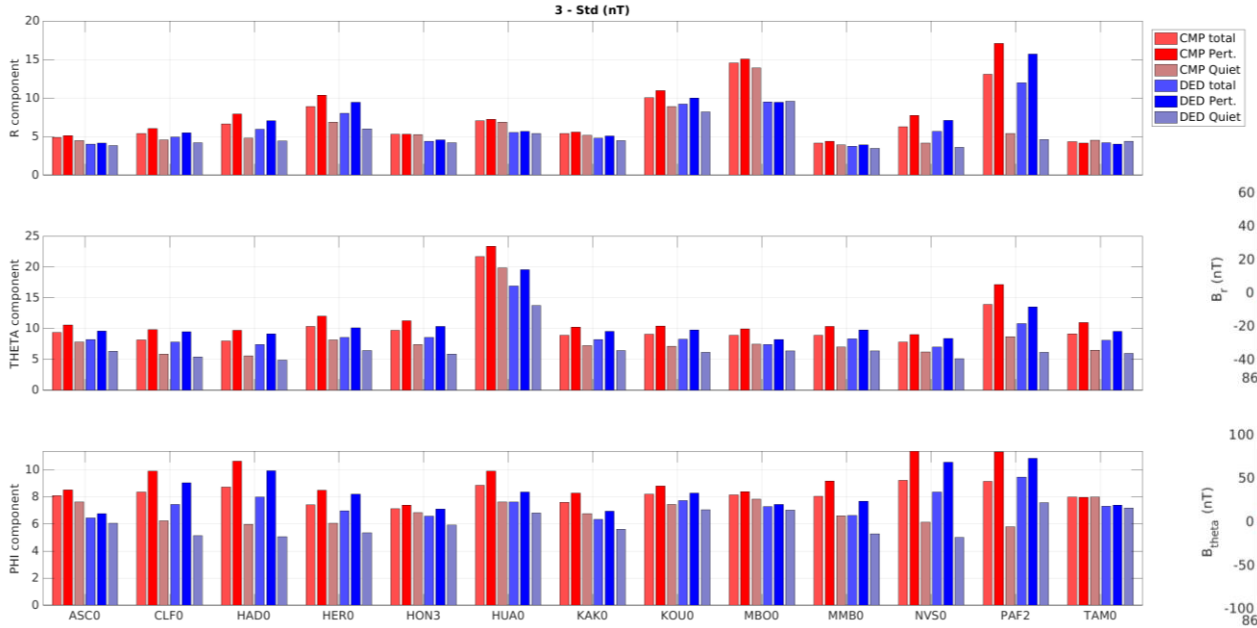
Equivalent Current Function

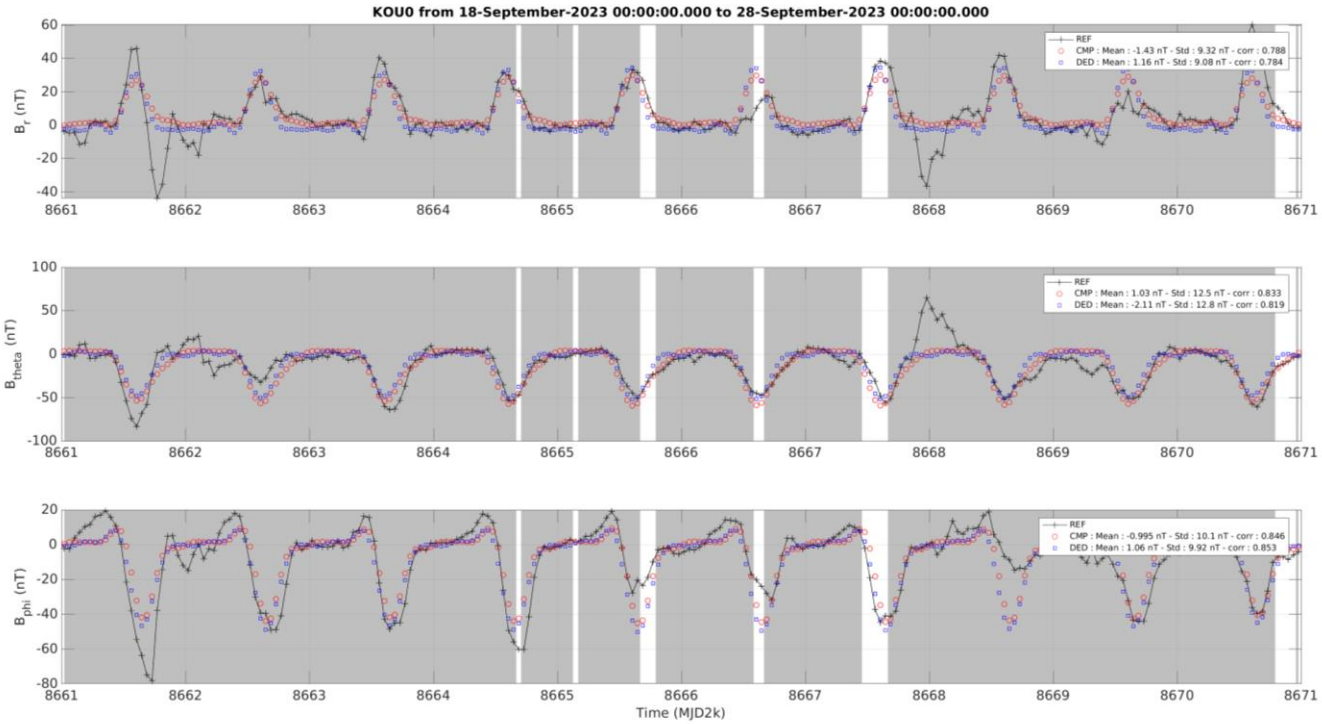


Total Current Intensity

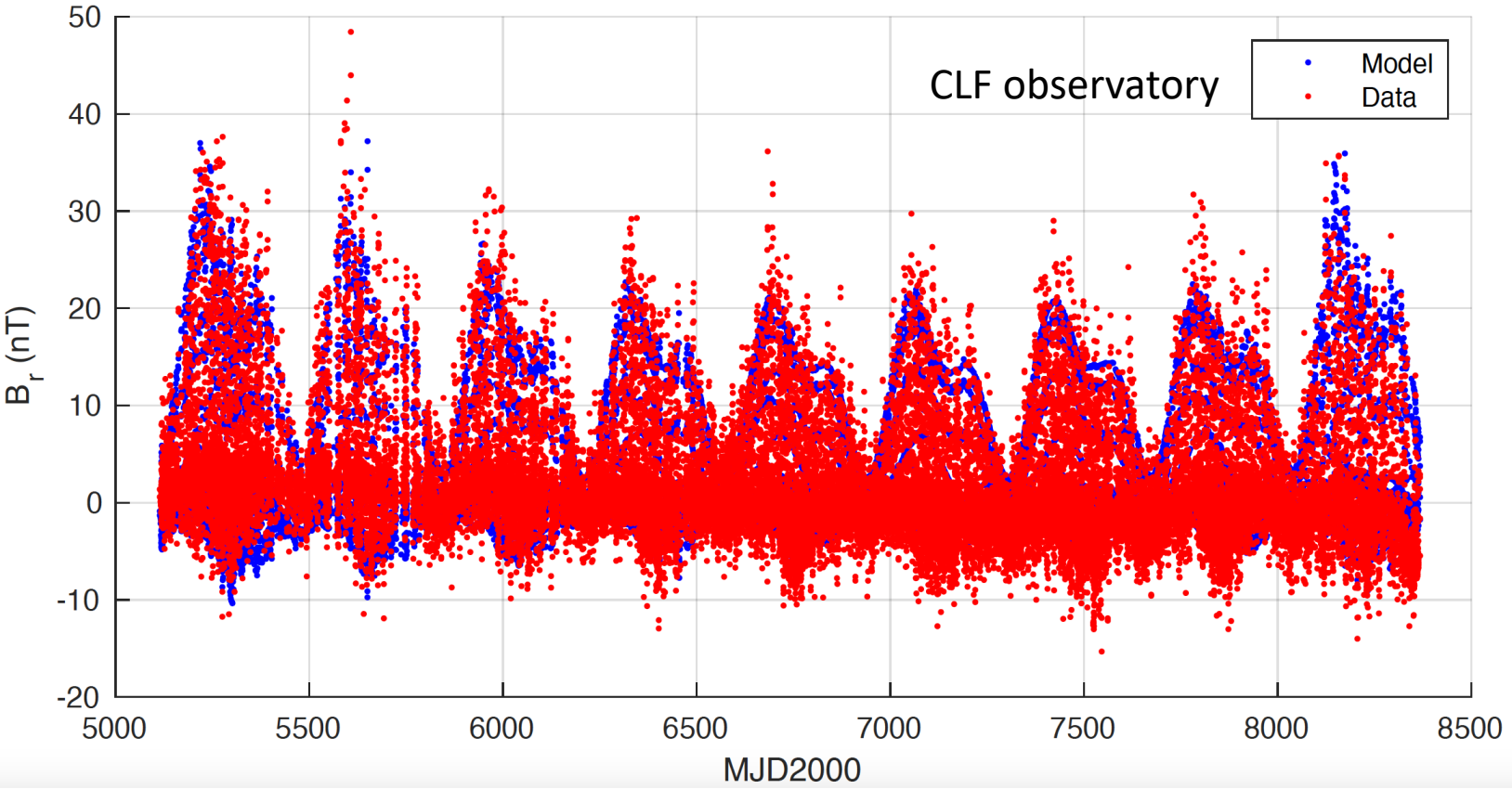


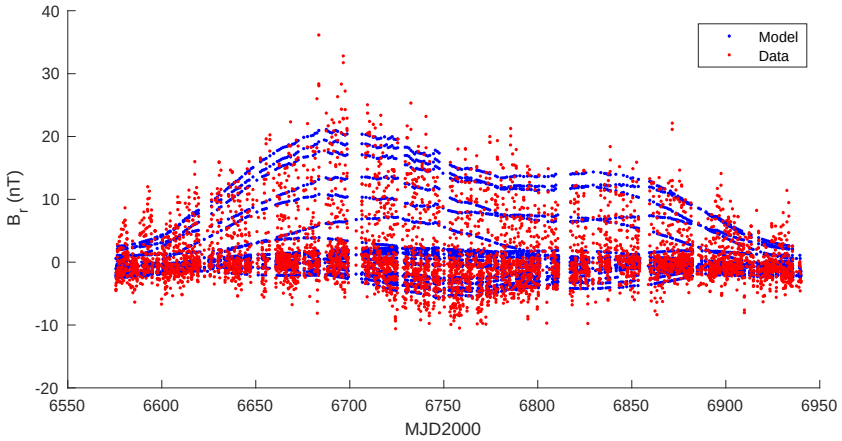
Model Predictions at Ground (1)

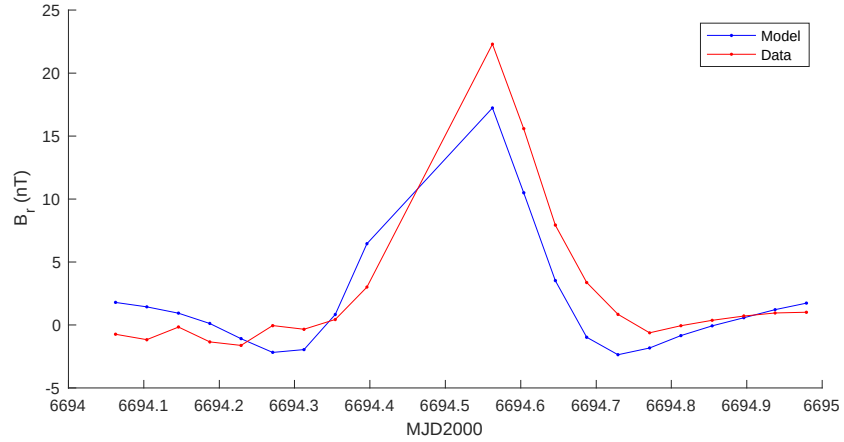




Model Predictions at Ground (2)







Conclusions & Perspectives

- DIFI models can be used to correct for external field variations for various applications.
  - Satellite data processing and geomagnetic field modeling
  - Marine and aeromagnetic survey data processing
  - Magnetic field based navigation
- DIFI models provide information on the geometry and climatology of ionospheric Sq and EEJ currents.
- Extension backward in time (“xDIFI”) using time-varying QD basis functions is ongoing.