Investigating the Predictive Power of Magnetohydrodynamic Models for Geomagnetically Induced Currents in the UK

THE UNIVERSITY of EDINBURGH

Ewelina Florczak [1], Ciaran Beggan [2], Kathy Whaler [1]

[1] University of Edinburgh, [2] British Geological Survey

British Geological Survey

Introduction

Space weather events cause disturbances in the Earth's geomagnetic field. Rapid field fluctuations often result in the induction of quasi-direct currents, known as **Geomagnetically Induced Currents (GICs)** in conductive structures on the Earth's surface (*Figure 1*).

Since space weather and GICs can be damaging to various technological systems and human activity, a good forecasting capability is important in order to mitigate their impacts.

Accurate forecast of GIC occurrence via computational modelling is a challenging task. The main goal of this study is to assess the performance of currently available **MHD models** for ground magnetic field and GIC prediction in the UK.

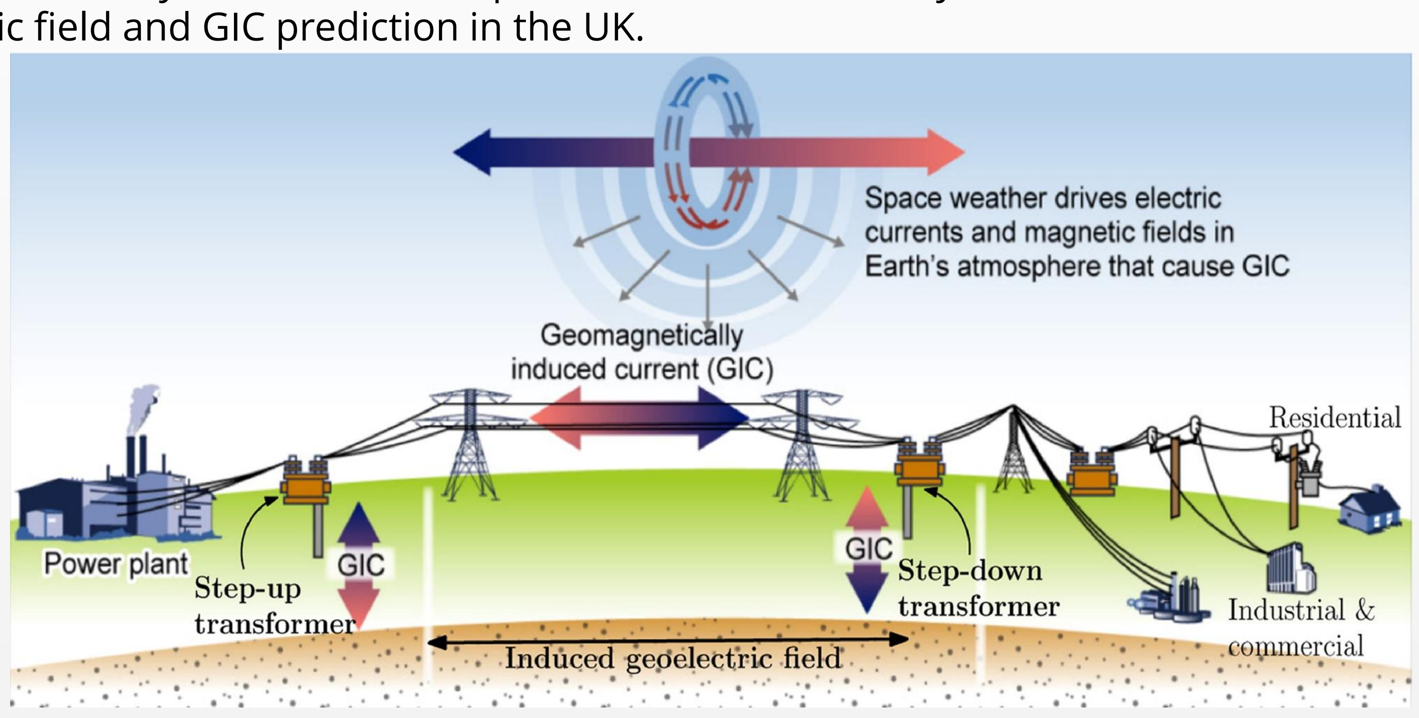

Figure 1: Induction of GICs, their cause and effects.
Source: https://www.gao.gov/assets/700/696284.pdf

Methodology

1. Acquire **ground magnetic field (B-field)** measurements from 3 UK observatories *(Table 1, Figure 2)* for 7-8 September 2017 storm *(Table 2)* using International Real-Time Magnetic Observatory Network (INTERMAGNET).

IAGA code	Station Name	Geo. Latitude	Geo. Longitude
HAD	Hartland	50.995 °N	355.516 °E
ESK	Eskdalemuir	55.314 °N	356.794 °E
LER	Lerwick	60.138 °N	358.817 °E

Table 1: UK observatories details.

Event	Start Time	End Time
1	23:00 UT 07 Sep 2017	04:00 UT 08 Sep 2017

Table 2: Geomagnetic storm duration.

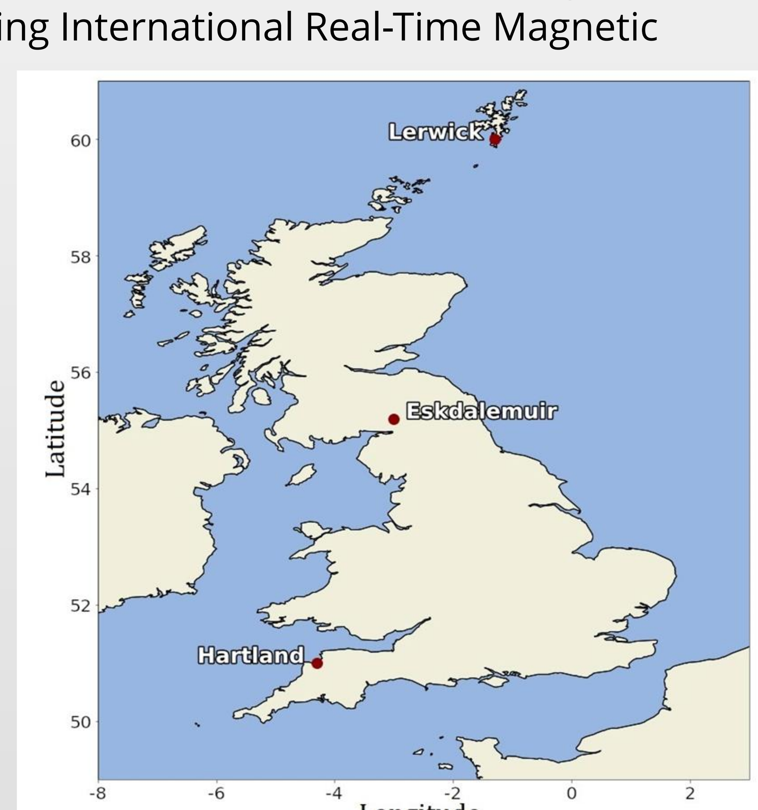

Figure 2: Observatories included in this study.

2. Compare with values simulated by various **MHD models** (details below) of magnetosphere and ionosphere.

SWMF — **Space Weather Modeling Framework**
- version v20180525
- high-resolution grid with 9,623,552 cells
- solar wind data input: OMNI
- source: *Community Coordinated Modeling Center (CCMC)*

SWMF_RCM — **Space Weather Modeling Framework coupled with Rice Convection Model**
- version v20180525
- high-resolution grid with 9,623,552 cells
- solar wind data input: OMNI
- source: *Community Coordinated Modeling Center (CCMC)*

GUMICS-4 — **Grand Unified Magnetosphere-Ionosphere Coupling Simulation**
- version 4-HC-20140326
- adaptation level 5 grid with 350K cells
- solar wind data input: OMNI
- source: *Community Coordinated Modeling Center (CCMC)*

Gorgon — **Gorgon**
- cartesian grid with a uniform resolution of 0.5 Earth radii and 9,600,000 cells
- solar wind data input: OMNI
- source: *Imperial College London*

3. Compute resulting **geoelectric field (E-field)**, from both measured and simulated values, using **magnetotelluric transfer functions**, which relate B- and E-field components at a certain location, taking into account Earth's conductivity structure.

4. Calculate GIC flowing through the Great Britain (GB) high voltage (HV) network using the **Lehtinen-Pirjola matrix method:**

$$[\boldsymbol{I^e}] = ([\mathbf{1}] + [\boldsymbol{Y^n}][\boldsymbol{Z^e}])^{-1}[\boldsymbol{J^e}]$$

where $\boldsymbol{I^e}$ is the GIC at each node, $\boldsymbol{Y^n}$ is the network admittance matrix, $\boldsymbol{Z^e}$ is the earthing impedance matrix, $\boldsymbol{J^e}$ is the voltage between nodes and $\mathbf{1}$ represents the identity matrix.

5. Select substations most affected by GIC response to a **test E-field of 1 V/km** (*Table 3, Figure 3*).

6. Compute **GICs as time series** in the entire network based on extrapolated E-field values from both measured ground data and modelled from MHD simulations.

7. Calculate **Performance Metrics** to assess the predictive capabilities of each model.

Station Name	Geo. Latitude	Geo. Longitude	Voltage	Max GIC
Indian Queens	50.39 °N	-4.90 °E	400 kV	238.83 A
Pembroke	51.68 °N	-4.99 °E	400 kV	257.15 A
Torness	55.97 °N	-2.41 °E	400 kV	130.50 A
Dounreay	58.58 °N	-3.75 °E	275 kV	143.18 A

Table 3: Nodes most affected by GICs.

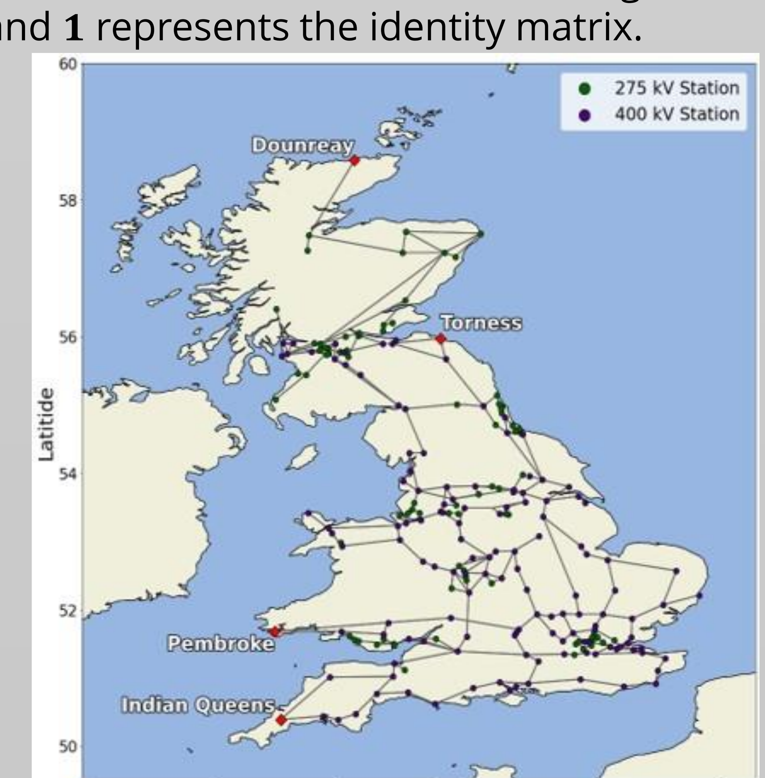

Figure 3: HV nodes in the British network. Nodes with largest modelled GIC are labelled (see *Table 3*).

Results

The comparison between measured and simulated **ground B-field perturbations** for Event 1 are shown in *Figure 4*. The left column represents the northward component (**B_x**) and the right column the eastward component (**B_y**). The black line corresponds to the observatory (INTERMAGNET) measurements of the external-only magnetic field, whilst different coloured lines represent values simulated by each MHD model.

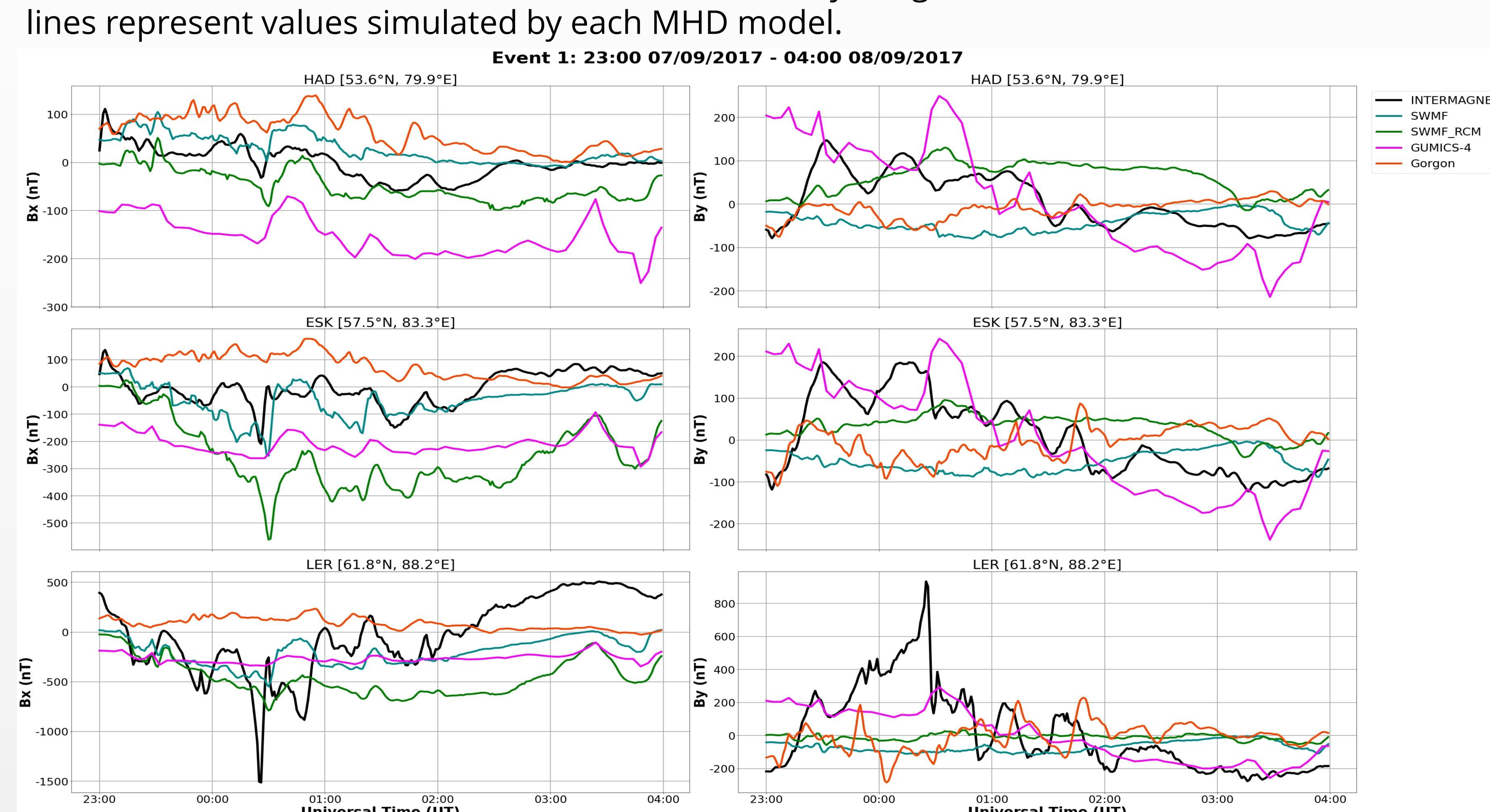

Figure 4: Ground B-field simulations compared with measurements for Event 1.

Modelled values of B_x and B_y show differences in both amplitude and temporal variability compared to the measurements. Results indicate than model accuracy decreases at higher latitudes, as shown by the average RMSE values (*Figure 5*).

There is no clear winner in B-field simulations ranking. SWMF seems to forecast B_x the best, however slightly shifted in time. The B_y prediction ranking varies at each observatory but overall range of error values is lower than for the B_x component, possibly indicating better model accuracy in the B_y forecast.

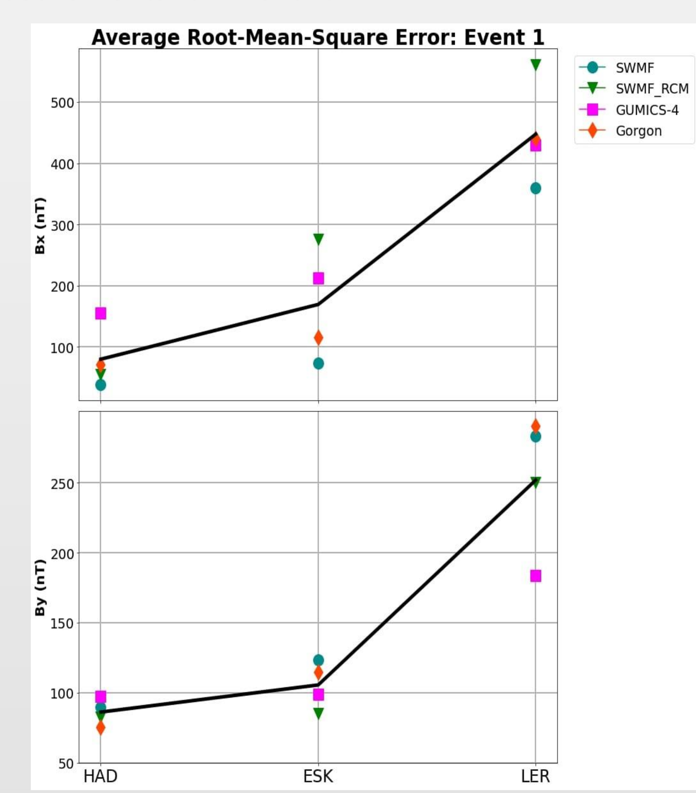

Figure 5: RMSE for B-field simulations.

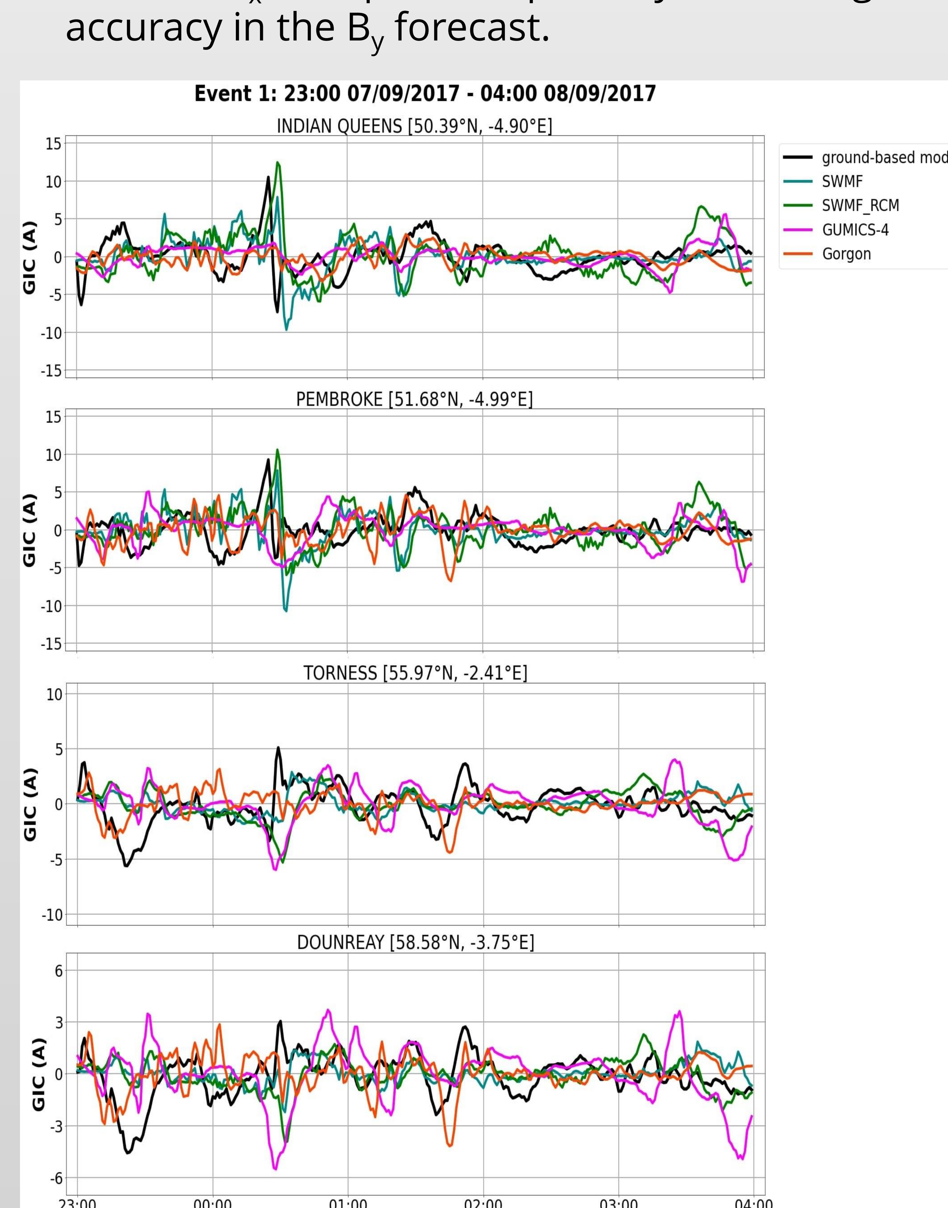

Figure 6: Ground-based model GIC results vs simulations for selected substations during Event 1.

The GIC results (*Figure 6*) for Indian Queens and Pembroke show that SWMF and SWMF_RCM correctly capture the peak after midnight, but on average produce the largest RMSE (*Figure 7*). GUMICS-4 overestimates the GICs at Torness and Dounreay. The overall best model in GIC forecast, based on average RMSE, seems to be Gorgon.

Results also imply that accuracy increases at higher latitude nodes.

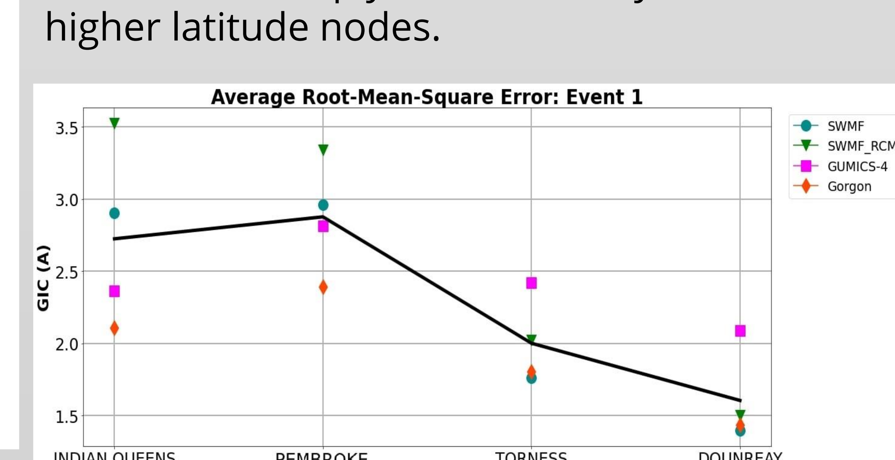

Figure 7: RMSE for GIC simulations.

Conclusion

Based on the results presented, the following conclusions can be drawn:

- The model accuracy in B-field forecast decreases at higher latitudes.
- The B_y simulations produce lower values of error in comparison to B_x forecast, suggesting better model performance in terms of the eastward component.
- GIC prediction accuracy tend to increase at higher latitudes.
- Gorgon simulations of GIC on average produce the best results.

Discrepancies between measurements and simulations occur due to several limitations and simplifications in MHD models, such as simplistic solar wind input parameters that cause timing errors or shift in modelled currents giving an opposite sign of ground B-field perturbations. The close distance between observatories of ~10 degrees latitude (compared to a global scale) may result in relatively small differences in the models (as the grid cells are usually > 0.25 R_E).

Acknowledgements

The results presented rely on data collected at magnetic observatories. We thank the national institutes, in this case British Geological Survey, that support them and INTERMAGNET for promoting high standards of magnetic observatory practice (www.intermagnet.org).

Simulation results have been provided by the Community Coordinated Modeling Center at Goddard Space Flight Center through their public Runs on Request system (http://ccmc.gsfc.nasa.gov).

Results from Gorgon global MHD model were provided by the Plasma Physics Group at Imperial College London.