Optimizing a Neural Network for Regional Forecasting of Ground Magnetic Perturbations Using Spherical Elementary Current Systems

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ML-Helio Conference 2022

Introduction

- The solar wind's interaction with the Earth's magnetic field can cause Geomagnetically Induced Currents (GICs) at ground level, which are hazardous to power and communications infrastructure.
- Fast, accurate, and precise forecasts of GICs allow providers to mitigate damage to their networks.
- Some recent ML forecasting models are trained on solar wind parameters for inputs and ground-level horizontal component of the magnetic field $\mathbf{B}_H$ for targets (*e.g.,* from SuperMAG stations).
- However, a model trained on a single magnetometer's data can only be expected to give good predictions for that station's location. Geomagnetic field variations can be highly localized compared to interstation separation distances (Ngwira et al. 2015).
- We have developed a method using the Spherical Elementary Current Systems technique to forecast GICs anywhere, not just near magnetometers. This poster describes the optimization of some dataset features and SECS hyperparameters.

What Needs to be Optimized?

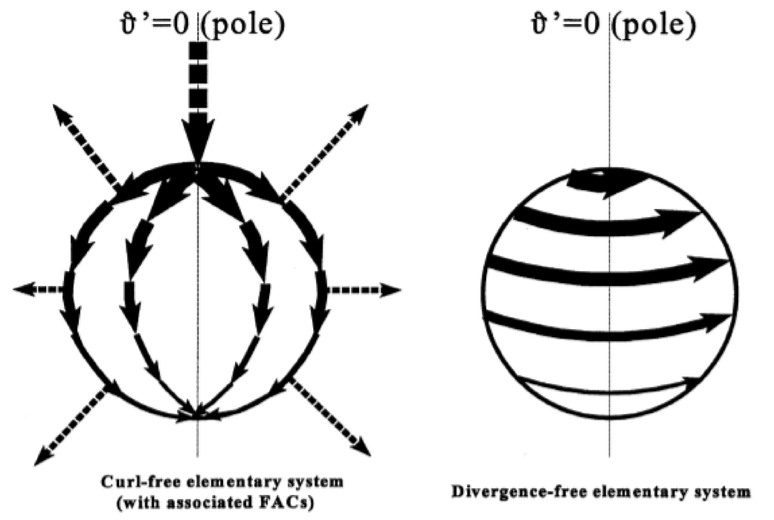
- The performance of this model is influenced by several factors, namely:
  - Spatial extent of elementary systems
  - Density of elementary systems
  - Fitting cutoff parameter ε (systems with $\mathbf{I}_0 < \mathbf{I}_{0,max} \cdot \varepsilon$ have their $\mathbf{I}_0$ set to 0)
- The spatial extent of the elementary systems (*i.e.,* the interpolation region) was chosen to cover mid- and high-latitude, non-polar areas of North America. This choice represents the goals of our research, but in principle can be changed to cover any region of the Earth's surface.
- System density and cutoff parameter ε were optimized via a grid search over the following ranges:
  - Rows of systems: 1 → 20
  - Columns of systems 1 → 20
  - ε: [5e-1, 1e-1, 5e-2, 1e-2, 5e-3, 1e-3, 0]
- The combinations of the above values that produced models with the best RMSE, explained variance, and Pearson correlation coefficient (r) were identified.

Interpolation with Spherical Elementary Current Systems

How can we interpolate $d\mathbf{B}_H$ far away from mag stations?

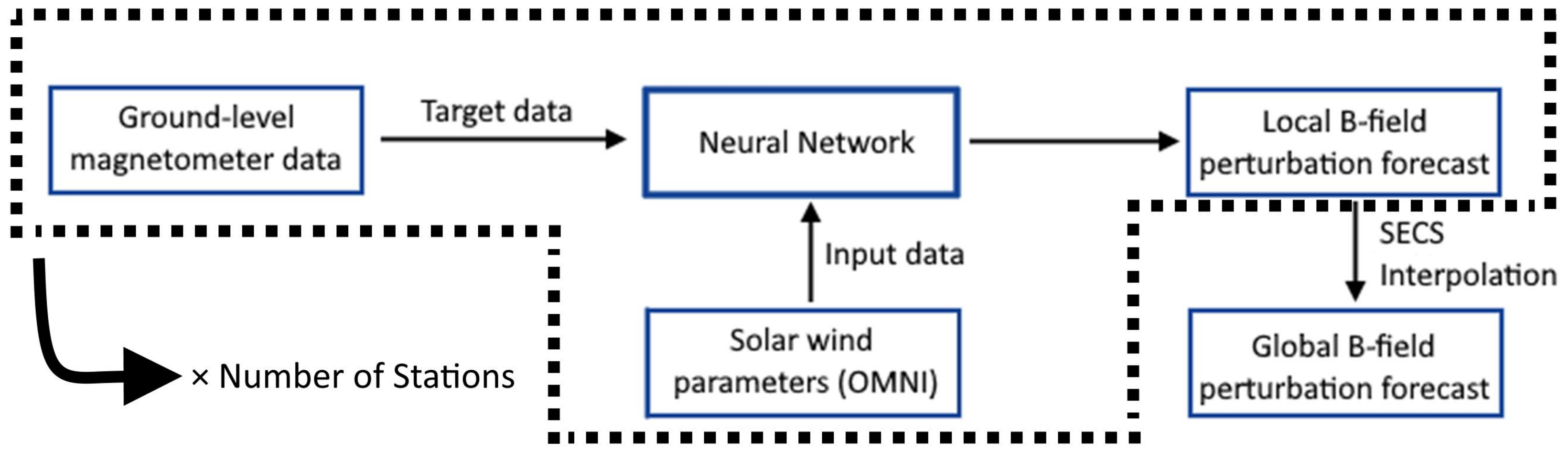
Spherical Elementary Current System (SECS) Analysis. At each timestep, a hypothetical current sheet is constructed at ~100 km altitude. The vector field describing the current is expressed as a superposition of several curl-free (CF) and/or divergence-free (DF) basis fields, each centered at a different point on a latitude-longitude grid. The CF basis fields are related to the magnetic field via Ampère's law; the DF fields via the Biot-Savart law.

$$B_{\vartheta'}(r,\vartheta') = -\frac{\mu_0 I_0}{4\pi r \sin\vartheta'} \cdot \left(\frac{\frac{r}{R_I} - \cos\vartheta'}{\sqrt{1 - \frac{2r\cos\vartheta'}{R_I} + \left(\frac{r}{R_I}\right)^2}} + \cos\vartheta' \right)$$



Equation and elementary system diagram from (Amm & Viljanen 1999)

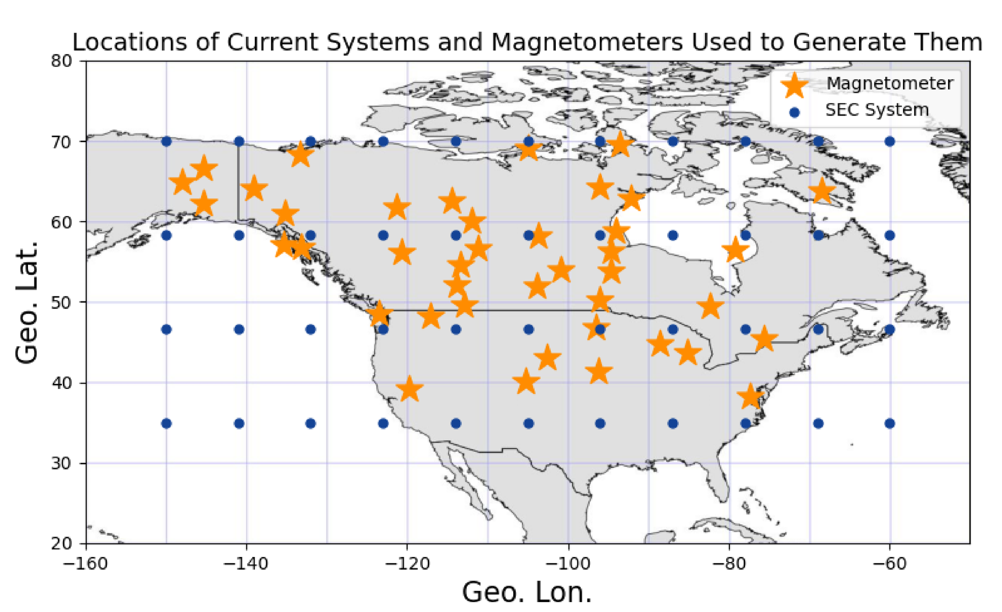
Interpolating the Ground-Level Perturbation Forecast. In the superposition, each elementary basis field has a strength represented by the scaling factor $\mathbf{I}_0$. We tune the values of $\mathbf{I}_0$ so that the overall field is fit to the predicted $\mathbf{B}_N$ or $\mathbf{B}_E$ values at each station. Because the ionospheric model is continuously defined, Ampère's law provides a global/regional forecast of B-field perturbations. In this study we fit our SEC model to the predictions from 40 North American SuperMAG magnetometers that satisfy both ≥25% yearly data availability and ≥50% average data availability.

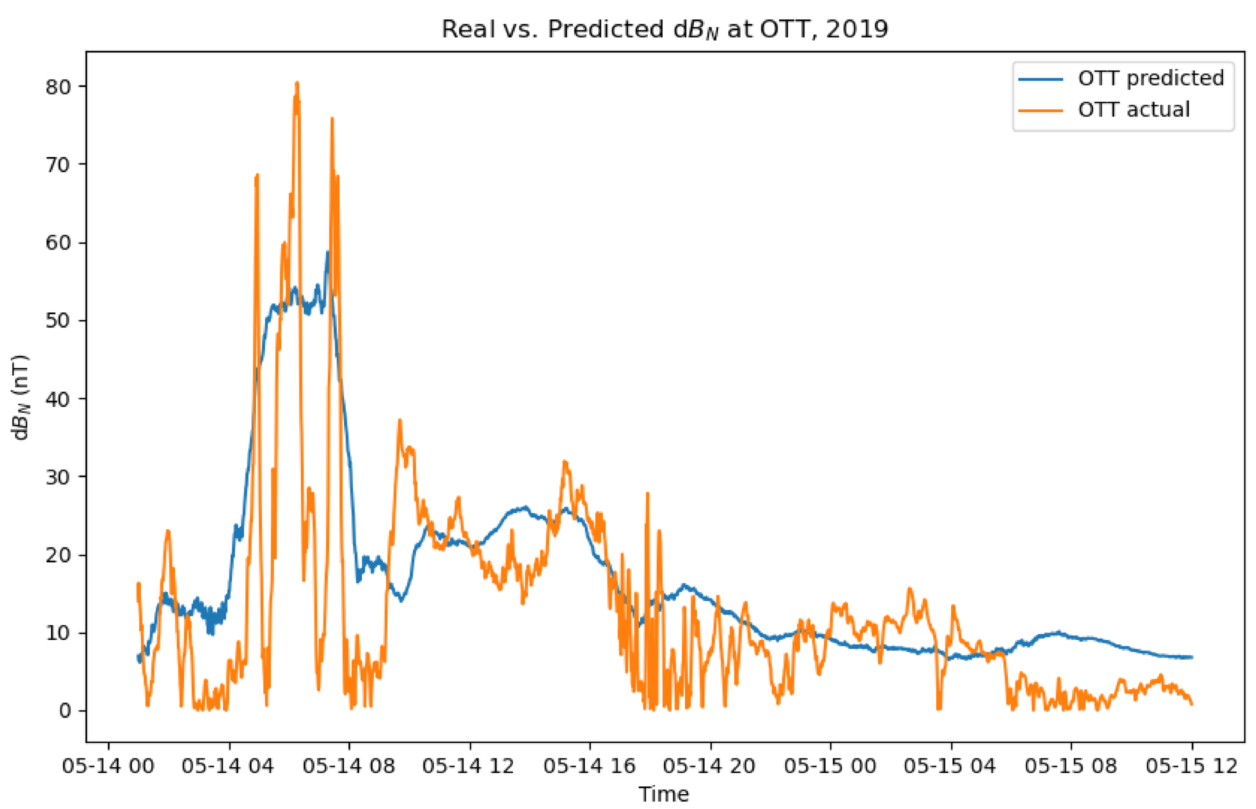


Results

This grid-search optimization reveals that, for our set of magnetometers and our region of interest, the best Spherical Elementary Current Systems interpolation of $d\mathbf{B}_H$ forecasts uses a grid of elementary current systems with 4 rows, 11 columns and an ε value of 0.001.

Our analysis has shown that these hyperparameters are not sensitive to small changes in the model (*e.g.,* small changes in the number of neural network nodes or in the size of the region of interest). However, for major changes, such as forecasting GICs in Europe instead of North America, the hyperparameters must be carefully reselected.





Additional MAGICIAN Team Presenters

- Amy Keesee (poster)
- Michael Coughlan (poster)
- Victor Pinto (poster)
- Talha Siddique (poster)
- Sai Gowtam Valluri (talk)
- Matthew Blandin (poster)
- Dogacan Ozturk (poster)
- Jasmine Kobayashi (poster)

Acknowledgements and References

This work is supported by NSF EPSCoR T-2 Award #1920965

- Ngwira *et al.* 2015. Characteristics of extreme geoelectric fields and their possible causes: Localized peak enhancements.
- Amm & Viljanen 1999. Ionospheric disturbance magnetic field continuation from the ground to the ionosphere using spherical elementary current systems.
- OMNIWeb data taken from omniweb.gsfc.nasa.gov
- SuperMAG data obtained from supermag.jhuapl.edu