



A Regional dB/dt Forecast Using Deep Learning and Spherical Elementary Current Systems

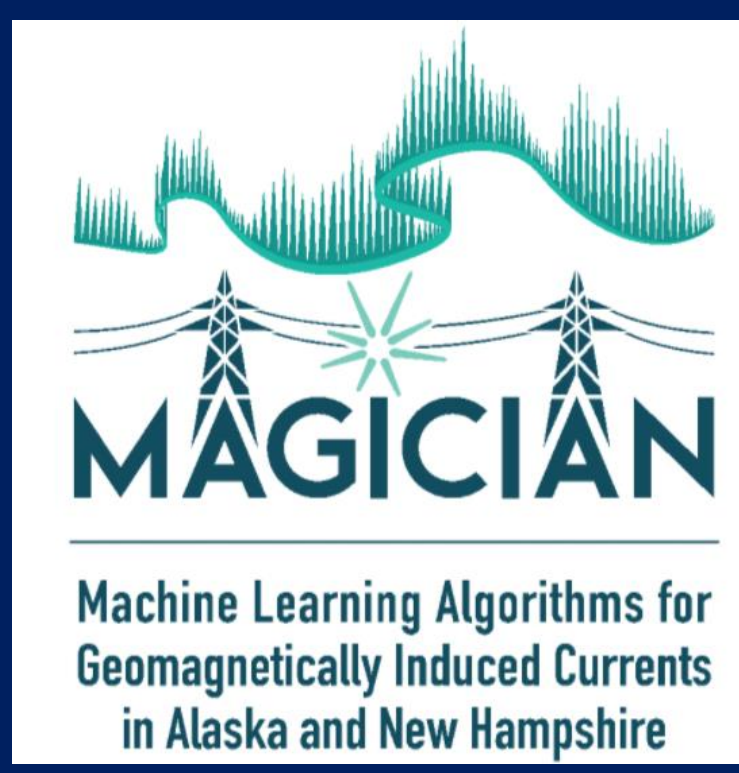
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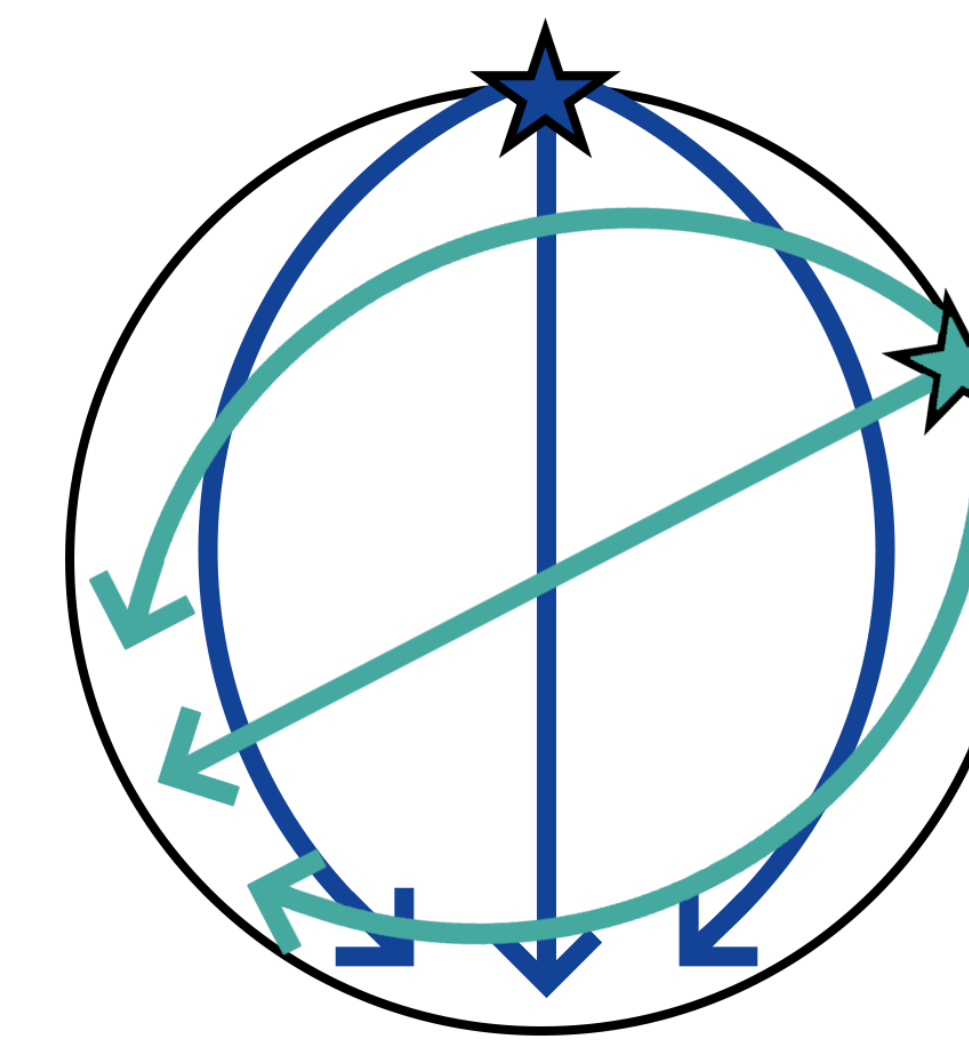
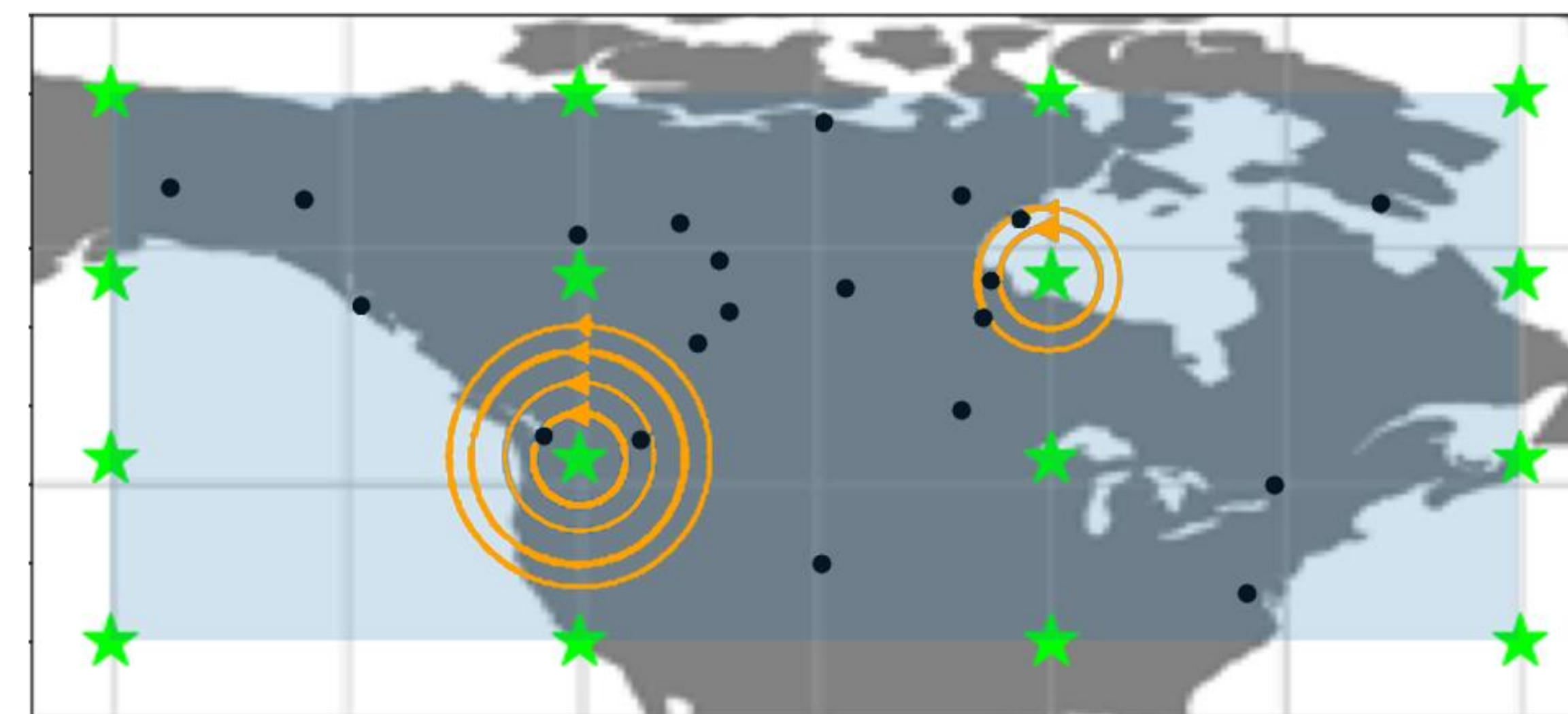
Overview

- 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.
- Fluctuations in the horizontal component of the ground magnetic field (dB_H/dt) are commonly used as a proxy for GIC measurements and forecasting.
- Fluctuations are often highly localized during geomagnetic storms. It is important to understand to what degree dB_H/dt is localized and why.
- We present a flexible deep learning model which predicts Spherical Elementary Current Systems coefficients in order to forecast dB_H/dt over large regions at high spatial resolution.
- This model will be a key component in upcoming data-driven studies of localized magnetic fluctuations.

Spatial Interpolation with Spherical Elementary Current Systems

How can we estimate dB_H/dt far away from magnetometer stations?

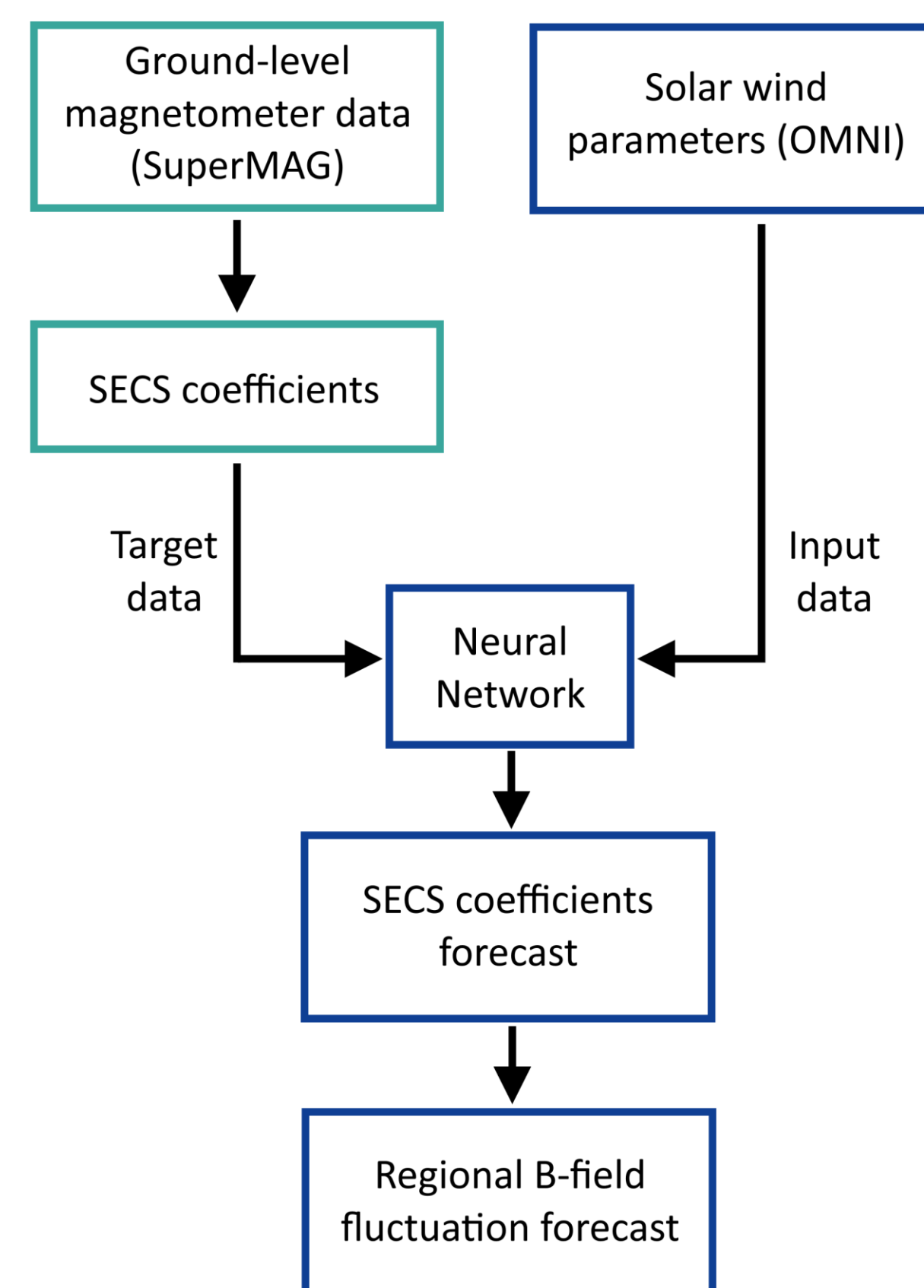
Spherical Elementary Current System (SECS) Interpolation. A hypothetical current sheet is constructed at ~ 100 km altitude. The vector field describing the current is expressed as a superposition of divergence-free basis vector fields, each centered at a different point on a latitude-longitude grid. In the superposition, each elementary basis field has a strength coefficient. We tune the values of each coefficient so that the overall current sheet reproduces the true B_N and B_E values at all magnetometers. The total current sheet is then related to the magnetic field via the Biot-Savart law.



Left figure: The green stars are hypothetical locations of Current Systems; the orange circulating fields around them show their contribution to the model current sheet. Each system contributes different amounts of current. The total model current sheet is the sum of each of these vector fields. The model current sheet is fit to measurements from magnetometers (black circles) inside the light blue rectangle.

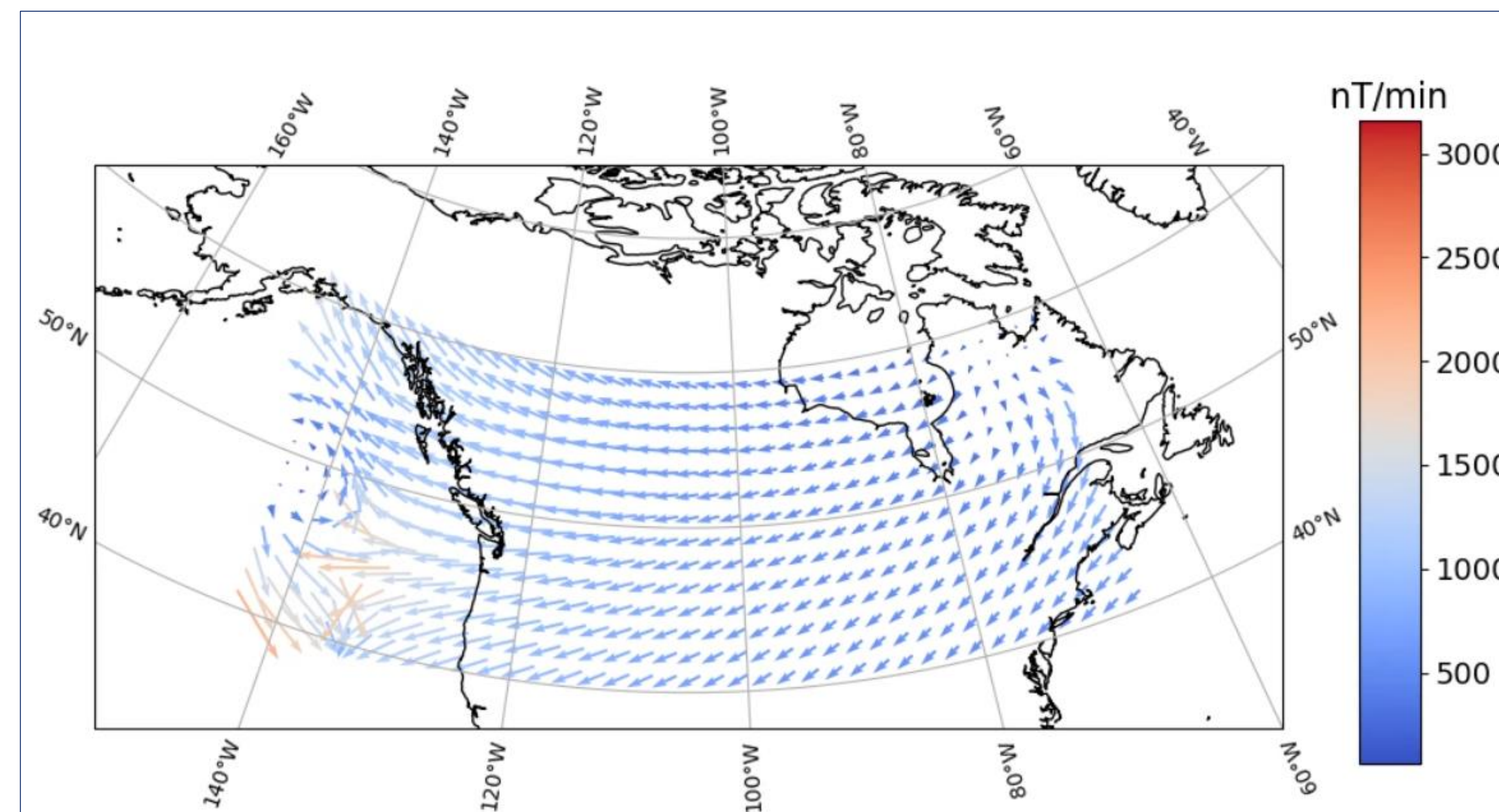
Right figure: The magnetic contribution of two example Current Systems are superposed to obtain the total ground magnetic field.

Forecasting Method



- Current System coefficients are predicted by a convolutional neural network. A max-pooling layer is inserted after each convolutional layer. The convolutional segment is then followed by a fully-connected segment with dropout regularization.
- Input data are 1-minute cadence OMNI data with 60 minutes of time history. Target data are 1-minute cadence Current System coefficients derived from North American SuperMAG magnetometers with >50% data availability. All data is from storm time.
- The model is validated at each magnetometer via a leave-one-out scheme.

Model Output: dB_H/dt Vector Maps



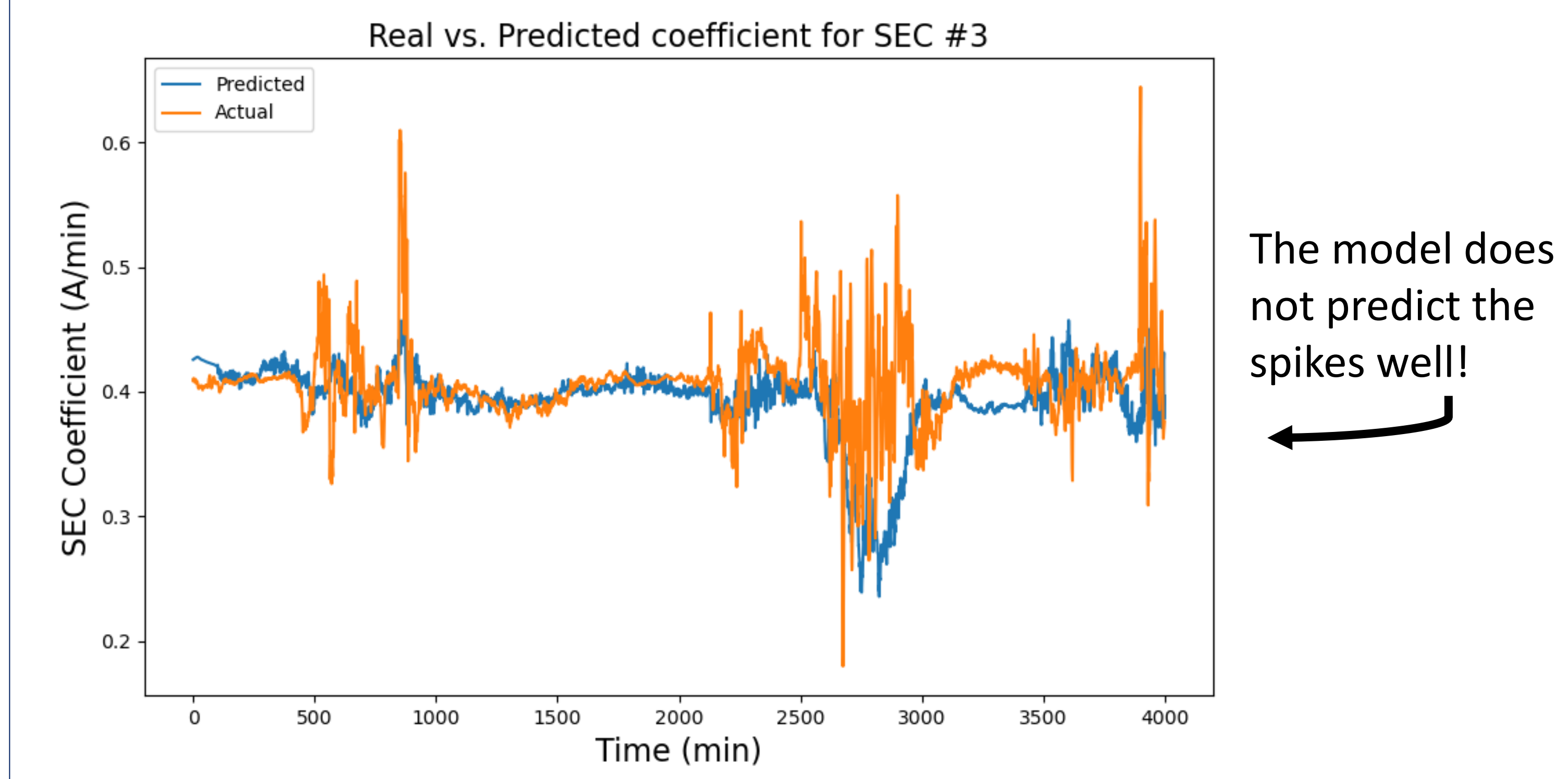
- This is a map of dB_H/dt generated using the SECS interpolation technique described in the section above.
- Though it still needs refinement, this method offers a versatile way to extend dB/dt forecasts beyond areas right next to magnetometer stations.
- Localized structures in both direction and in magnitude can be resolved.
- Vectors can be spaced arbitrarily tightly, though accuracy at small scales is limited by distribution of magnetometers as well as location inside the region of interest.



Watch an animation here!

Ways to Improve Model Performance

The combined SECS-CNN hyperparameter space is very large. A lot of time needs to be spent finding the right combination of hyperparameters for a given region of interest. Current System coefficients' time series can have larger and higher-frequency spikes than dB/dt time series. Spikes like these are generally difficult for machine learning models to predict. Therefore, forecasting dB_H/dt and then applying the SECS interpolation afterward might improve accuracy.



Acknowledgements and References

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- OMNIWeb data from omniweb.gsfc.nasa.gov
- SuperMAG data from supermag.jhuapl.edu
- Spherical Elementary Current Systems: Amm, O. (1997). Ionospheric elementary current systems in spherical coordinates and their application. *Journal of Geomagnetism and Geoelectricity*, 49(7), 947–955.