

Introduction

- ❖ The solar wind's interaction with the Earth's M-I system can cause Geomagnetically Induced Currents (GICs), which are hazardous to power and communications infrastructure.
- ❖ Fluctuations in the horizontal component of the ground magnetic field ($d\mathbf{B}_H$) or its time derivative are used as a proxy for GIC measurements.
- ❖ The fluctuations are often spatially localized during geomagnetic storms. Sparse magnetometer coverage makes studying these fluctuations difficult.
- ❖ Our goal is to obtain a $d\mathbf{B}_H$ forecast at every point in a large region using the Spherical Elementary Current Systems interpolation technique.
- ❖ We used a neural network to model the physics that connects the solar wind to $d\mathbf{B}_H$. Now we seek to modify the model for interpretability, eventually allowing us to explain localized areas of $d\mathbf{B}_H$ in terms of their M-I drivers.

Conclusions and Key Insights

- ❖ We have made progress towards a predictive model of across an entire region.
- ❖ The CNN model performs much better with very low initial learning rates ($\sim 10^{-9}$) with the Adam optimizer. This is because the large number of target features creates a "spiky" loss landscape.
- ❖ The loss is calculated from multiple target features by taking its mean across each target feature. This may destroy information that another loss function might preserve.
 - ❖ What are some possible alternatives?
- ❖ Other architectures will be investigated, e.g. XGBoost or chained multi-target regression.
- ❖ So far only solar wind inputs are used. The next iteration will include ionospheric data from sources such as DMSP and AMPERE.

Acknowledgements and References

- This work is supported by NSF EPSCoR T-2 Award 1920965 & NSF Award 2331527
- ❖ Amm & Viljanen 1999. *Ionospheric disturbance magnetic field continuation from the ground to the ionosphere using spherical elementary current systems.*
 - ❖ OMNIWeb data from omniweb.gsfc.nasa.gov
 - ❖ SuperMAG data obtained from supermag.jhuapl.edu

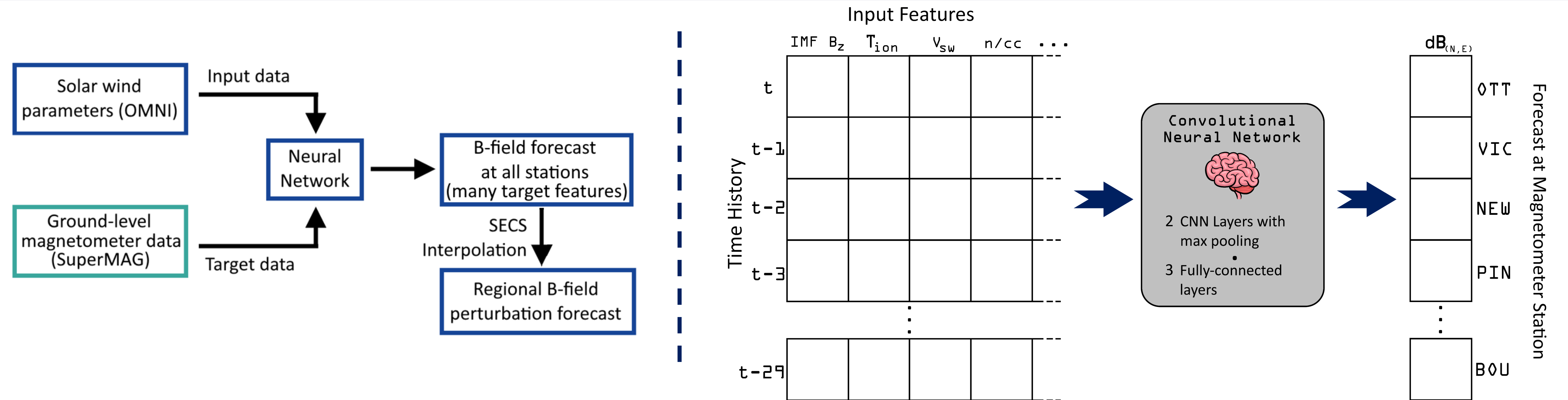


GitHub



Website

Magnetic Multi-Target Prediction



- ❖ A single convolutional neural network is trained to predict all magnetometers' measurements at once (24 target features).
- ❖ Theoretical Advantage: Information is shared between many of the target features, so as the model learns to predict one feature, it will learn a little bit about how to predict the other features.
- ❖ To help with the imbalanced dataset, the loss function is combination of **Mean Squared Error** and **Percentile Range Loss**. k is a constant and $P(D, q)$ is the q th percentile of D .

$$\text{Loss} = \text{MSE} + k \cdot \text{PRL}$$

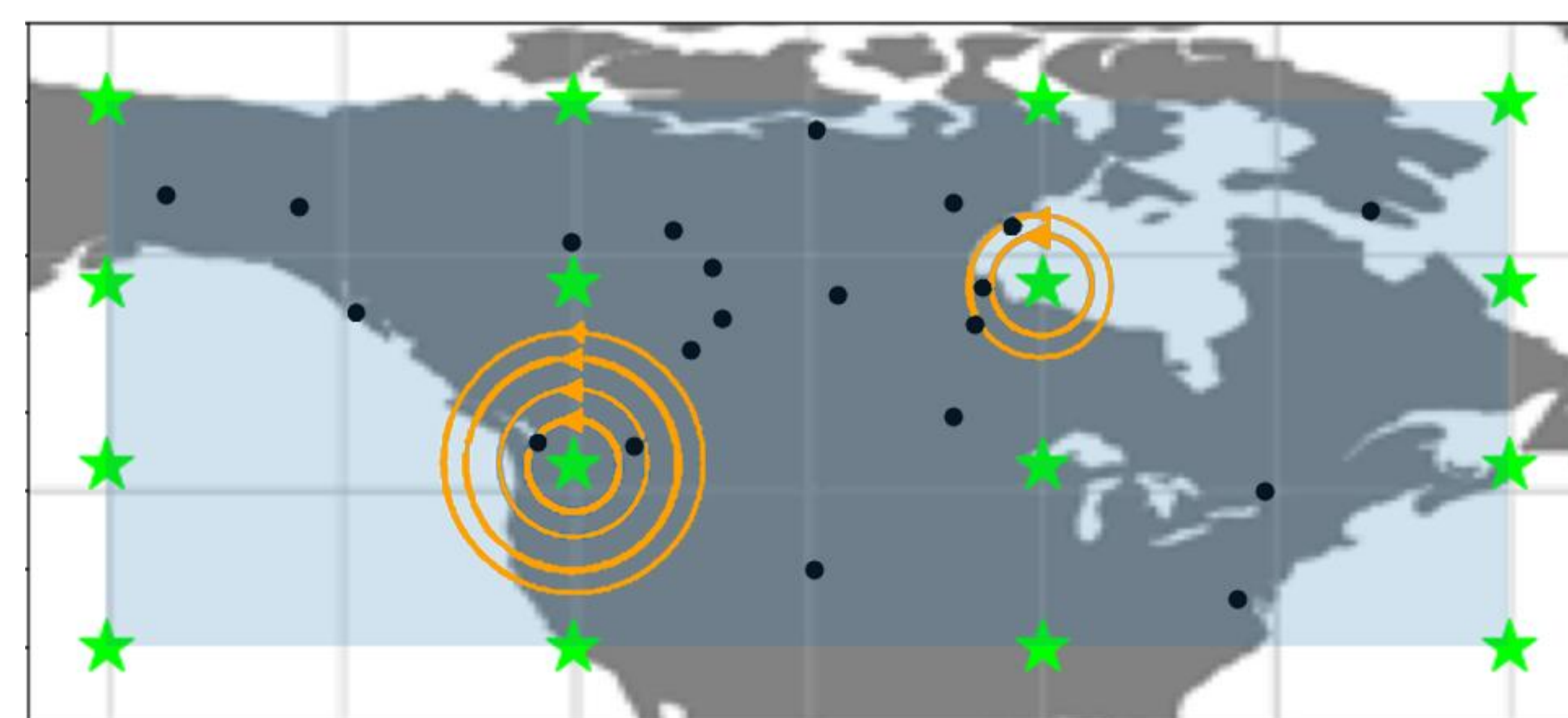
$$= \overline{(y_{\text{true}} - y_{\text{pred}})^2} + k \cdot \frac{\|P(y_{\text{true}}, 98) - P(y_{\text{true}}, 2) - P(y_{\text{pred}}, 98) + P(y_{\text{pred}}, 2)\|}{2}$$

The outputs of the neural network ($d\mathbf{B}_N$ and $d\mathbf{B}_E$ at each magnetometer station) are **spatially interpolated** in an electrodynamics-informed way to create a **forecast map over the entire region**.

Mapping the Magnetic Field with Spherical Elementary Current Systems

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

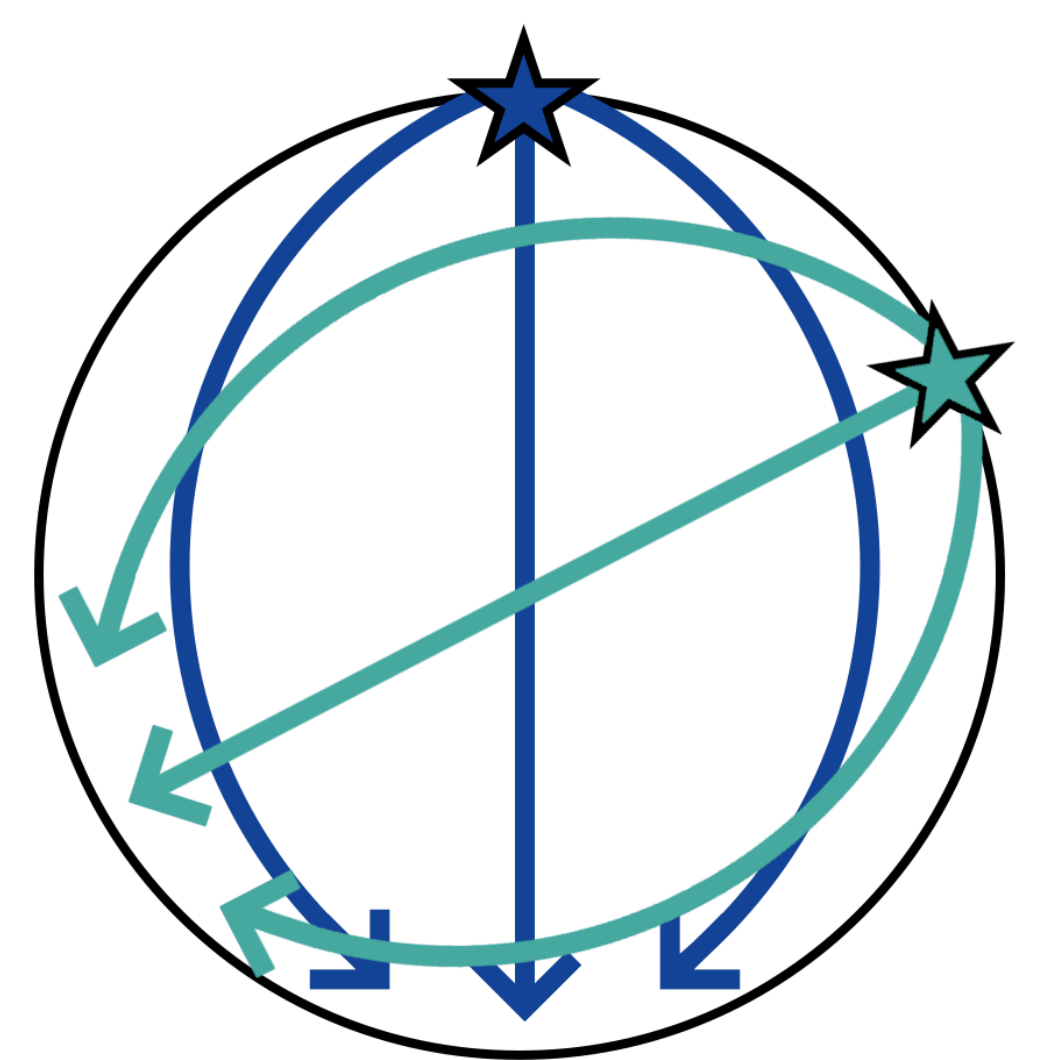
Spherical Elementary Current System (SECS) Interpolation. A hypothetical current sheet is constructed at ~ 100 km altitude. The vector field describing the current is expressed as a superposition of divergence-free basis vector fields, each centered at a different point on a latitude-longitude grid. 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 \mathbf{B}_N and \mathbf{B}_E values at all magnetometers. The total current sheet is then related to the magnetic field via the Biot-Savart law.



● = Magnetometer ★ = Current System Pole
 ← = Current Vector Field

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.



- ❖ The magnetometer forecast vector (CNN output) is used to fit a grid of Spherical Elementary Current Systems, representing ionospheric currents.
- ❖ From these currents, we derive 1-minute cadence $d\mathbf{B}_H$ values across the region during storm time in Solar Cycle 24 (2009-2019).
- ❖ Interpolations are validated by leaving each station out 1 by 1 and at comparing at that station's site.
- ❖ The entire process is differentiable (though not learnable), which enables certain attribution methods such as DeepLIFT and Integrated Gradients.
- ❖ An automated algorithm identifies localized geomagnetic disturbances (**black contours**) in the prediction.

