Analyzing the Influence of Ion Temperature Maps on Probabilistic Predictions of Localized Geomagnetic Perturbations

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MAGICIAN
Machine Learning Algorithms for Geomagnetically Induced Currents in Alaska and New Hampshire

Introduction

- Rapid changes in the ground magnetic field (dB/dt) can lead to Geomagnetically Induced Currents (GICs).
- Directly predicting dB/dt has shown to be challenging, as its variable nature is difficult to predict at one-minute resolution.
- dB/dt often exhibits large, highly localized spikes, showing substantial differences in measurements within small spatial areas which can be attributed to drivers originating in the ionosphere and magnetosphere [3].
- Region-to-Specific Difference (RSD) [2] is a parameter that can be used to quantify this localization effect and has been shown to correlate with solar wind parameters.
- Here we explore the effect of including ion temperature maps from the Two Wide-Angle Imaging Neutral-Atom Spectrometers (TWINS) on the prediction of the maximum RSD in a region (RSD_{max}) crossing a threshold value.
- We employ a Convolutional Neural Network for the predictions and utilize the SHapley Additive exPlanation (SHAP) method to determine how each of the inputs influence the model's predictions [1].

Method

- One CNN model was trained using only the solar wind and ground magnetometer data (SWMAG), and a second was trained with these datasets and included the ion temperature maps (TWINS). Dimensionality reduction of the maps was done using MaxPooling.
- The model predicts a probability that the RSD_{max} in the region will exceed the 99^{th} percentile.
- It outputs a mean (μ) and a standard deviation (σ) of a Gaussian distribution using the Continuous Rank Probability Score (CRPS), enabling us to understand the model's uncertainty in it's predictions.

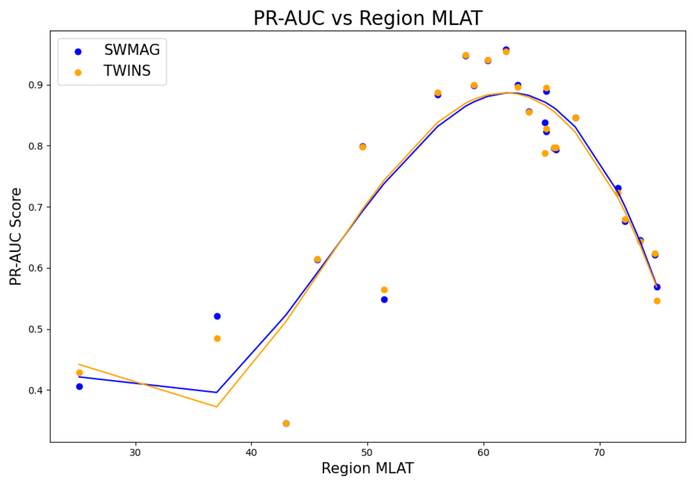

Figure 1. Area Under the Precision-Recall Curve (PR-AUC) for each region as a function of MLAT. Lower MLAT stations show worse AUC scores, with a peak seen between 55-65 MLAT, and a drop in scores at higher latitudes. Lines indicate polynomial fit to data used to emphasize the trend.

Identified Regions

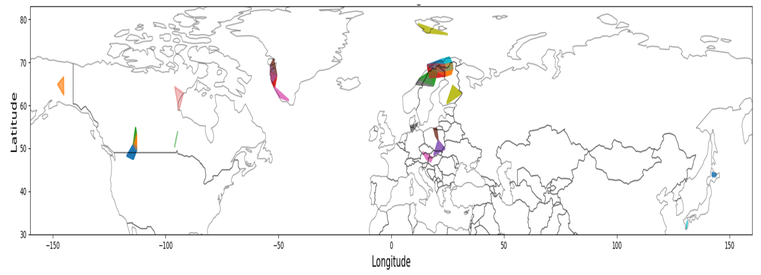

Figure 2. Regions identified for this study using a combination of automatic iterative searching and manual selection.

Model Predictions

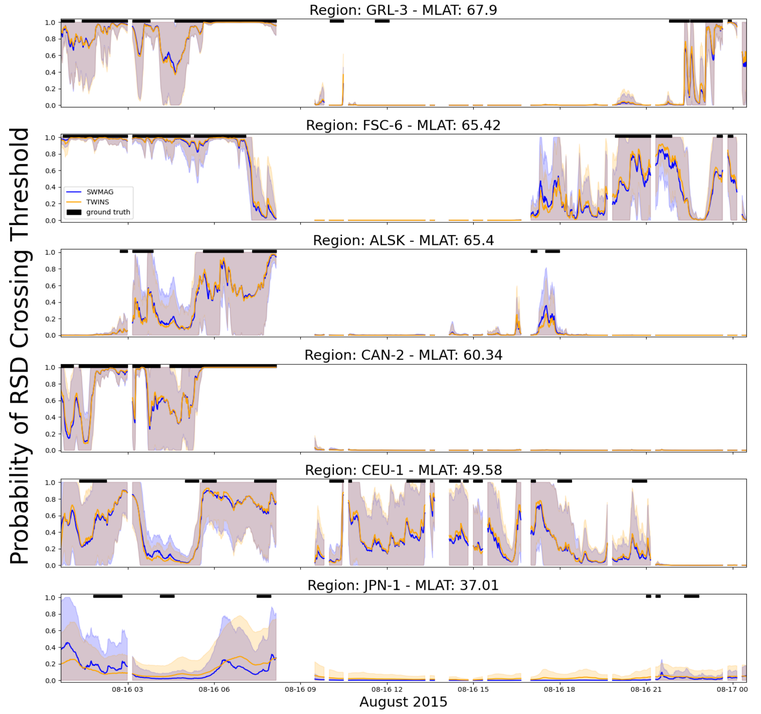

Figure 3. Model output comparisons for the SWMAG and TWINS models for a sample of examined regions. Black bar at the top of each panel indicates when the target class is positive (RSD_{max}) exceeds the threshold). The blue line (shading) indicates the mean(std) of the SWMAG model, and the orange the same for the TWINS model. The areas of overlap in shading appear grey.

References/Acknowledgements

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[1] M. Coughlan, A. Keesee, V. Pinto, R. Mukundan, J. P. Marchezi, J. Johnson, H. Connor, and D. Hampton. Probabilistic Forecasting of Ground Magnetic Perturbation Spikes at Mid-Latitude Stations. *Space Weather*, 21(6), June 2023.

[2] A. P. Dimmock, L. Rosenqvist, D. T. Welling, A. Viljanen, I. Honkonen, R. J. Boynton, and E. Yordanova. On the Regional Variability of d *B* /d *t* and Its Significance to GIC. *Space Weather*, 18(8), Aug. 2020.

[3] C. M. Ngwira, D. Sibeck, M. V. D. Silveira, M. Georgiou, J. M. Weygand, Y. Nishimura, and D. Hampton. A Study of Intense Local d *B* /d *t* Variations During Two Geomagnetic Storms. *Space Weather*, 16(6):676–693, June 2018.

DeepSHAP Contributions

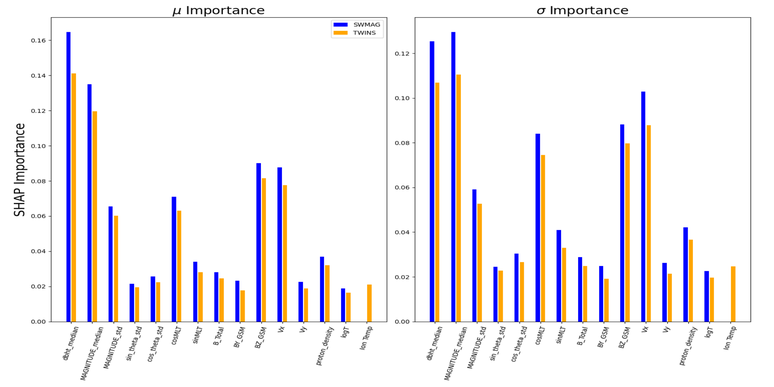

Figure 4. Averaged feature importance across all testing data as calculated by the DeepSHAP method. Left panel is the importance for the mean of the Gaussian distribution as output by the CRPS loss function, right panel is the importance for the standard deviation of that Gaussian. Blue results are for the SWMAG model and orange for the TWINS model. SWMAG results are higher by default because there is one less parameter contributing to the overall importance percentages.

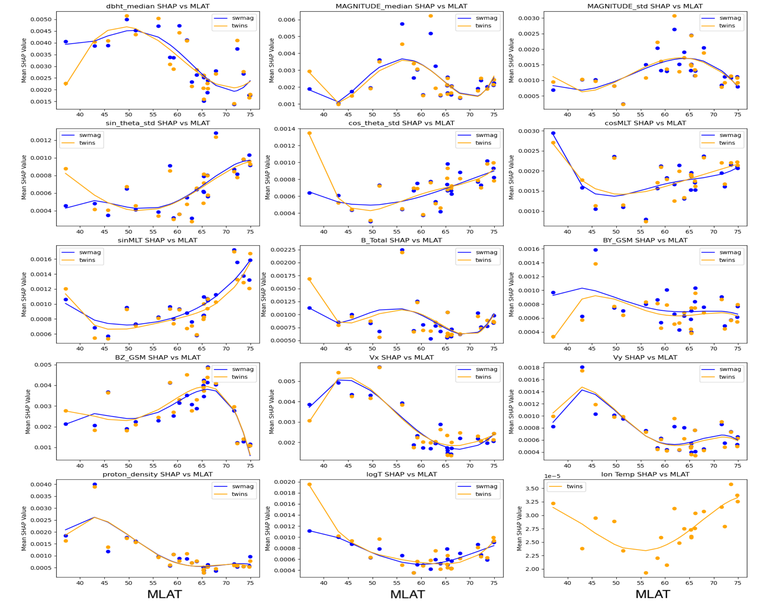

Figure 5. Importance of each feature as a function of the region MLAT. Scatter plots indicate the median feature importance across all of the test data for each variable. Lines are polynomial fit to the data.

Conclusions

- Both versions of the model show skill in their ability to forecast RSD_{max}, but the affect of including the ion temperature maps is minimal.
- Models show best skill in the 55-65 MLAT range with degraded performance at low and high magnetic latitudes.
- cosMLT shows more importance than sinMLT, indicating the model is sensitive to the noon and midnight MLT ranges.
- A dependence exists between the region's MLAT and the affect of different input parameters on the model's output.

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