Uncovering the Relationships between Localized Geomagnetic Disturbances and the Solar Wind

Raman Mukundan[1,2], Amy Keesee[1,2], José Marchezi[2], Mike Coughlan[1,2], Victor Pinto[3], Don Hampton[4]

[1]*Department of Physics and Astronomy, University of New Hampshire*
[2]*Institute for the Study of Earth, Oceans, and Space, University of New Hampshire*
[3]*Departamento de Física, Universidad de Santiago de Chile*
[4]*Geophysical Institute, University of Alaska Fairbanks*
GEM Summer Workshop 2024

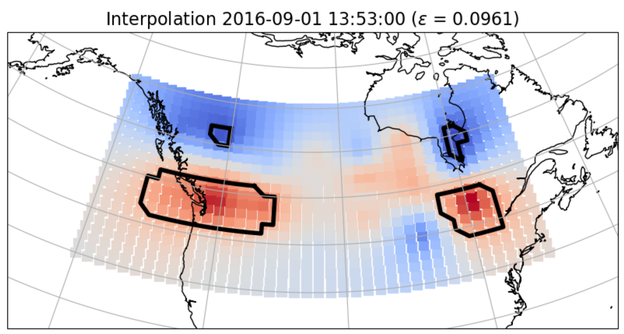
MAGICIAN — Machine Learning Algorithms for Geomagnetically Induced Currents in Alaska and New Hampshire

Introduction

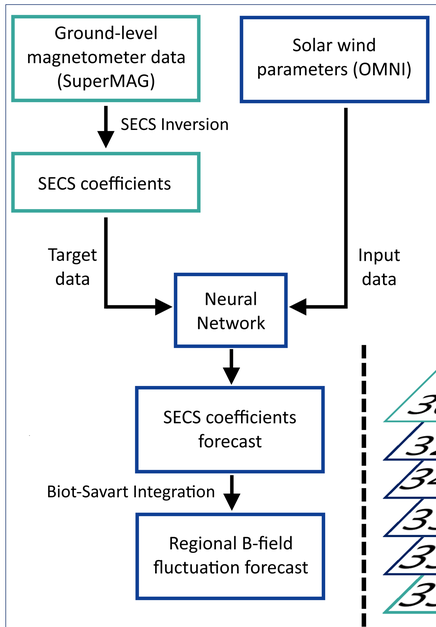
- The solar wind's interaction with the Earth's magnetic field can cause Geomagnetically Induced Currents (GICs), which are hazardous to power and communications infrastructure.
- Disturbances to the horizontal component of the ground magnetic field ($d\mathbf{B}_H/dt$) are commonly used as a proxy for GIC measurements and forecasting.
- Localized geomagnetic disturbances (LGMDs) often arise during geomagnetic storms. It is important to understand to what degree $d\mathbf{B}_H$ and $d\mathbf{B}_H/dt$ are localized and why.
- We use the Spherical Elementary Current Systems interpolation technique to build a statistical picture of LGMDs' spatial attributes, refining our previous work.
- We model the physics that connect the solar wind to LGMDs with a neural network, then perform a sensitivity analysis to interpret the neural network's understanding.

Mapping the Magnetic Field

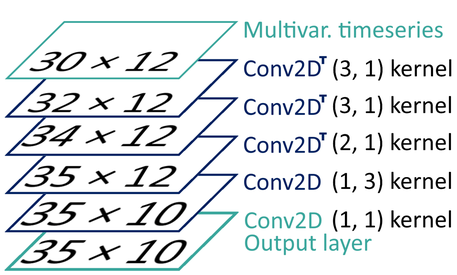
1. SuperMAG data from 25 North American stations with the best availability used to fit a grid of Spherical Elementary Current Systems.
2. Interpolate 1-minute cadence SuperMAG $d\mathbf{B}_N$ measurements during storm time in Solar Cycle 24 (2009-2019).
3. Draw contours around areas with high absolute deviation from baseline – these are LGMDs!
4. Compute the number of LGMDs in each 1-minute "snapshot", and their perimeters and latitude-longitude aspect ratios.



Bowshock to the Ground with a Neural Network

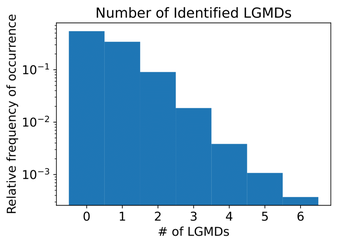


- Current System coefficients are predicted with a convolutional neural network (CNN) to account for the relative locations of the Current Systems.
- A sequence of convolutional and transpose-convolutional layers transforms a multivariate timeseries "image" into a grid of Current System coefficients.

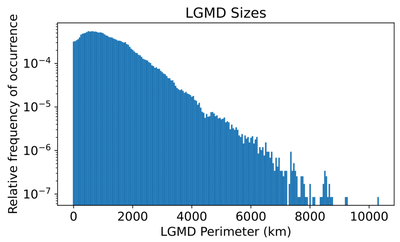


Statistics of Localized Geomagnetic Disturbances

We compute statistics about LGMD spatial scales on our entire dataset of 395,463 timesteps from all storm time in Solar Cycle 24.
(This does not yet involve the CNN. See the "Sensitivity Analysis" panel for a preliminary replication of these results with the CNN.)

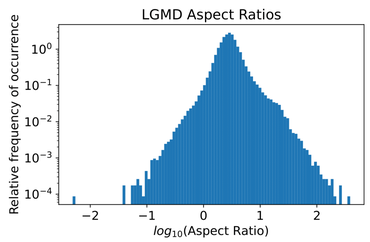


About 46% of timesteps during geomagnetic storms contain at least one LGMD

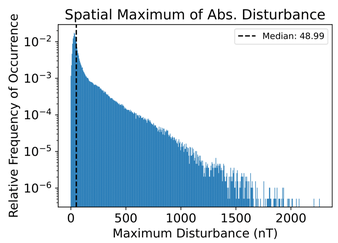


Typical perimeter of LGMDs (~1000 km) agrees with a few-hundred-kilometer scale as estimated in the literature

E.g., Dimmock et. al (2020), Dimitrakoudis et al. (2022)



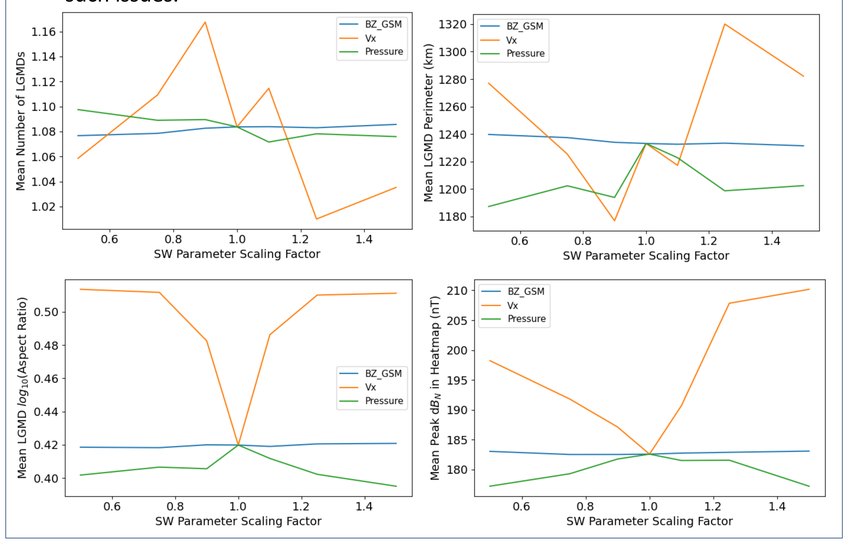
Over 98% of LGMDs are extended further in the east-west direction than they are in the north-south direction



The maximum $|d\mathbf{B}_N|$ in the entire heatmap rarely exceeds 100 nT, but it has a large range

Sensitivity Analysis of the Neural Network

- Three solar wind parameters were varied one at a time (OAT) by multiplying their timeseries by a scaling factor, leaving the other parameters unchanged.
- The altered multivariate timeseries is used as input to the CNN to produce a new set of heatmaps and distributions like those in the panel to the left. This process is then repeated using a different scaling factor.
- A "V" or "Λ" shape could suggest the CNN has not properly learned the relevant physics. We plan to experiment with new CNN architectures to solve such issues.



Acknowledgements and References

This work is supported by NSF EPSCoR Award OIA-1920965 and 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