Global Earth Magnetic Field Modeling and Forecasting with Spherical Harmonics Decomposition

Panagiotis Tigas*
OATML
University of Oxford, UK

Téo Bloch*
University of Reading, UK

Vishal Upendran*
IUCAA
Pune, India

Banafsheh Ferdoushi*
University of New Hampshire
Durham, NH, USA

Yarin Gal
OATML
University of Oxford, UK

Siddha Ganju
NVIDIA Corporation
Santa Clara, CA, USA

Ryan M. McGranaghan
ASTRA LLC
Louisville, CO, USA

Mark C. M. Cheung
Lockheed Martin ATC
Palo Alto, CA, USA

Asti Bhatt
SRI International
Menlo Park, CA, USA

https://sites.google.com/view/geoeffectivenet/

PROBLEM SETTING

Motivation

Geoeffectiveness characterizes impact of solar storms on terrestial systems, defined on a global scale through "geomagnetic indices" that give an indication of activity. Driven by geomagnetic field perturbations, measured by ground magnetometers on Earth's surface.

Challenge

Disturbances starting from the Sun reprocessed by Earth's magnetospere reach the ground: (1) Single spatial point measurement of the solar wind a proxy for the 3D solar wind structure. (2) Perturbations on the ground sampled sparsely by magnetometers. (3) Need to *connect the dots* from the solar wind to the global impact of Earth.

Contributions

1. *Spherical Harmonics* based, *compressed sensing* technique to recover global maps of the geomagnetic perturbation from sparse measurements. Improve of temporal candence by >**10x**.
2. *Deep Spherical Harmonics* model for forecasting geomagnetic disturbances from solar wind data, improving over the state-of-the-art [3] by **14.53%** (`SuperMAG[1]` evaluation) and **24.35%** (MHD evaluation)

SPHERICAL HARMONICS

RECONSTRUCTION ← BASED → FORECASTING

Data

1. `SuperMAG` [1] measurements (data from 2013)
2. `MHD` simulation (`OpenGGCM`) for same dates

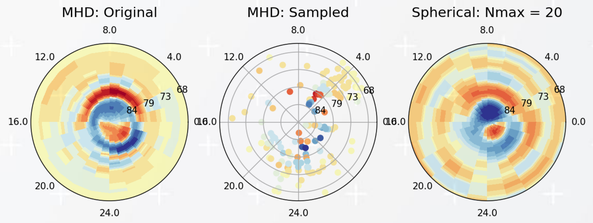


Fig 1. `MHD` simulation sampled at `SuperMAG` locations as input for reconstruction

Method

LASSO regression on Spherical Harmonics to obtain sparse representation of global ΔB.

- **Hyperparameters:** Max no. of modes and LASSO penalty α.
- Parameter sweeps to minimize L1 error and maxximize coefficient of determination (R2) using least mossible number of modes.
- Find the "knee" of performance enhancement.

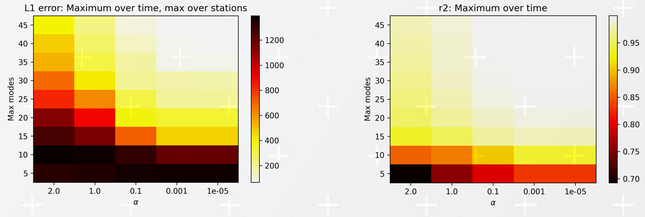
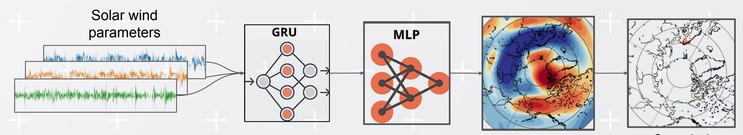


Fig 2. 20 maximum modes and $\alpha = 0.1$ selected for this work



Model: GRU-based RNN to MLP
Input: 25 mins long past Solar Wind data [2]
Output: Spherical Harmonics of global geomagentic perturbations of 20 minutes into the future.

Model	`SuperMAG` (val) RMS (nT) ↓	`MHD` RMS (nT) ↓
Ours.	**24.23**	**27.02**
Weimer [2013] model	28.35	35.72

Table 1. Forecasting model Performance

REFERENCES

1. Gjerloev, J. W. "The SuperMAG data processing technique." Journal of Geophysical Research: Space Physics 117.A9 (2012).
2. Papitashvili, Natasha, Dieter Bilitza, and Joseph King. "OMNI: A Description of Near-Earth Solar Wind Environment." cosp 40 (2014): C0-1.
3. Weimer, Daniel R. "An empirical model of ground-level geomagnetic perturbations." Space Weather 11.3 (2013): 107-120.