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Modeling and Forecasting Ground Geomagnetic Perturbations using Deep Learning on Spherical Harmonics Decomposition

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Geomagnetic induced currents (GICs) are an important consequence of geomagnetic disturbance on the Earth, and they could impose hazards to our infrastructures like power grids, oil pipelines, railways, and telecommunication systems. Accurate estimation of GICs are required for reliable space weather prediction capability and for mitigation strategy on the Earth. The challenge, however, is that GICs data is not readily available except until recently for extreme cases. On the other hand, GICs are partly driven by the rate of change in ground magnetic perturbations (dB/dt) which can be measured on the Earth surface by ground magnetometers. There has also been a modeling effort to predict dB/dt across the globe. For example, physics based numerical magnetohydrodynamic models (MHD) have been in operation in NOAA Space Weather Prediction Center for a couple of years. The challenge, however, with current forecasting models is that either they are computationally expensive (such as MHD models) while not capturing important small-scale structures measured on the ground, or use averaged geomagnetic and solar wind measurements within empirical models that do not provide a dynamic forecast and only produce a statistical representation of behavior.

In this study, we created a high-resolution (spatial and temporal) global model of ground geomagnetic perturbation by applying a compressed sensing technique to decompose global geomagnetic variations in terms of Spherical Harmonics down to 1 min cadence, based on sample measurements from the SuperMAG network. The model is evaluated by sampling ground perturbation from MHD simulations at SuperMAG locations, and comparing the reconstruction with the ground truth MHD data as well as Wiemer 2013 model. We also developed a forecasting model in Spherical Harmonics using solar wind measurements from Lagrangian point 1 (from the OMNI database) to predict global magnetic perturbation on the ground by using a Deep Neural Network. The model performance was evaluated and has improved the performance in the Wiemer, 2013 model by 14% and MHD simulation by 24%.

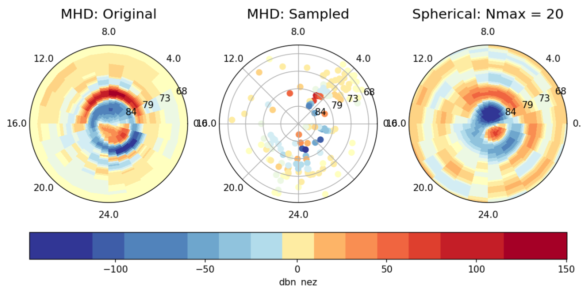

Figure 1. Comparison of reconstruction with the MHD simulation. Left: MHD simulation; Center: MHD simulation sampled at SuperMAG station locations; right: Reconstruction.