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Prediction of Global Geomagnetic Field Disturbances using Recurrent Neural Network: Preliminary results

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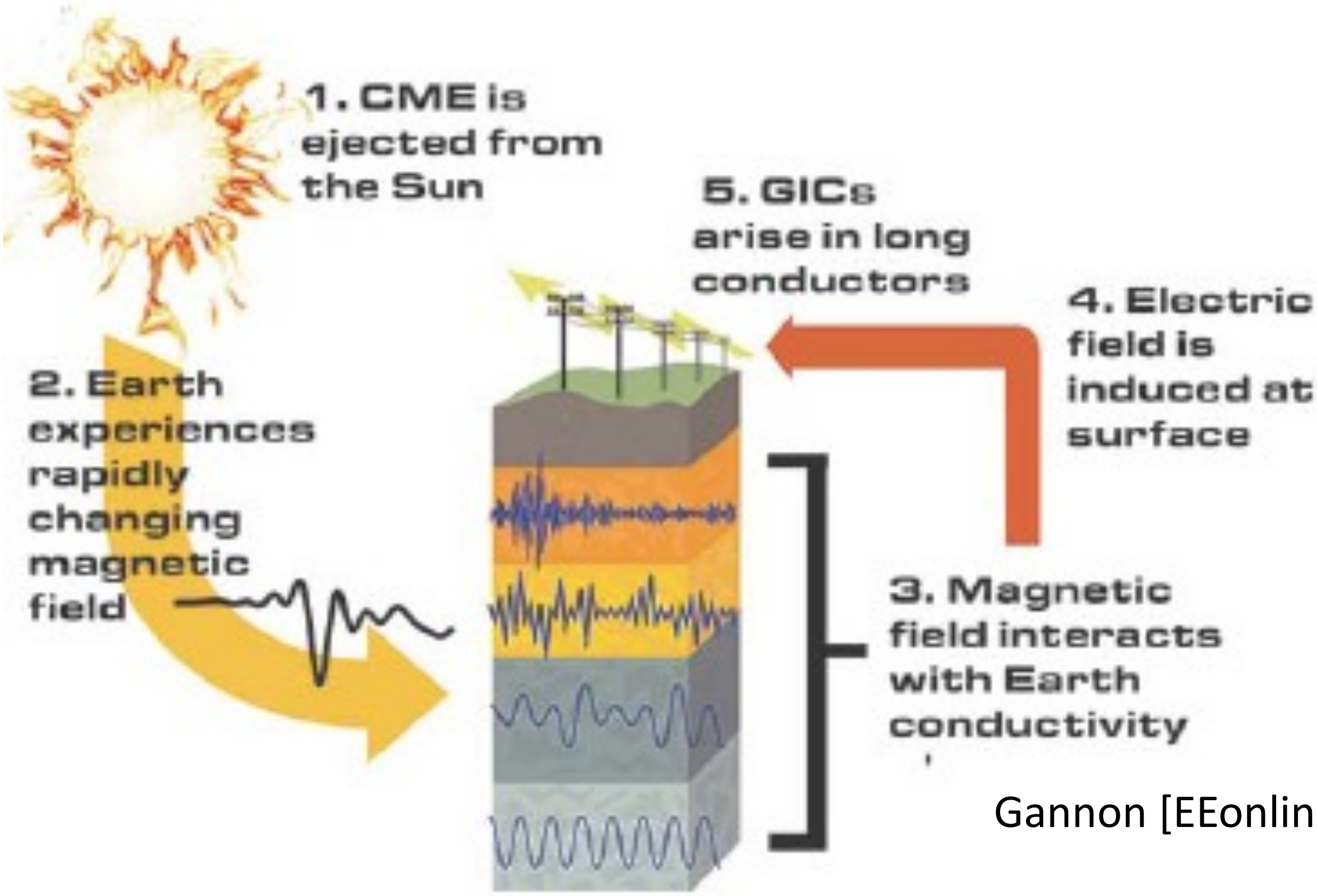
Motivation
Forecast of Geomagnetically Induced Currents (GICs)



Gannon [EEonline, 2016]

- Worldwide/Nationwide GIC data are not available
- Our study focuses on large geomagnetic field disturbances, a trigger of GICs.

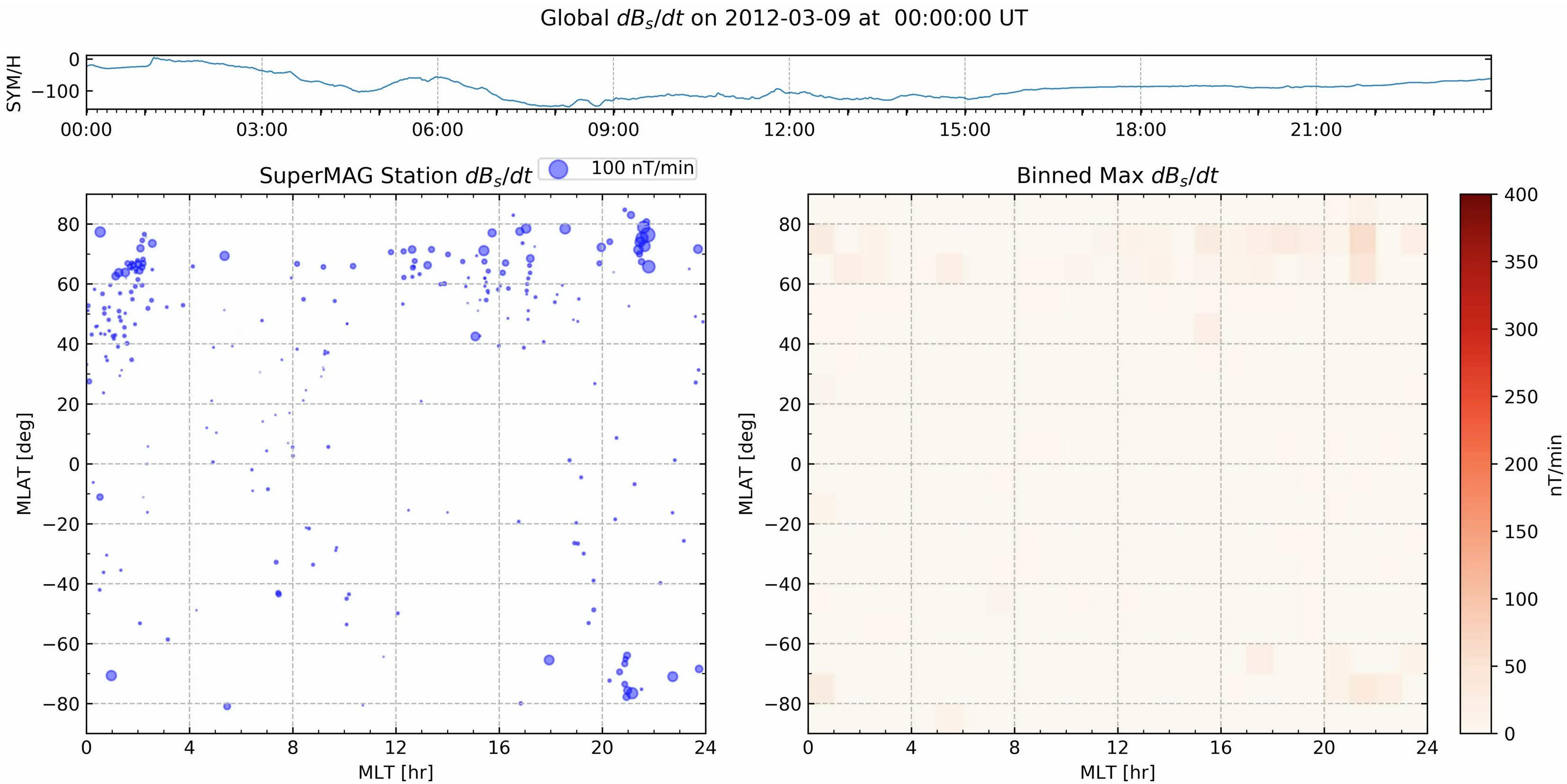
Recurrent Neural Network (RNN) for predicting geomagnetic field disturbance (dB/dt)

- DATA:
  - OMNI solar wind and IMF conditions in 2012 and 2015
  - SuperMAG surface & vertical disturbances (i.e., dBs/dt & dBz/dt) in 2012 and 2015
  - 80% for training, 20% for validation to determine the best input combination, and the 2012-03-09 storm for testing

- Method: Multi-variate Long Short Term Memory (LSTM) network
  - 50 neurons in a single hidden layer, 50 epochs with a batch size of 72
  - Adam's stochastic gradient decent as an optimization algorithm
  - Mean absolute error as a loss function

- Two machines are trained for dBs/dt and dBz/dt predictions.
  - Input: IMF Bz, Solar Wind Density, dBs/dt (or dBz/dt) at a present minute (t-1)
  - Output: dBs/dt (or dBz/dt) at the next minute (t)

SuperMAG Data Binning



- To provide an even spatial resolution, we binned SuperMAG data into 10° MLAT x 1hr MLT grids and select max dBs/dt and max dBz/dta in each bin as our dataset.

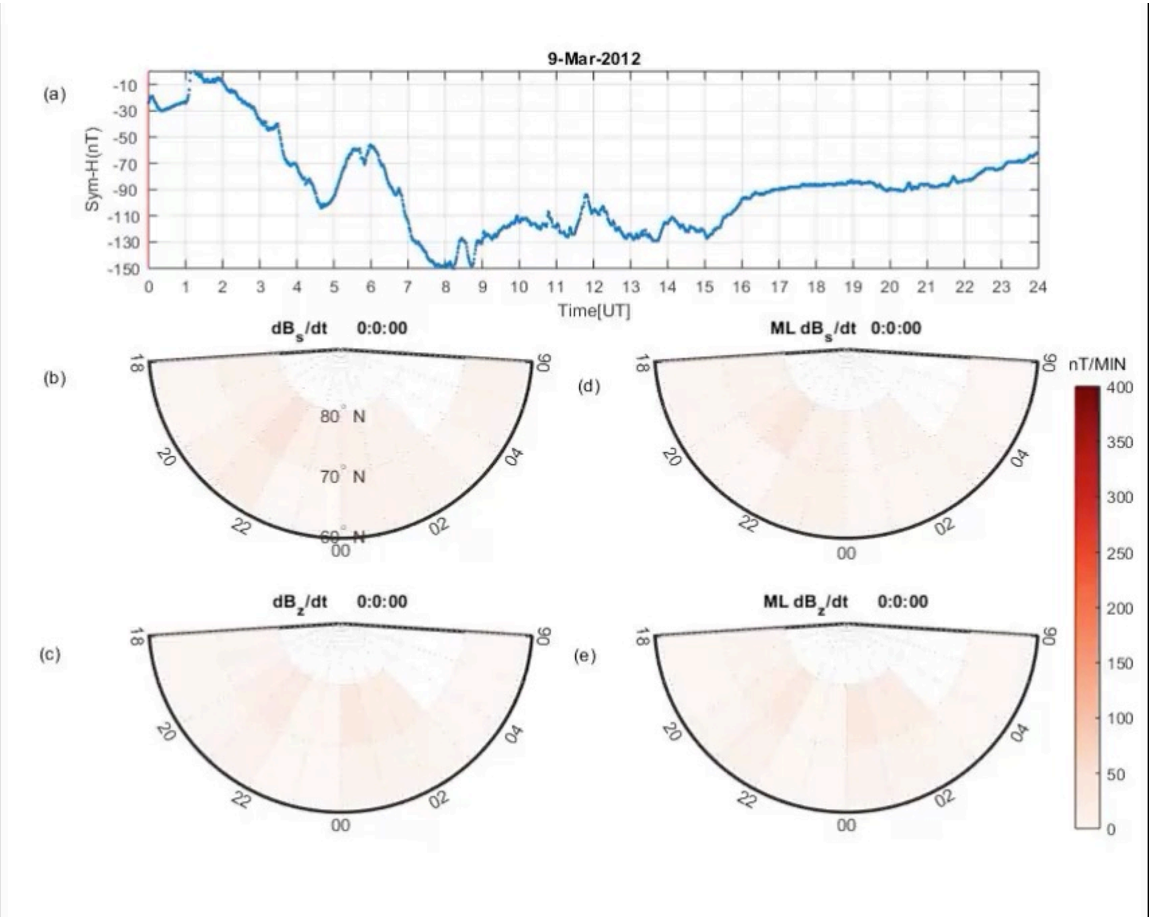
- We consider 100nT/min as a minimum dB/dt that triggers GICs.

Model Results over the Nightside Northern Hemisphere

Sym-H

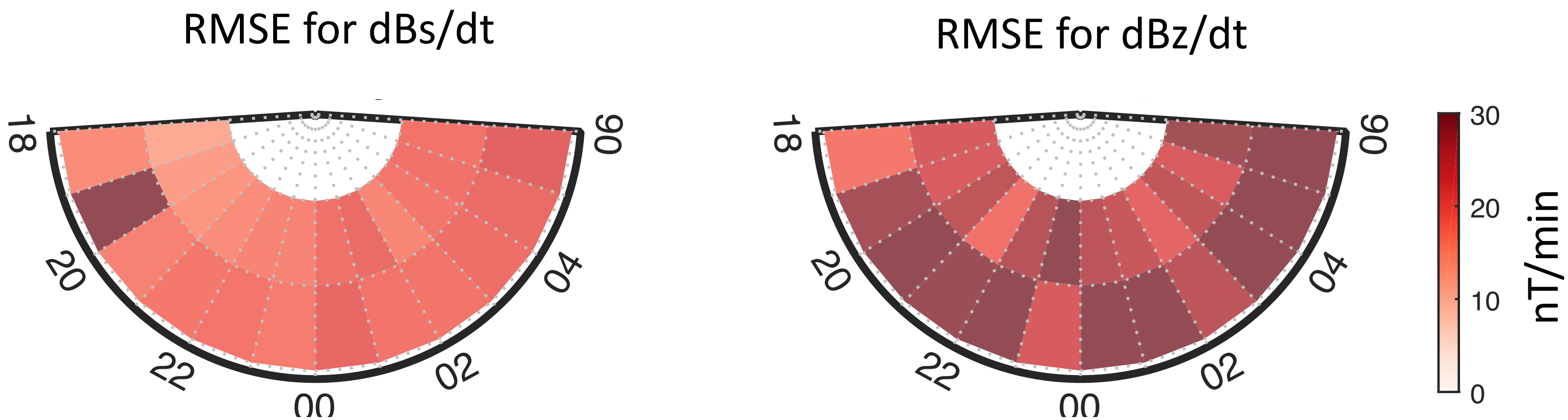
dBs/dt

dBz/dt



Our machine-learned predictions (right) show a good agreement with the binned SuperMAG data (left) on a larger spatial scale

Model Results over the Nightside Northern Hemisphere



Considering ± 30nT/min of RMSE, our machine may miss or falsely predict ~100nT/min of geomagnetic disturbance.

However, it won't be troublesome to forecast several hundreds nT/min that potentially produces a catastrophic GIC event.

Improvement needed in future

- Train machines with longer periods of data.
- Use a longer time history of input (e.g. 60 mins of SW/IMF data).
- Remove dBs/dt and dBz/dt from the input.
  - Our current model may find stronger correlation with dB/dt at t-1min.
- Consider sophisticated solar wind propagation from the bow shock to each bins.
  - 60min delay from the bow shock to the nightside bins were assumed.
- Consider finer spatial resolution for higher latitude
- Use better validation techniques than RMSE [Welling et al. SW2018; Maimaiti et al. SW2019; Camporeale. JGR 2020]
- Use different machine learning techniques
  - Multi-layered LSTM, Artificial Neural Network, Convolutional Neural Network, Principal Component Analysis, etc.

Summary

- We developed a prototype of a machine-learned global dB/dt model using multi-variate LSTM.
- We trained a machine using the OMNI solar wind/IMF data and the SuperMAG data in 2012 and 2015.
- The prototype model catches over 100nT/min of dB/dt relatively well on 09 Mar 2012 geomagnetic storm.
- Once matured, this model can provide an advanced warning of Geomagnetically induced currents (GIC) that typically comes with large dB/dt.

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What did I learn as a ML beginner?

- I feel dumb. Many mistakes.

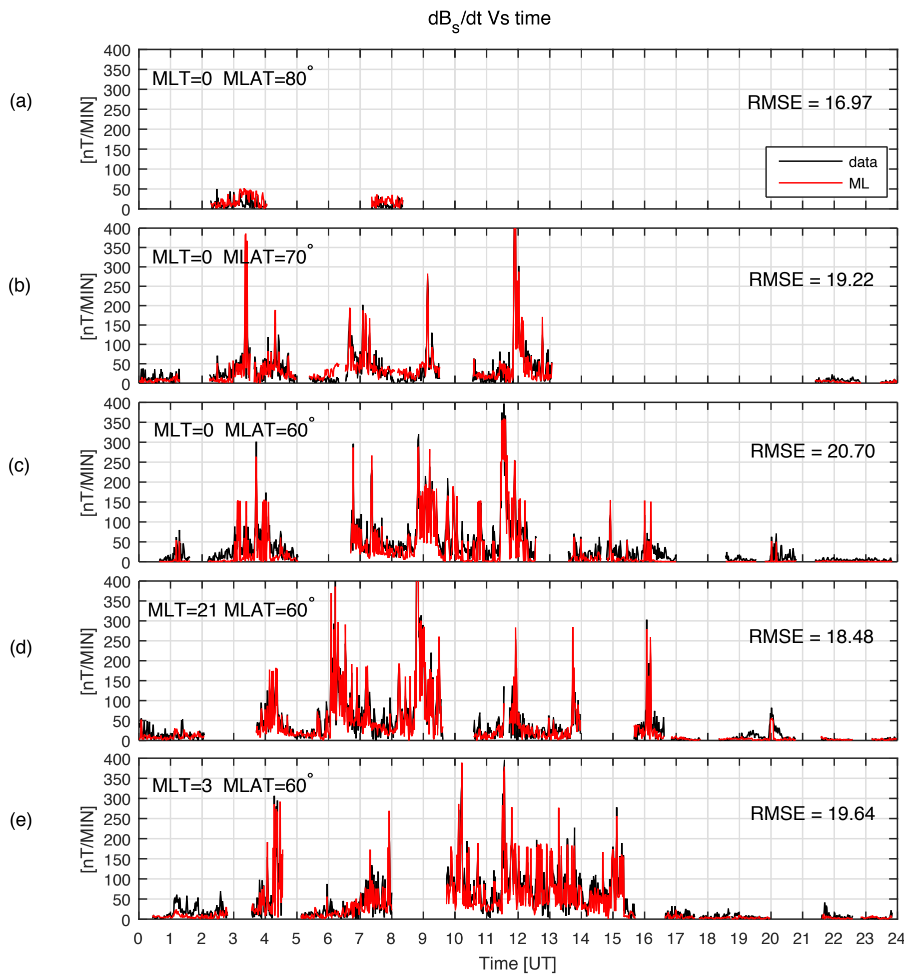
- Machine-learning is not a magic, but a good tool if we use it well.

- The users' view on how to use data and what to predict is important.
  - Data binning, mining, etc.
  - Binary (yes/no) and value predictions

- Machine-learned models can be a good alternative of current empirical models (Weimer, Tsyganenko, Ovation-PRMIE, etc) in future.

Thank you!

Model Results
dBs/dt vs time at 5 local bins



The machine-learned dBs/dt prediction at five local bins (red) follows a general trend of the binned SuperMAG data (black).

The RMSE ranges 17 – 21 nT/min, relatively smaller than 100 nT/min, minimum dB/dt of our interest (i.e., minimum dB/dt for GICs)