Low-latency modeling of near-Earth-space magnetic fields for resource exploration

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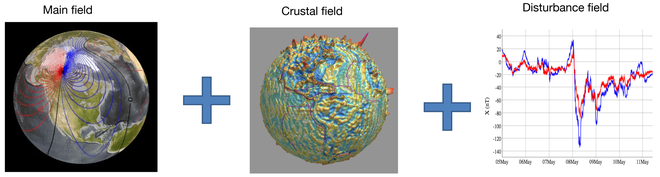
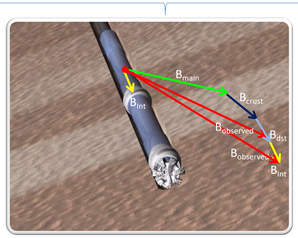
1. A natural reference for underground navigation

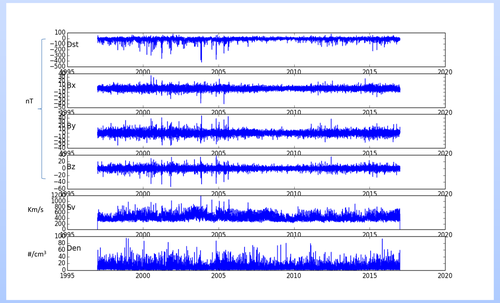
NOAA's National Centers for Environmental Information (NCEI), in partnership with the University of Colorado and industry develops geomagnetic field models to be used by directional-drilling companies to navigate underground. The magnetic field measured by a sensor near Earth's surface is the sum of magnetic field generated by a variety of sources. NCEI's High Definition Geomagnetic Model - Real Time (HDGM RT) models the core, crustal and disturbance magnetic field and provide it to the customers in real-time.

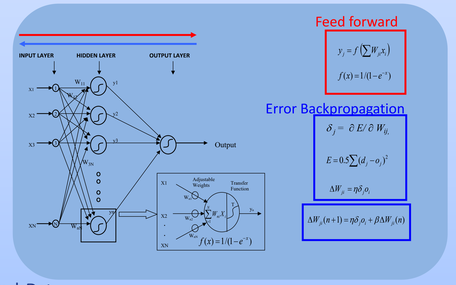




3. Improving the latency of magnetic disturbance predictions using machine-learning modeling

- To reduce our prediction-latency, we developed a Machine-learning (ML) model to derive a key model input (*Disturbance-storm-time index, Dst*)
- One-step ahead Dst prediction solely based on solar-wind data.
- We use the solar wind magnetic field, plasma velocity and density measured at Lagrangian point L1.
- Trained a Recurrent-Neural-Networks (RNNs), and specifically a variant with Long Short-Term Memory (LSTM),
- Validated the ML model on test data and against other predictive models of *Dst*





$$y_j = f\left(\sum W_{ji} x_i\right)$$

$$f(x) = 1/(1+e^{-x})$$

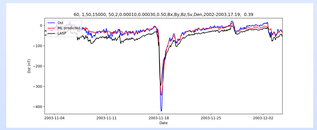
$$\delta_j = \partial E / \partial W_{ji}$$

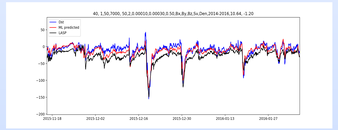
$$E = 0.5\sum (d_j - o_j)^2$$

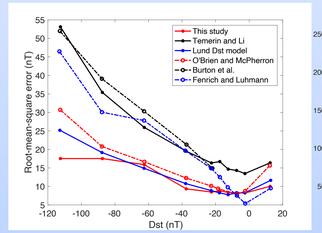
$$\Delta W_{ji} = \eta \delta_j o_i$$

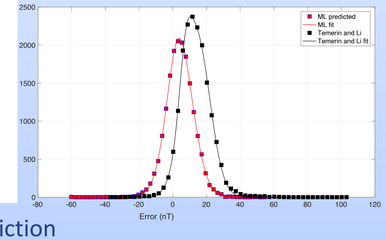
$$\Delta W_{ji}(n+1) = \eta \delta_j o_i + \beta \Delta W_{ji}(n)$$

Model was trained & tested on hourly values of solar wind and *Dst* data observed during 1997-2016







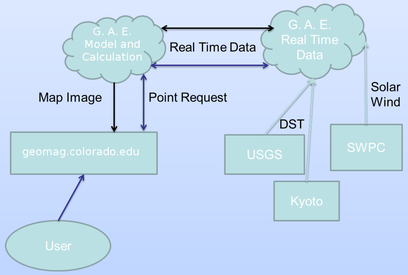


Benchmarking the ML prediction

Real-time Dst prediction is available 👉 https://geomag.colorado.edu/dst-predict

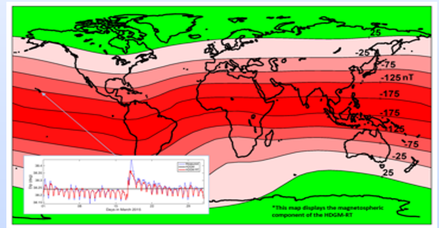
2. Real-time prediction of disturbance-field

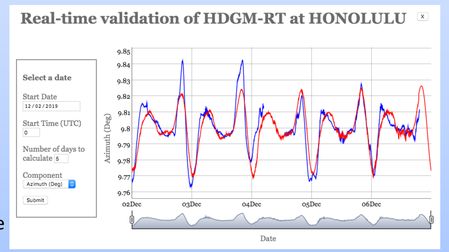
- Magnetospheric variations caused by space weather (*Maus & Lühr, 2005 & 2010*)
- Ionospheric daily variations (*Chulliat et al, EPS, 2016*)
- Induced variations in the Earth and Oceans
- Driven in real time with the *Disturbance Storm Time* index (*Dst*) and solar-wind data from the Deep Space Climate Observatory (DSCOVR) satellite
- Cloud-based implementation
- Real-time validation against Honolulu (HON) geomagnetic observatory data



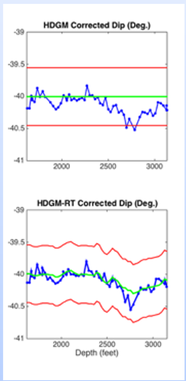
HDGM-RT	Uptime (%)	Median data latency (sec)	Response time (sec)
2015-2019	>95.84	3597	0.672
2020 -	-	< 0	-

👉 A major factor contributing to the high-latency is the in obtaining *Dst* indices, a key model driver .





https://www.ngdc.noaa.gov/geomag/HDGM/hdgm_rt.html



Corrected dip (blue line) and model values (green line) when using the RT model (lower plot) and without using the RT model (upper plot)

4. Summary

- Earth's magnetic field provides a natural frame of reference for underground navigation
- NCEI/CIRES magnetic model, HDGM-RT provides comprehensive magnetic mapping
- To reduce our prediction-latency, we developed a Machine-learning (ML) model to derive a key model input (*Disturbance-storm-time index, Dst*)
- The ML predicted model is solely driven by the solar-wind observations
- Our ML predicted *Dst* indices compare favorably with the observation and other predictive models.

5. References

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6. We thank

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