

Observation and Model Needs: Ground Effects Panel

Key Questions:

1. What observations/models are needed to fulfil user needs and to improve, test, and validate models?
2. What are the key strategic space weather datasets and model capabilities needed to advance research & ops
3. What current (or past) assets (observations or models) have proved to be ineffective? Why?
4. Are there any other concerns/issues we're missing that you'd like to raise?
5. What do other subdisciplines need to know about your subdiscipline, and vice versa
6. What proposed assets (missions, observations, modeling efforts) need more attention and resources?

Topics to be covered by experts:

- 1) Magnetotelluric surveys; (2) GICs; (3) Operational modeling/forecasting; (4) User needs; and (5) Model validation

Moderator: Delores Knipp, Committee

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Space Weather Operations and Research Infrastructure Workshop: Phase II, Tuesday April 12, 2022, 1645 ET



Perspectives on Observation & Model needs: Ground effects

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Status - what has happened over the past 10 years



- FERC geomagnetic disturbance (GMD) standards and National Space Weather Strategy & Action Plan changed “the game” for ground effects in terms of high-level attention, financial support and technical work.
- Close coordination between scientists and power engineers has been critical for addressing the entire modeling & analysis chain down to thermal, reactive power etc assessments needed for quantifying the hazard. NERC GMD Task Force was one the main forums for these interactions.
- Modern geospace models have reached maturity allowing their usage in scientific GMD and GIC analyses.
- Rigorous community-wide validation of geospace models was conducted in the GMD context. Space Weather Modeling Framework was transitioned into operations at NOAA.
- MT surveys have now covered most of the contiguous U.S.
- Many utilities are measuring GIC. However, we should note that interpretation of the measurements will require information about the system configuration and thus close collaboration with the utilities.



Gaps – what needs to happen moving forward



- NERC GMD Task Force closed. We need to re-establish active connection between scientific and engineering communities. Need a "home" for these interactions.
- We need further assessments of the geoelectric field spatiotemporal structure in 1-in-100 year situations.
- We need rigorous validation of MT data usage in GIC applications.
- Modern geospace models have not yet reached maturity allowing modification of standards etc requiring industry actions and investments. We need to better understand model limitations especially in extreme event analyses. Instead of trying to capture detailed spatiotemporal GMD characteristics, we may want to consider "lower granularity" products such as auroral boundary motions.
- We need denser network of operational geophysical observatories in the U.S. as well continuity of global ground-based geomagnetic field observations.
- "Bz problem." How can we provide higher confidence long lead-time GMD predictions?

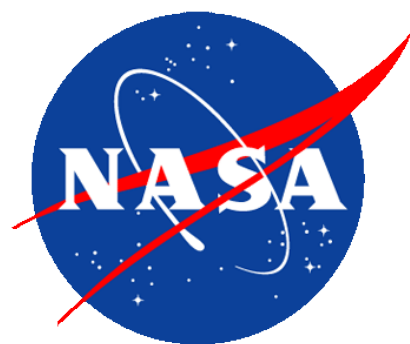




Follow Us Everywhere Under the Sun

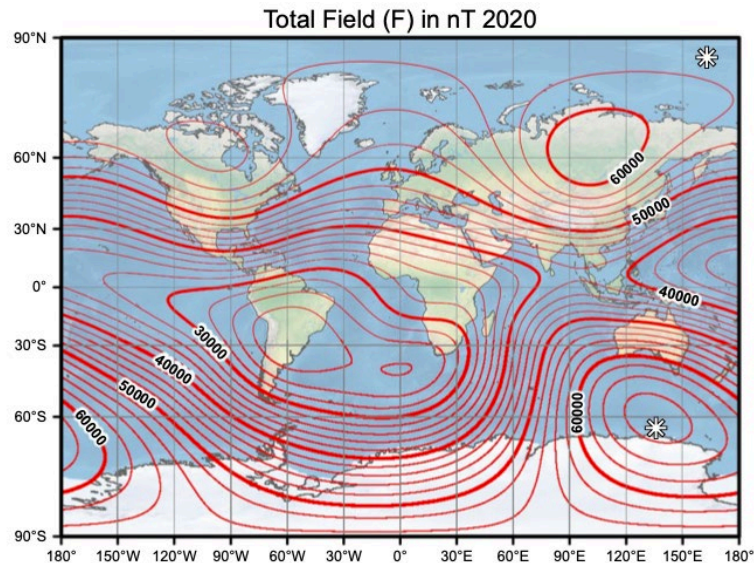
HELIOPHYSICS



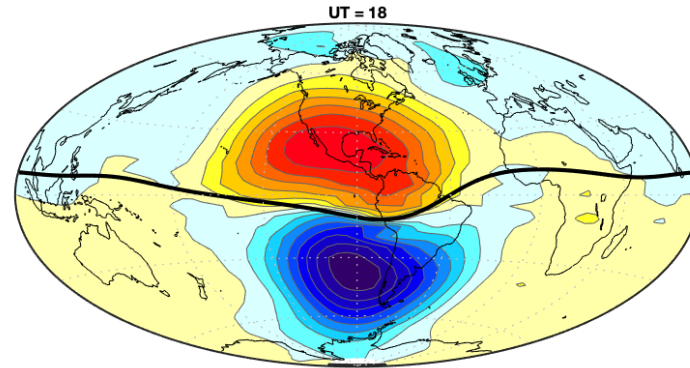


Geomagnetic Field Models

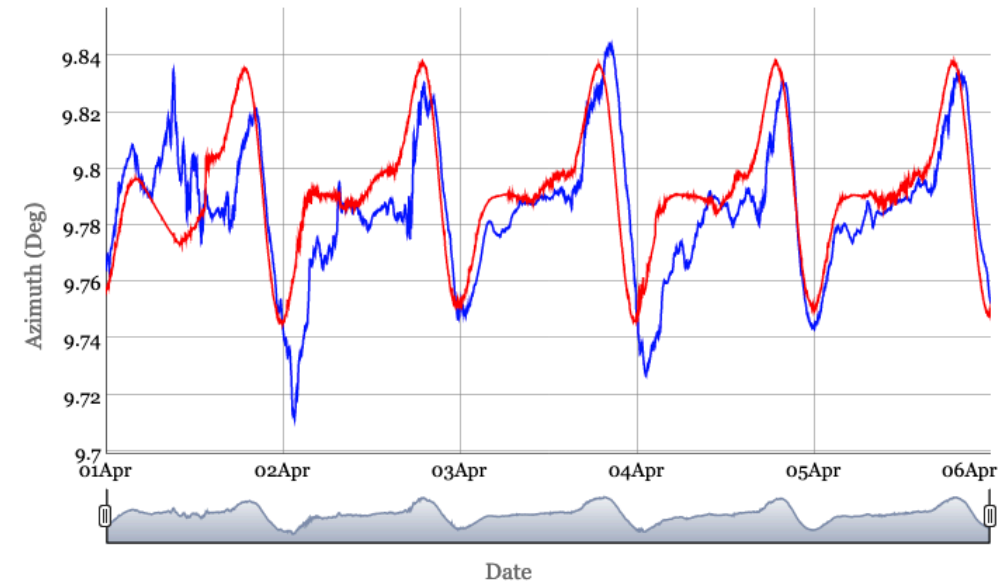
- Main field models (e.g., WMM, IGRF)
- Models incorporating climatological and/or real-time external field variations (e.g., DIFI, HDGM, etc.)



<https://www.ngdc.noaa.gov/IAGA/vmod/igrf.html>



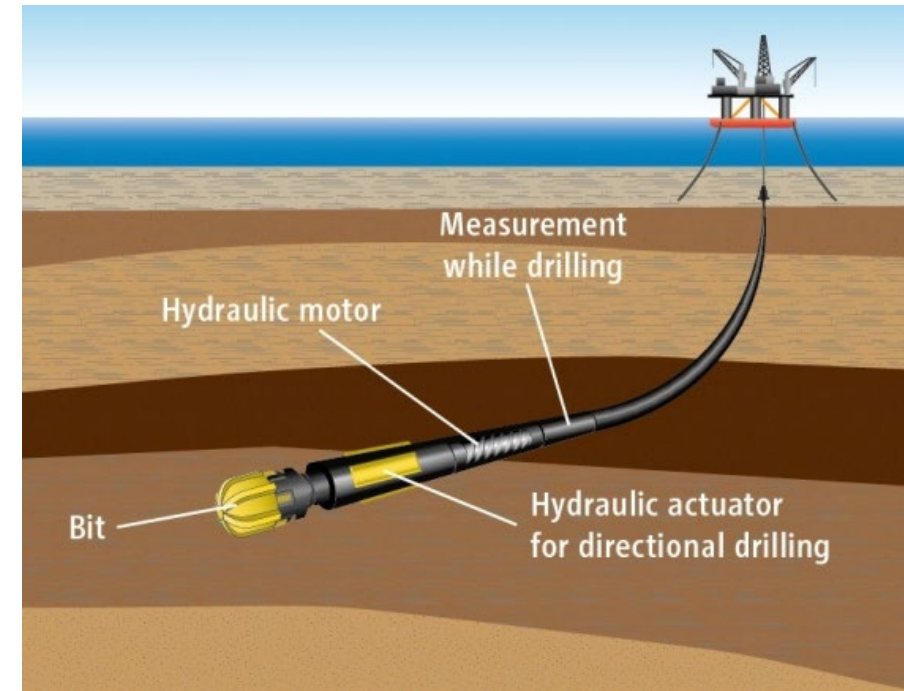
<https://geomag.colorado.edu/difi-6>



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

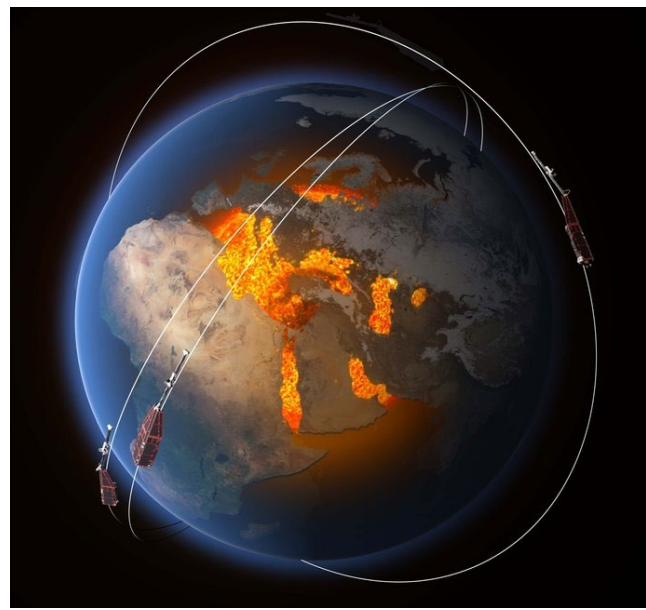
Model Uses

- Orientation & navigation
 - Airplanes, ships, submarines
 - Spacecraft attitude control
 - Antenna tracking
- Directional drilling (energy industry)
- Alternative positioning and navigation (MagNav)

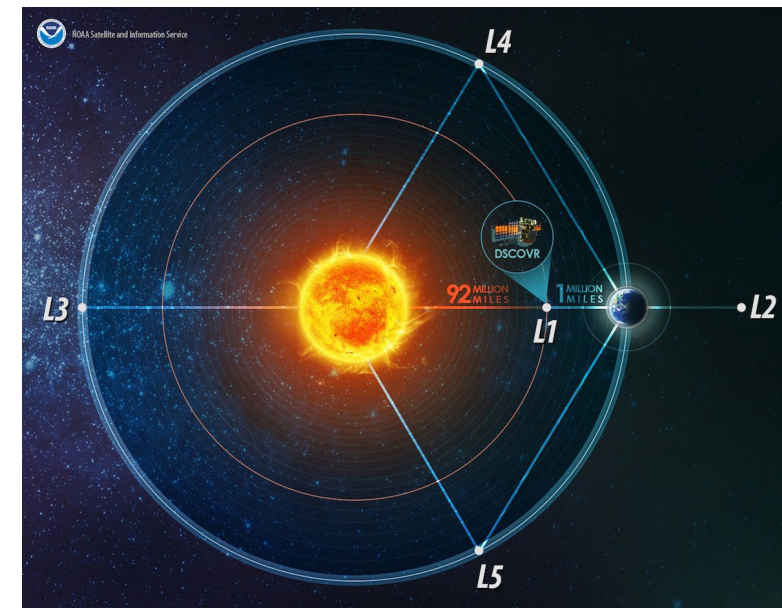


Data

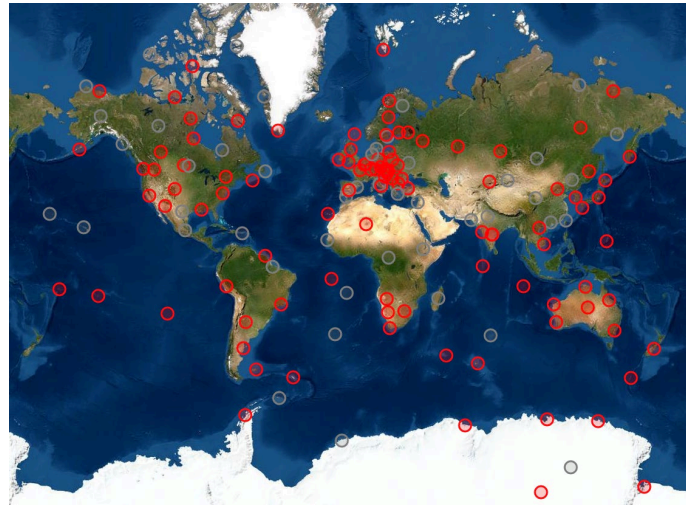
- Low-Earth orbit satellites (Swarm, Iridium, etc.)
- Ground-based observatories (INTERMAGNET)
 - Indices
 - Model input
 - Calibration
 - Validation
- L1 solar wind measurements (DSCOVR)



<https://directory.eoportal.org/web/eoportal/satellite-missions/s/swarm>



<https://solarsystem.nasa.gov/missions/DSCOVR/in-depth/>



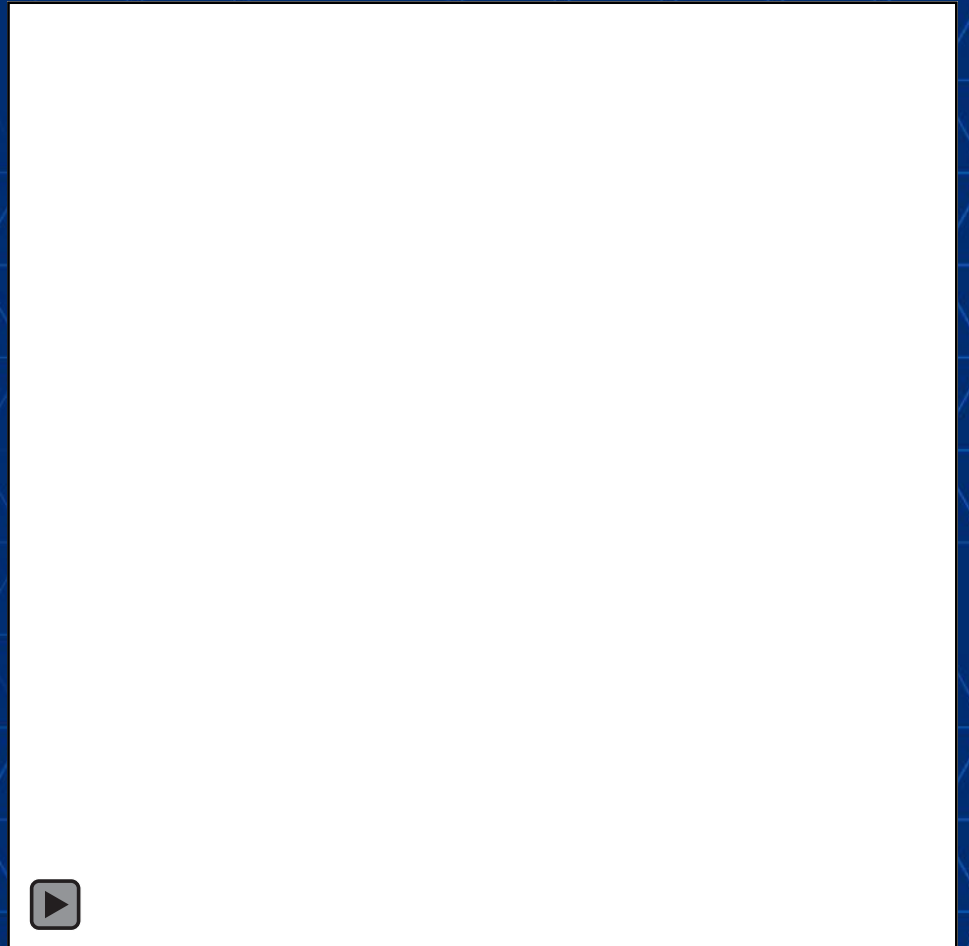
<https://intermagnet.github.io/>

Space Weather

A global exercise driven by local process

J. Gjerloev

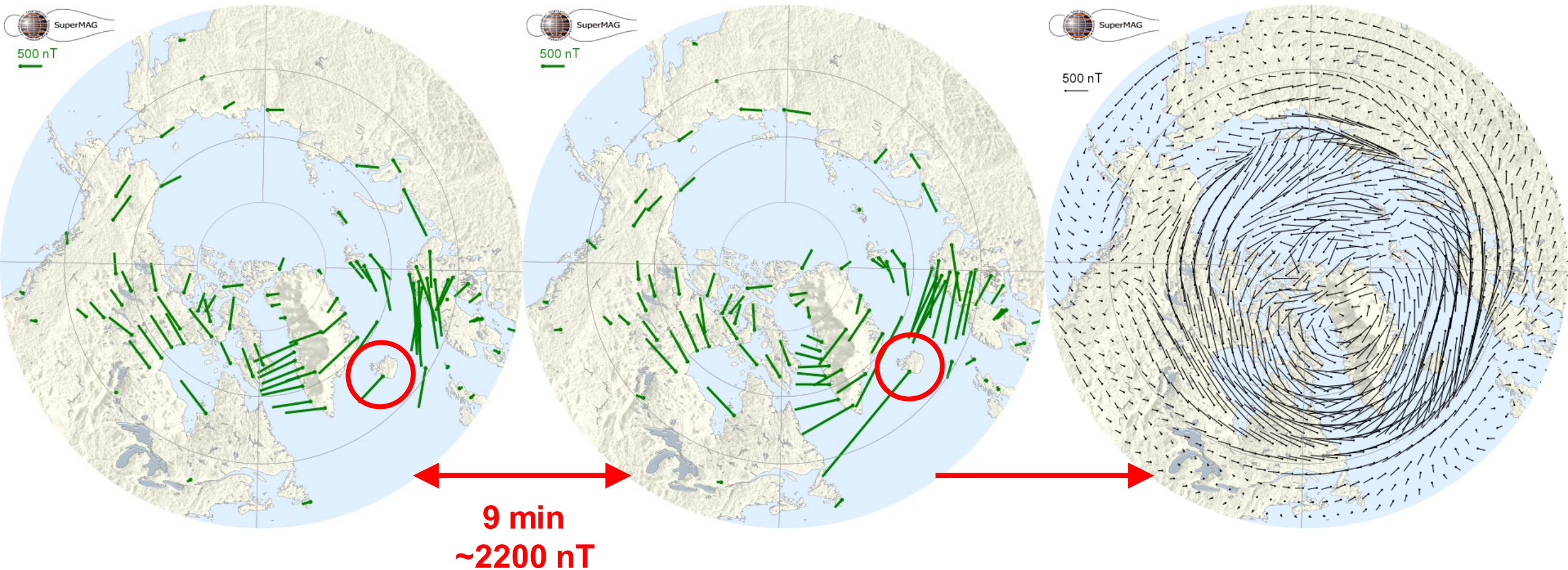
Acknowledgement: Shin Ohtani, Slava Merkin, Robin Bares, Matt Friel, Matt Potter



Space Weather

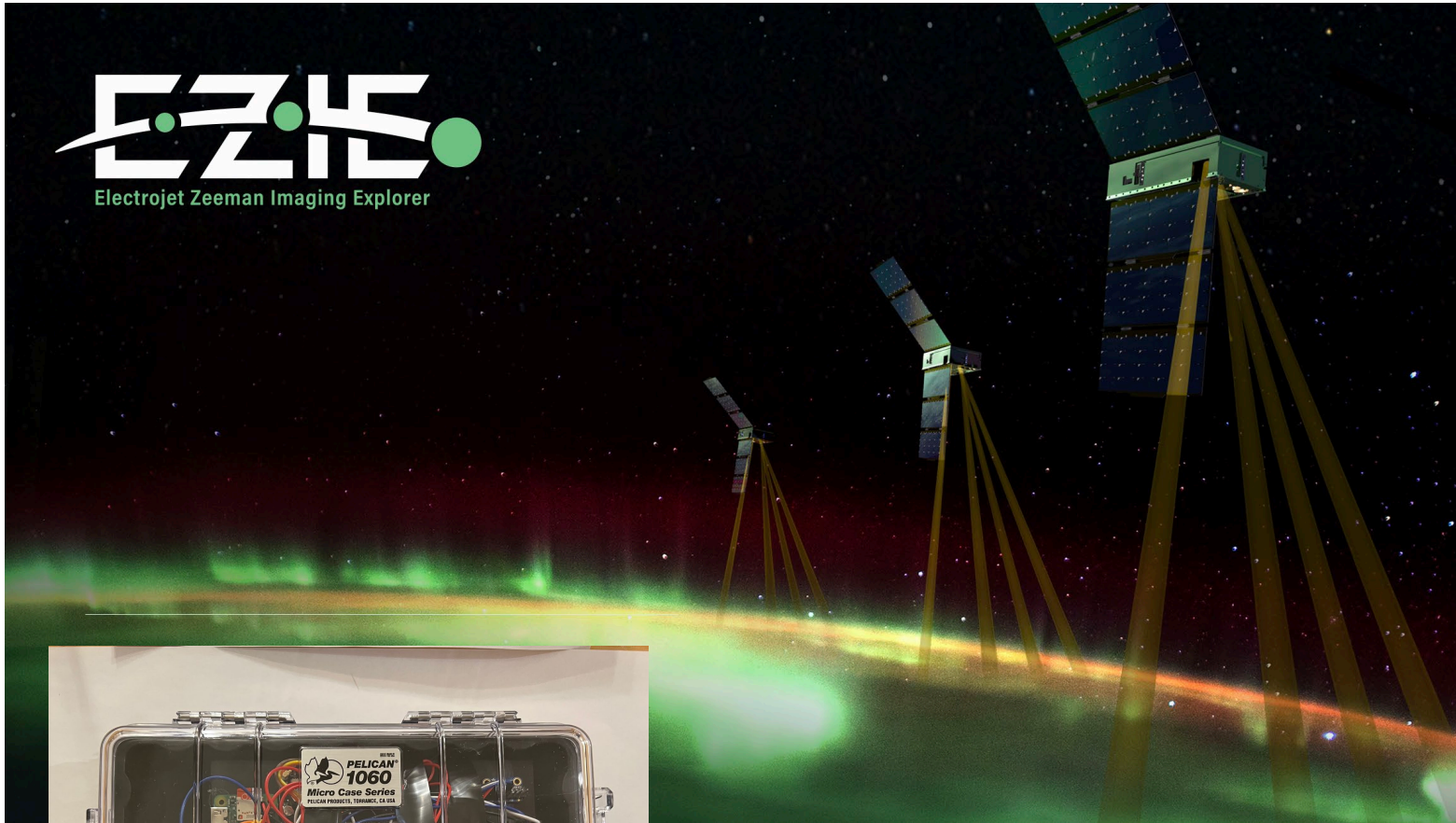
A global exercise driven by local process

Real-time Global Solution Measurements + Model

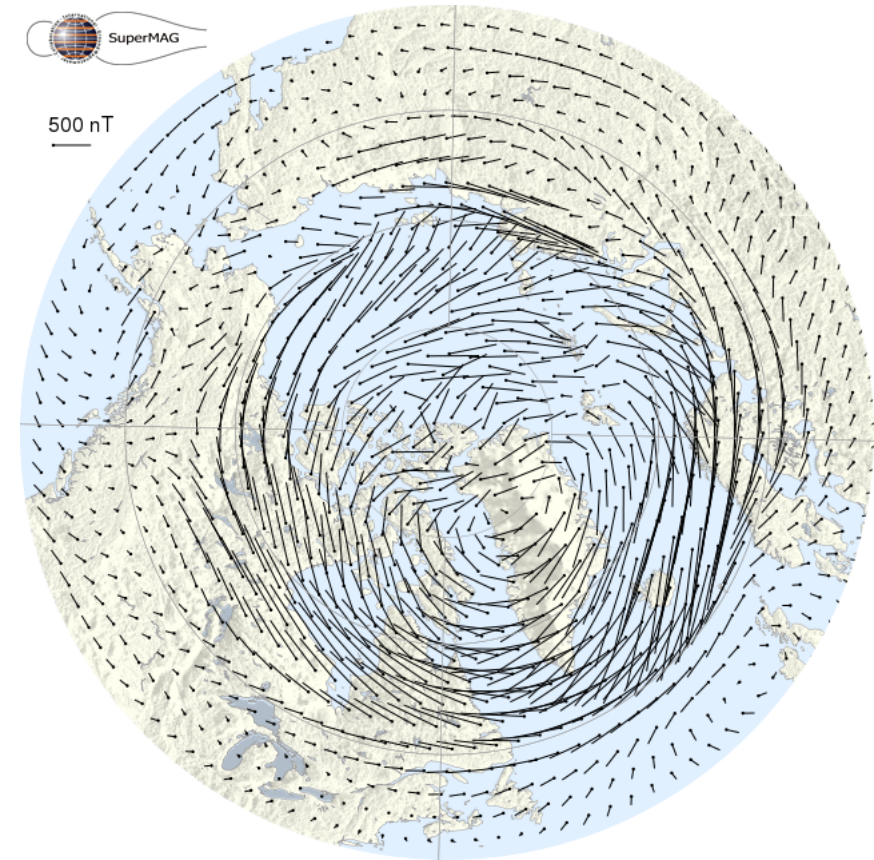


Space Weather

A global exercise driven by local process



Real-time Global Solution Measurements + Model



We need tens of thousands of stations!

3 types:

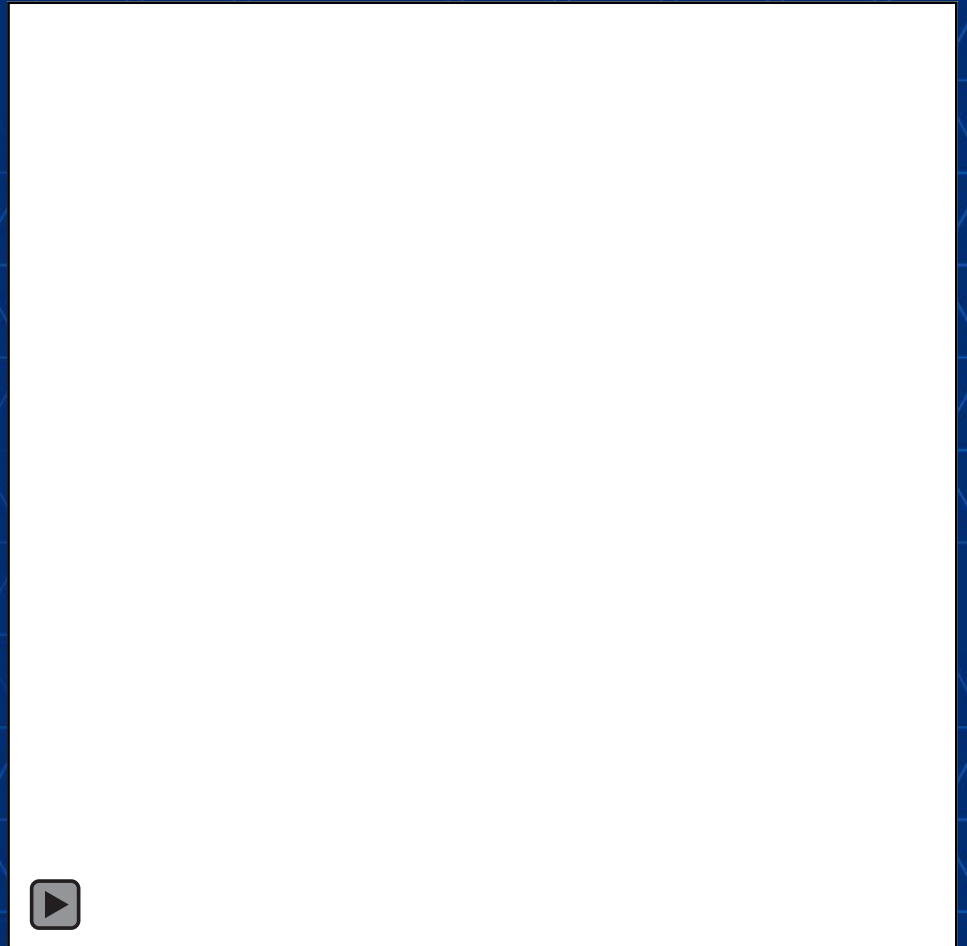
- observatories
- science grade variometers
- amateur grade variometers

Space Weather

A global exercise driven by local process

I argue that forecasting hinges on:

- Our understanding of what causes extreme events
- Global, continuous and real-time measurements



Modeling ground effects of space weather hazards: key assets and gaps

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E. Joshua Rigler, Benjamin S. Murphy
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U.S. Geological Survey

Greg M. Lucas
Laboratory for Atmospheric and Space Physics
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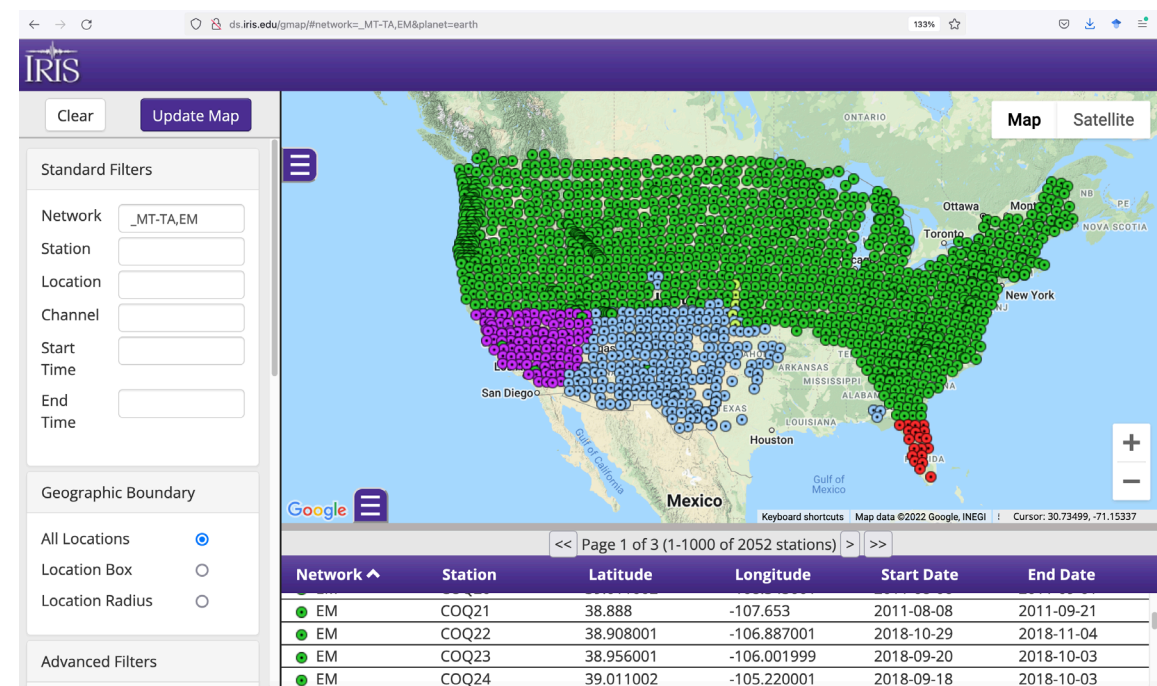
Paul A. Bedrosian
Geology, Geophysics, Geochemistry Science Center
U.S. Geological Survey

Contact: akelbert@usgs.gov

Space Weather Operations Research and Mitigation Working Group

Data Availability at IRIS

- Time series for **NSF**-funded USArray MT (2006-2018) and **NASA** and **USGS**-funded USMTArray (2019-ongoing) available from http://ds.iris.edu/gmap/#network=_MT-TA,EM
- All transfer functions (impedances) archived at <http://ds.iris.edu/spud/emtf>
- New MT time series data and metadata formats have been developed through USGS and IRIS collaboration <https://mt-metadata.readthedocs.io/en/latest/>
- Modern, flexible, user-friendly MT time series data formats, archiving and retrieval tools in last stages of development through USGS and IRIS collaboration <https://mth5.readthedocs.io/en/latest/>
- Time series for USMTArray 2019-2021 archived by USGS using the new procedures



IRIS SPUD EMTF interface showing the EM Transfer Function Query Parameters form. The form includes a map of the United States and various input fields for filtering data by location, time, and other parameters.

EM Transfer Function Query Parameters

Legend: Data Quality, Quality Warning, Release Status, Project, Min Period

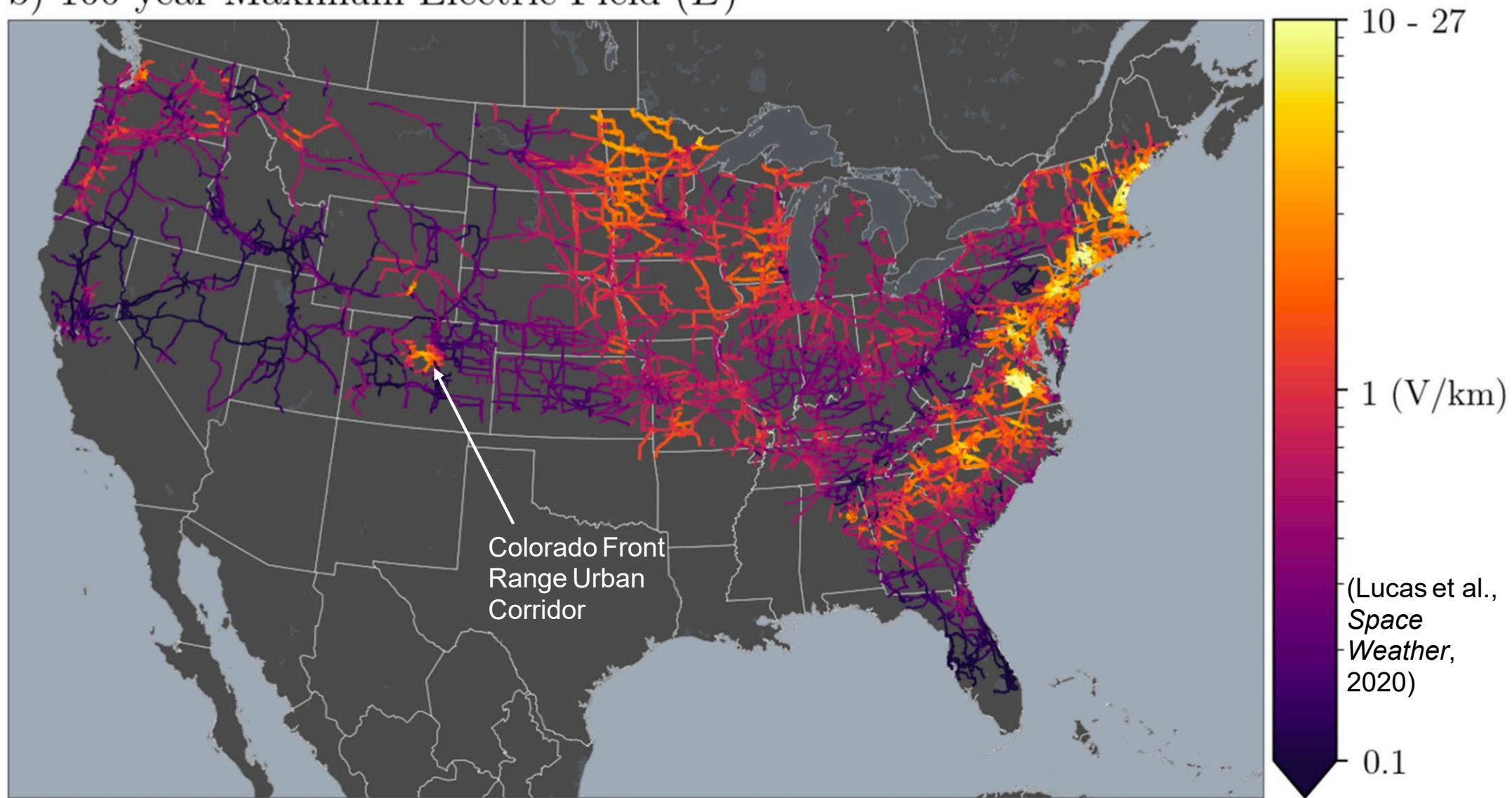
Max Lat: 48.77, Min Lat: 21.72, Max Lon: -74.36, Min Lon: -120.06

Start Date, End Date, Modified after, Min Quality, Period, Site ID, Project, Survey, Type, Author, Tags, Site Name, Remote Site, Remote ID, Release Status

This database is documented by [Kelbert et al \(2018\)](#).
The EMTF XML format and file conversion utilities are described by [Kelbert \(2019\)](#). Reading and writing of EMTF XML is supported by [EMTF FCU](#).
All data are oriented to geographic coordinates, but all historical files are also available in their original orientations. Please see the complete [change log](#) for database changes.
Data citations are provided for each survey; these should be referenced in publications.

Nation-Wide Hazard Map

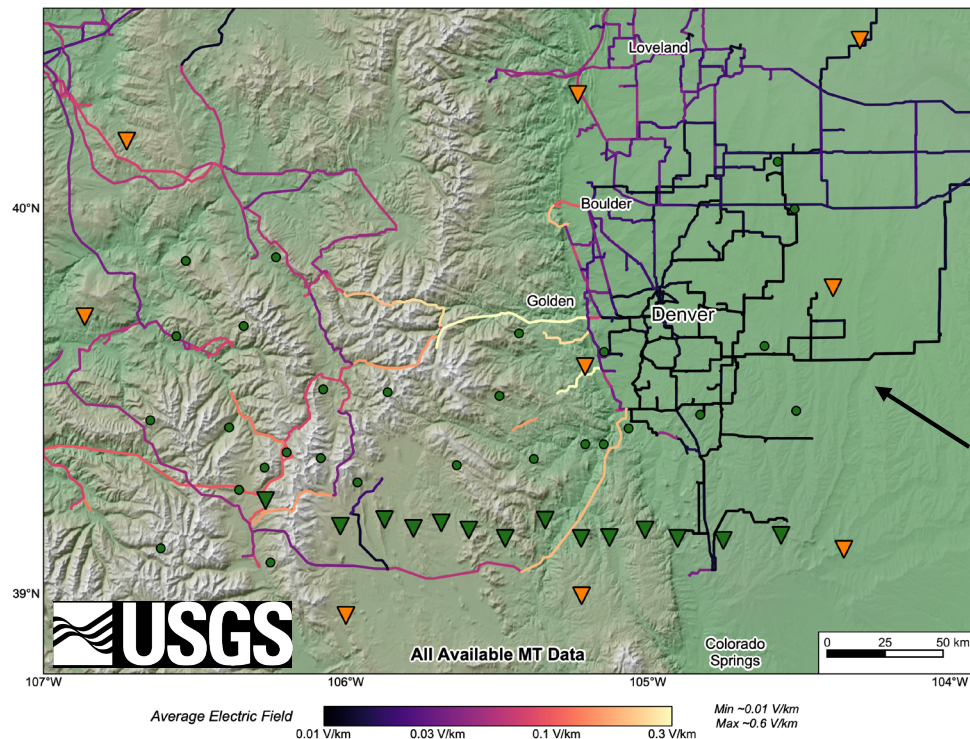
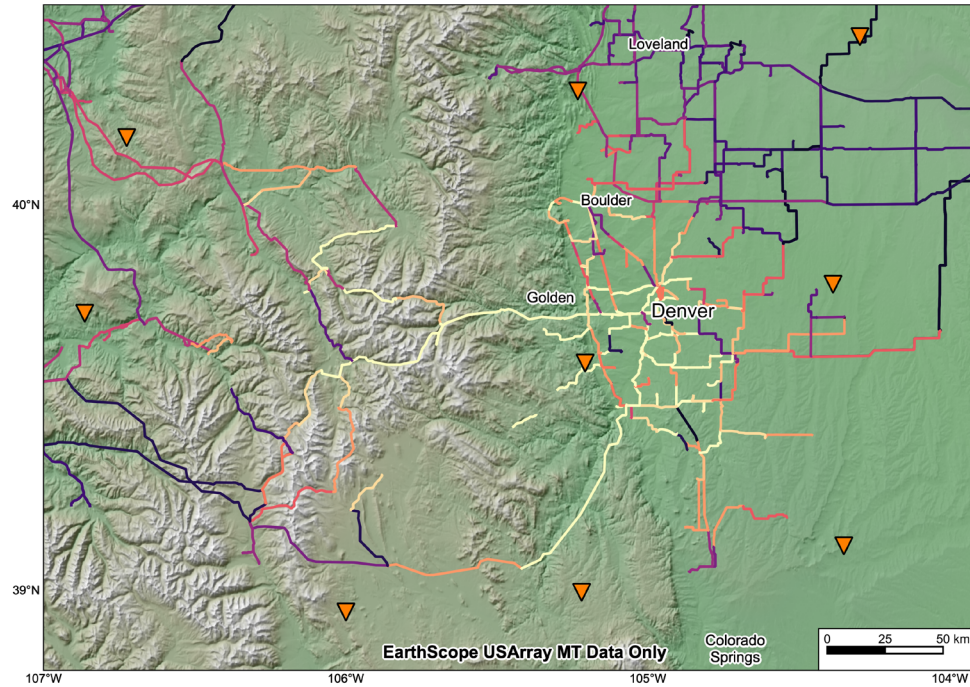
b) 100-year Maximum Electric Field ($\bar{E}$)



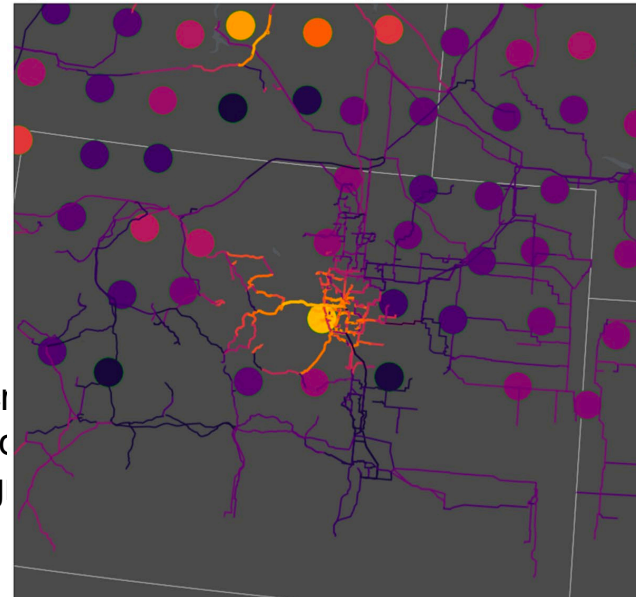
Example: Colorado Front Range

In the Denver area, high hazard estimates dominated by a single site. New data set collected by Benjamin Murphy, USGS provides a detailed picture. Big decreases in hazard compared to Lucas et al. (2020) results. Denver is a fairly low hazard region! (100-year max $E \lesssim 1$ V/km)

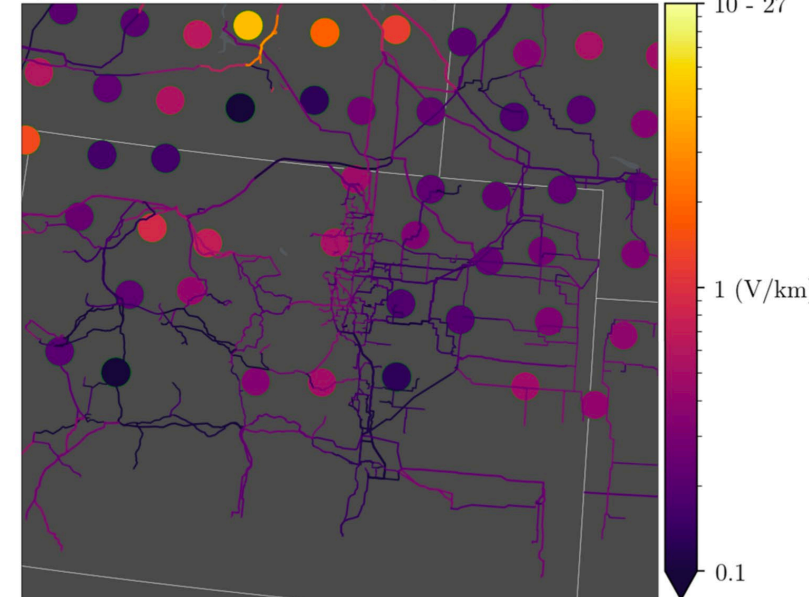
(Preliminary, based on single geomagnetic storm)



b) Maximum Electric Field ($\vec{E}$)



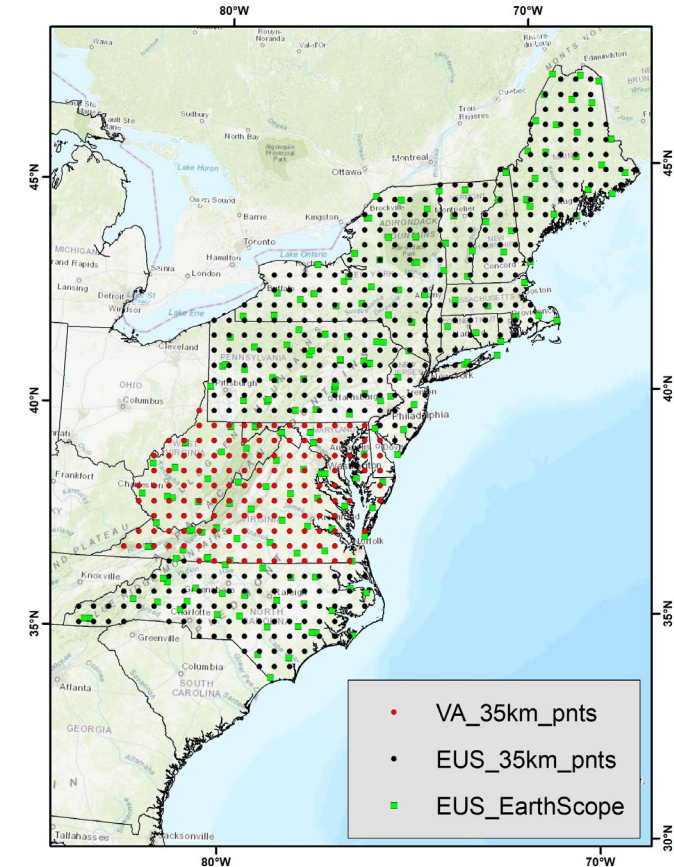
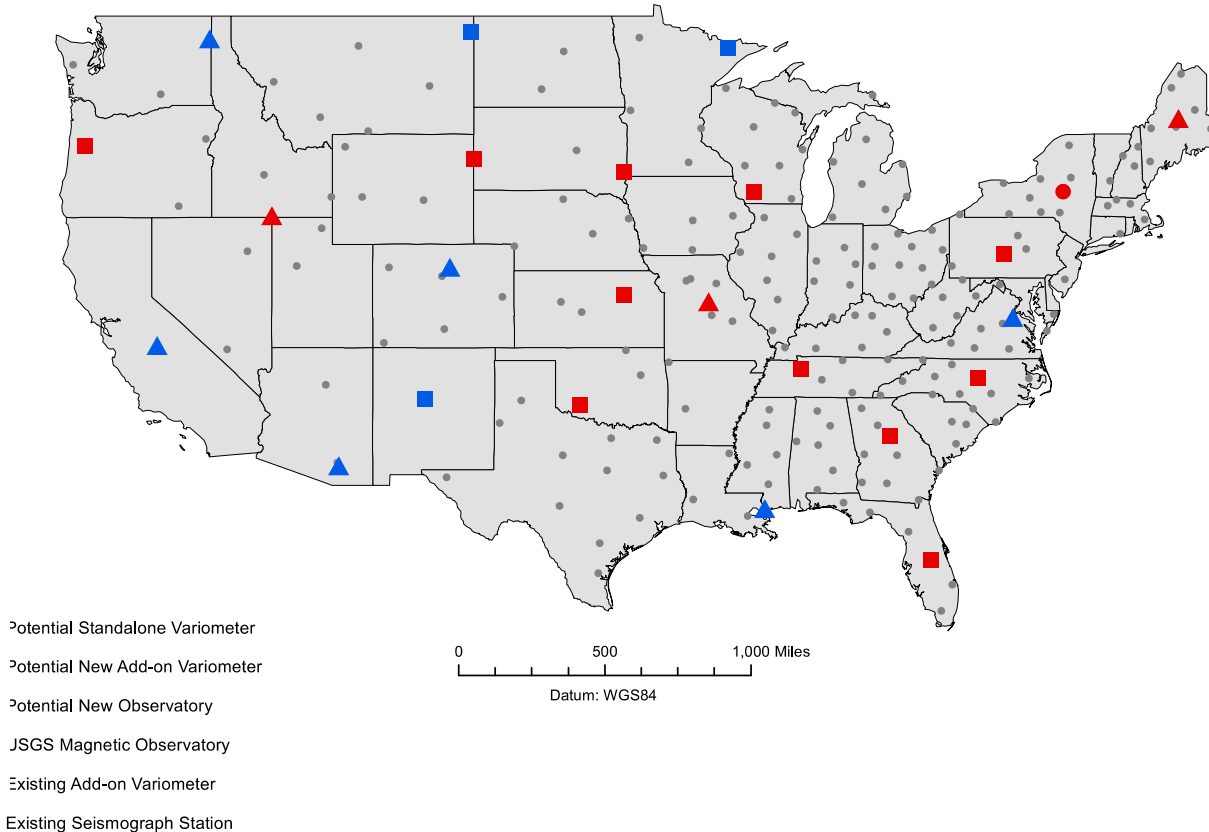
d) Maximum Electric Field ($\vec{E}$) (No COP24)



Decl
2 or
mag

A couple of aspirations:

1. denser geomagnetic monitoring
2. dense wideband magnetotelluric surveying of the Mid-Atlantic and Northeast U.S.



Denser geomagnetic monitoring (Lucas et al., 2020, <https://doi.org/10.1029/2019SW002329>) and denser magnetotelluric surveys (Murphy et al., 2021, <http://doi.org/10.1029/2020SW002693>) would significantly improve the accuracy of maps of magnetic-storm geoelectric field hazards. Dense wideband surveying would also enable realistic mapping of E3 EMP hazards across the geologically complex Mid-Atlantic and Northeast United States-- the most densely populated part of the United States (Love et al. 2021, <https://doi.org/10.1029/2021EA001792>).

Key observations/models to advance both research and operations:

- High-density, reliable and accessible real-time geomagnetic monitoring data
- High-density MT surveys / high-resolution 3D conductivity models
- Assimilative Geospace models of ground geomagnetic fields that accommodate for diverse and sparse data, and include the internal component from 3D Earth
- Real-time GIC modeling using a short-term forecast of ground electric fields and up-to-date power-grid system configurations
- Validation of forecasts in real-time, including against direct impact data

Strategic space-weather capabilities that are entirely missing at present:

- Geospatially accurate predictive ground geomagnetic field models – need real-time data assimilation!
- In going from ground-level electric fields to GICs, need accurate and timely grid system configuration parameters, - connectivity, grounding information, impact data, - to be 1) recorded and stored by the power-grid operators and 2) open for real-time and retrospective model validation by the research and operations communities
- Post-event analyses that include end users. During a magnetic storm, what was observed? What did you do? What were the effects of what you did?

PROVIDING OPERATIONAL FORECASTING OF GICS AHEAD OF IMPACTS TO CRITICAL INFRASTRUCTURE USING DENSE, PERMANENT ARRAYS OF MT OBSERVATORIES

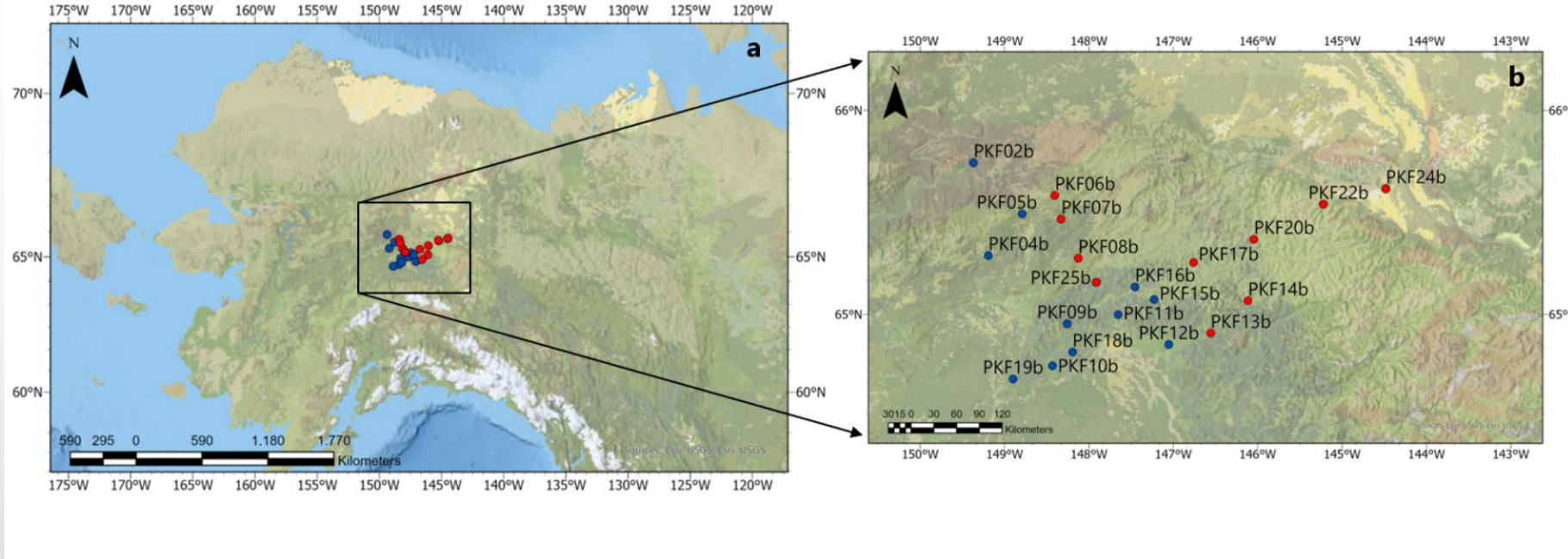
Adam Schultz¹, Rolando Carbonari², Brady Fry^{1,3}, Taylor Viti¹

¹National Geoelectromagnetic Facility
College of Earth, Ocean and Atmospheric Sciences, Oregon State University

²Hebrew University, Jerusalem, Israel

³Chaytus Research and Engineering, LLC, Corvallis, Oregon

Forecasting GICs 15, 30 or more minutes in advance from ground-based observations



(top) We operated a dense, synchronous array of MT stations in the interior of Alaska for several months to test the applicability of the MT “plane wave” assumption used in MT to image the electrical conductivity structure of the crust and mantle, and to do so under the complex ionospheric current systems in the auroral zone, as well as to probe the otherwise unexplored electrical structure of the AK crust and upper mantle.

This also afforded us a unique opportunity to see if the temporal-spatial patterns of a complex geomagnetic field in the auroral zone could be used to train a neural network to predict future ground-level magnetic and electric fields.

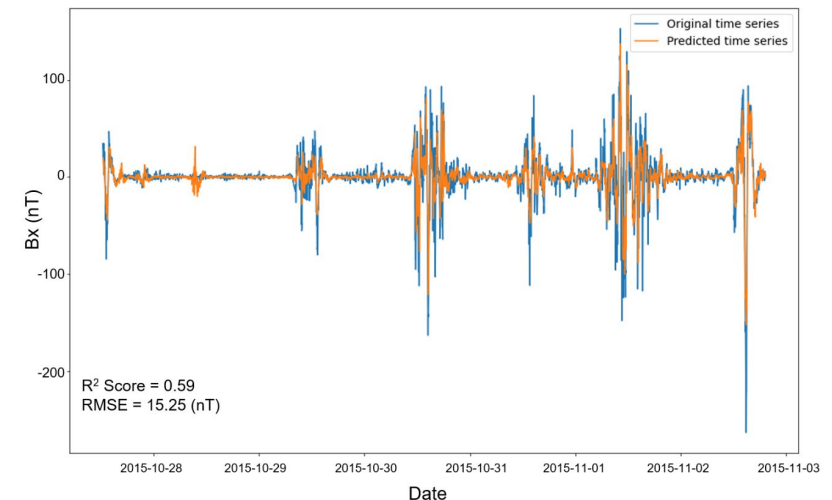
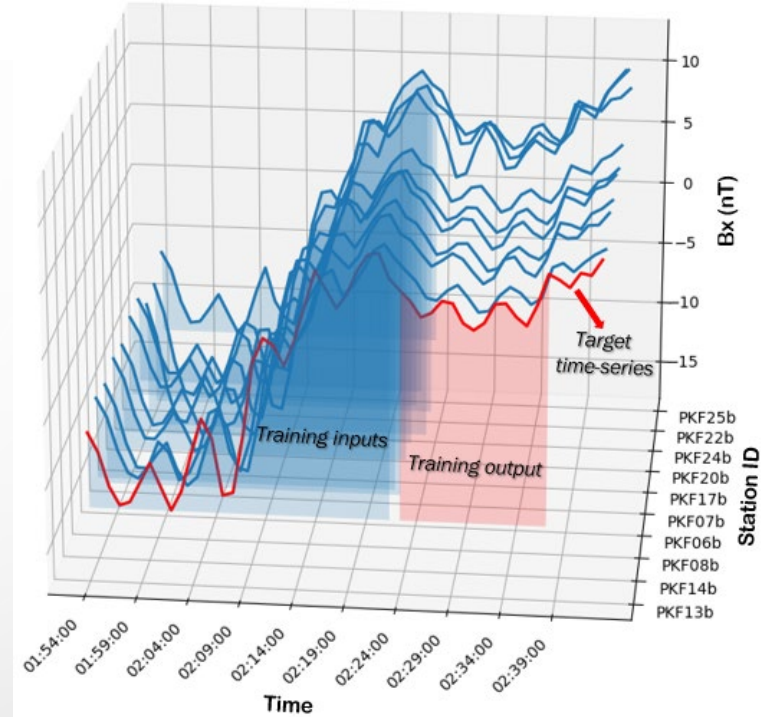
If this proved feasible, that is by showing the even complex auroral zone fields at ground-level could be forecasted in the near-term from ground-level field measurements, rather like the evolution of conventional weather fronts and pressure patterns as they move across the continent, then by combining the predicted fields with MT impedance data and with power flow models, one might be able provide actionable intelligence to power grid operators alerting them to possible GIC impacts in advance.

Neural network training sets for forecasting ground-level B, E fields

(Right-top) Example of input and output for the electromagnetic time-series. For the sake of brevity, only Bx components are shown here. The blue shadow outlines the input time windows while the red one indicates the training output used to predict the next 15 minutes of data. In the present work, the output or the target is a 15-minutes window of the target time-series while the inputs are windows with the preceding 30 minutes of data for the time-series of all the stations surrounding the target location.

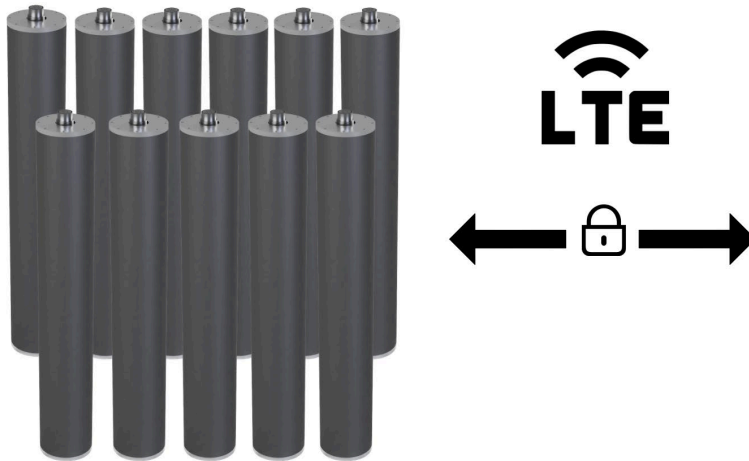
We apply a convolutional neural network (CNN), a multi-layered feed-forward neural network where each layer in the CNN applies different convolutional filters to the same data. The CNN we use is trained to learn a non-linear transfer function between n input and a target time series including past and future values of the time-series. Details of the algorithm will shortly be submitted in a paper to *Space Weather*, but some results appear below.

(Right-bottom) CNN prediction of Bx component of magnetic field vs. time (orange) at one of the Alaska interior MT stations plotted against actual time series (blue). The CNN was improved by using successive levels of low-pass filtration to the training set time series, each of which was decimated so lookback horizons of different length were applied to high-frequency and low-frequency content in the data, respectively.

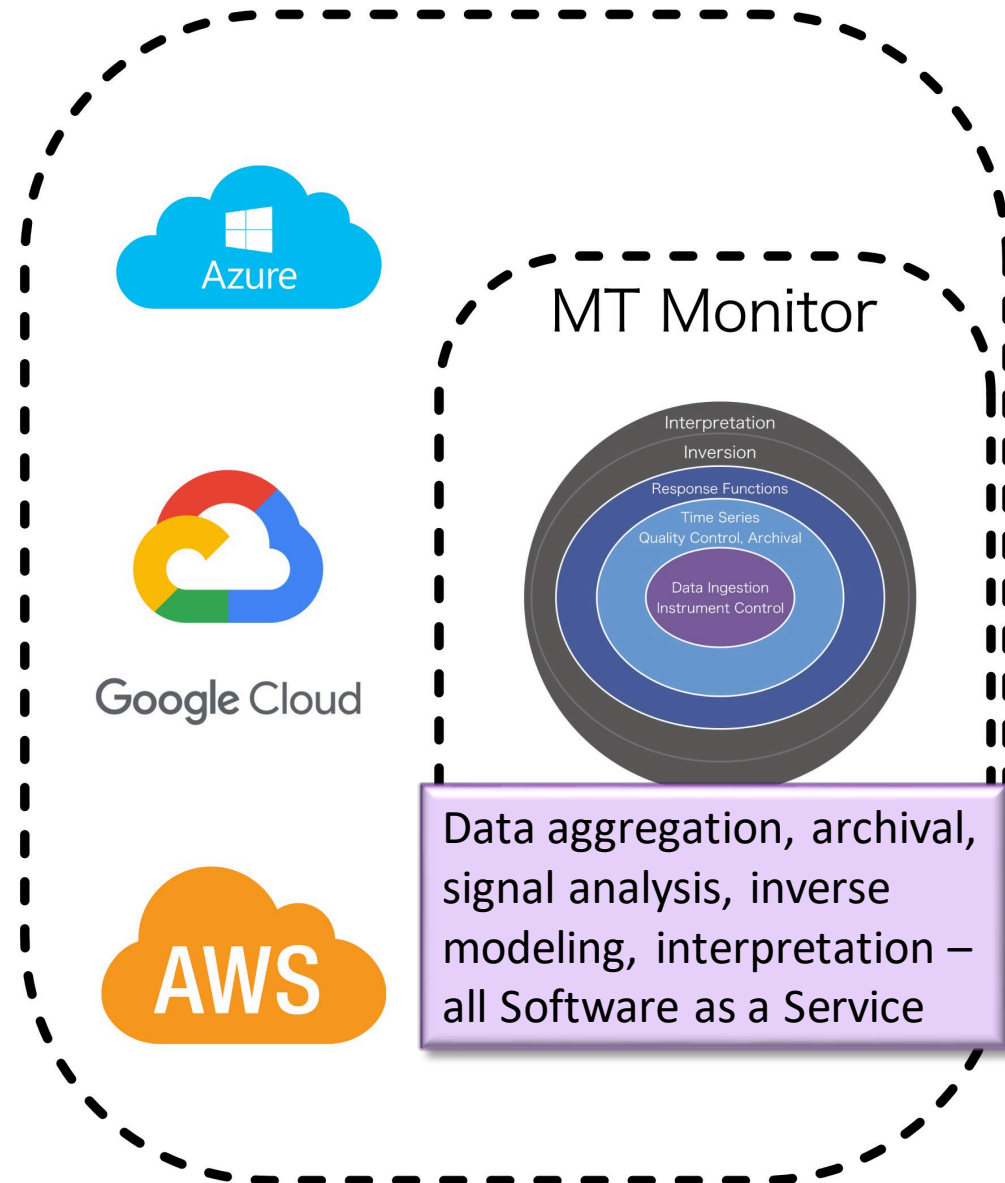


IoMT [the internet of MT]

Envisioning a national network of 400 permanent MT stations on a 140-km grid to provide operational forecasting of GICs in advance of ground-level impacts



We've developed a low-cost cloud synced, integrated MT system suitable for such permanent installations at scale

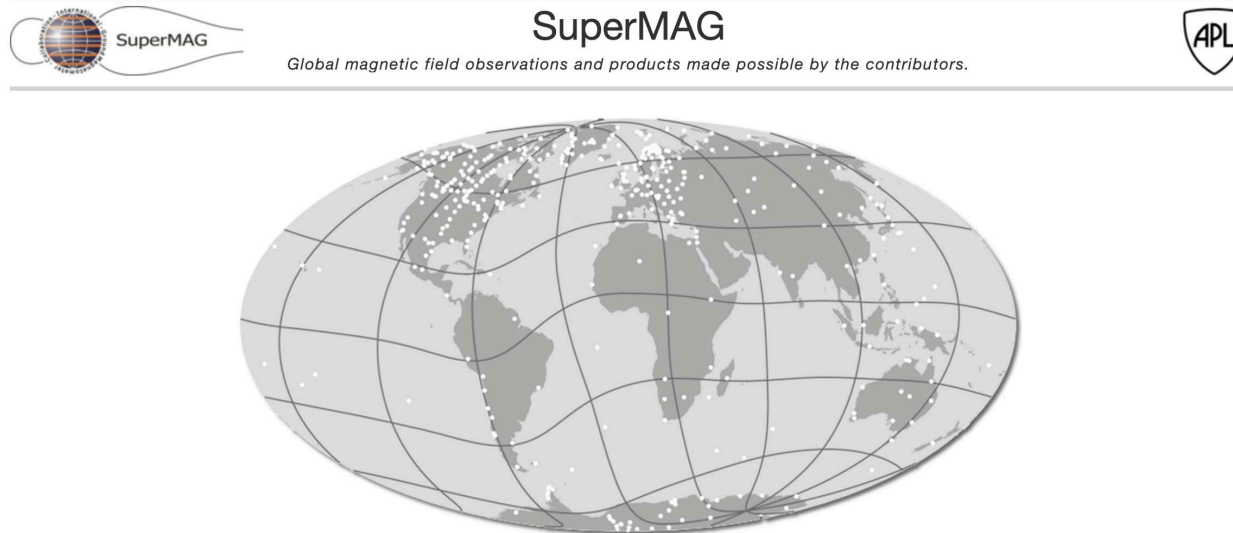


The importance of data in ground-level hazards science and operations

Jennifer Gannon
Computational Physics, Inc



Ground-based measurements need to be supported.

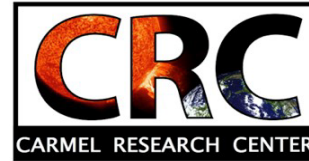


- **Combinations of data sets** are more than the sum of the parts
- **Long-term** support is needed (funding, infrastructure, collaborations)
- Need **both** science AND operations



The private sector is underutilized.

- There is a commercial geospace revolution going on – businesses large and small are **instrument and data providers**.
- Private sector is key in closing the loop on **model validation** for ground-based hazards.



Data is key for studying, predicting and validating our understanding of ground based hazards....

- Ground-based measurements need to be supported **long-term** for both science and operations.
- The **private sector** has complementary capabilities to academia and government groups that should be better utilized.

