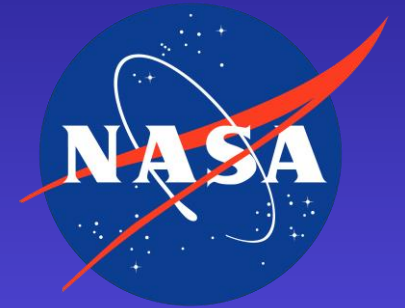




Unveiling a Continent: The US Array Magnetotelluric Program



Paul A. Bedrosian



MTNet EMinar, January 20, 2021



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Roadmap

- **Background and history**
- **Components of a national-scale array**
- **The U.S. ‘National Impedance Map’**
- **Science vignettes**
 - **Active tectonics and fossil margins**
 - **Mineral resource assessment**
 - **Space weather hazards**

Building the U.S. magnetotelluric array (MT Array)

- NSF funded EarthScope program (2003-2018)



- NASA funding (2019-2020)

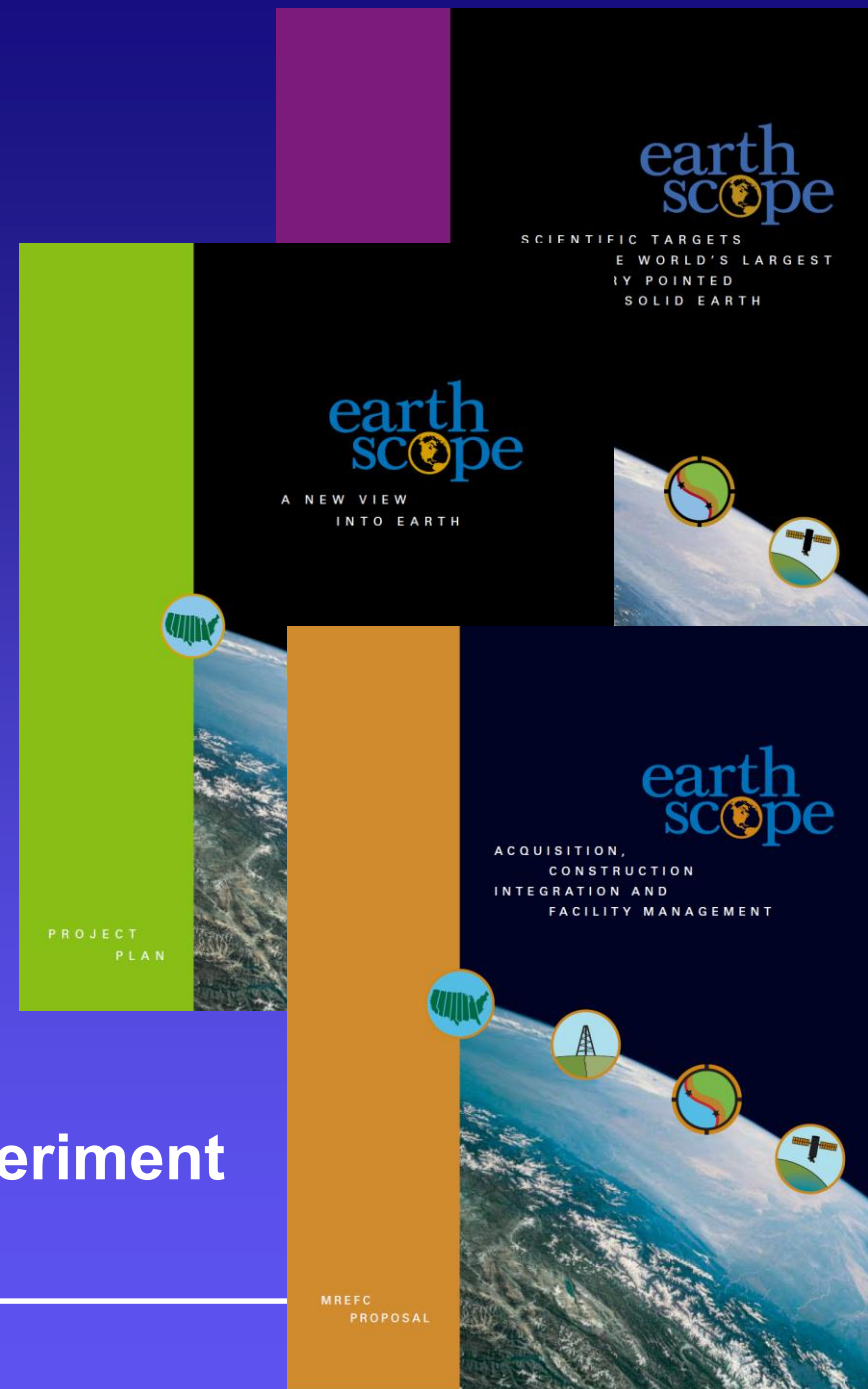


- USGS (2020-?)



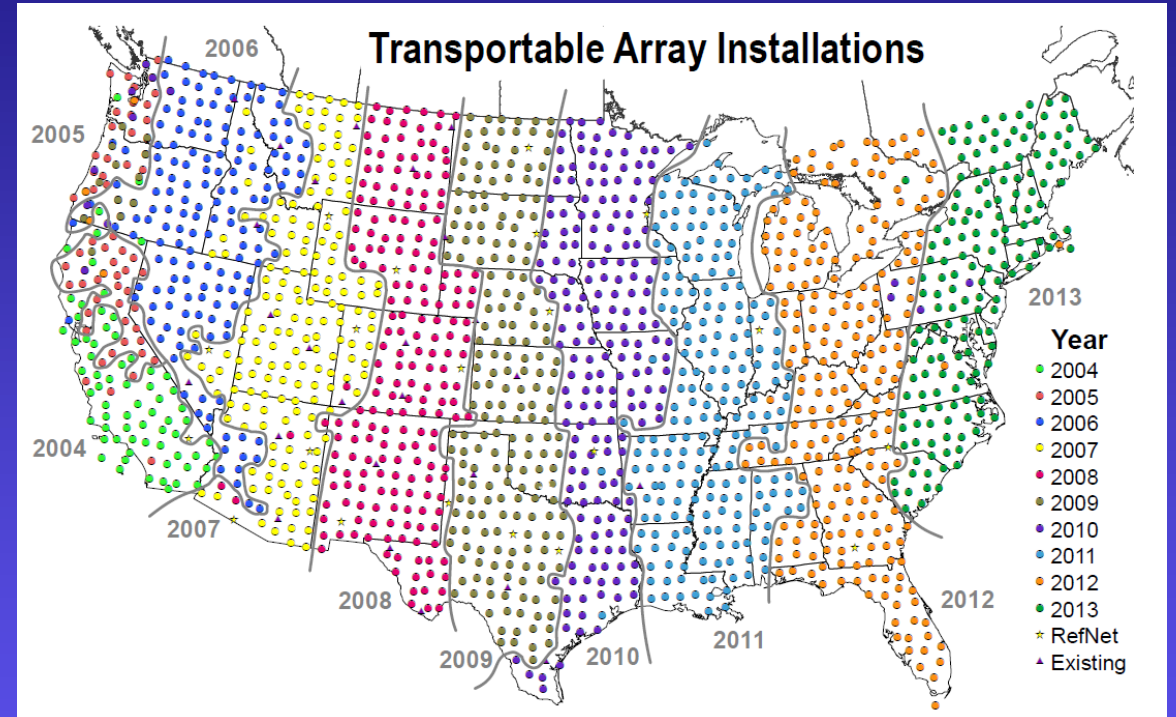
EarthScope USArray - the early years

- Science planning began in 1993
- Workshops & community input
- Project plan 2001
- Equipment & facilities (2003-2008) \$70M USD
- Operations & maintenance (2006-2018) \$20M/yr
- MT doubled... but predominantly a seismic experiment



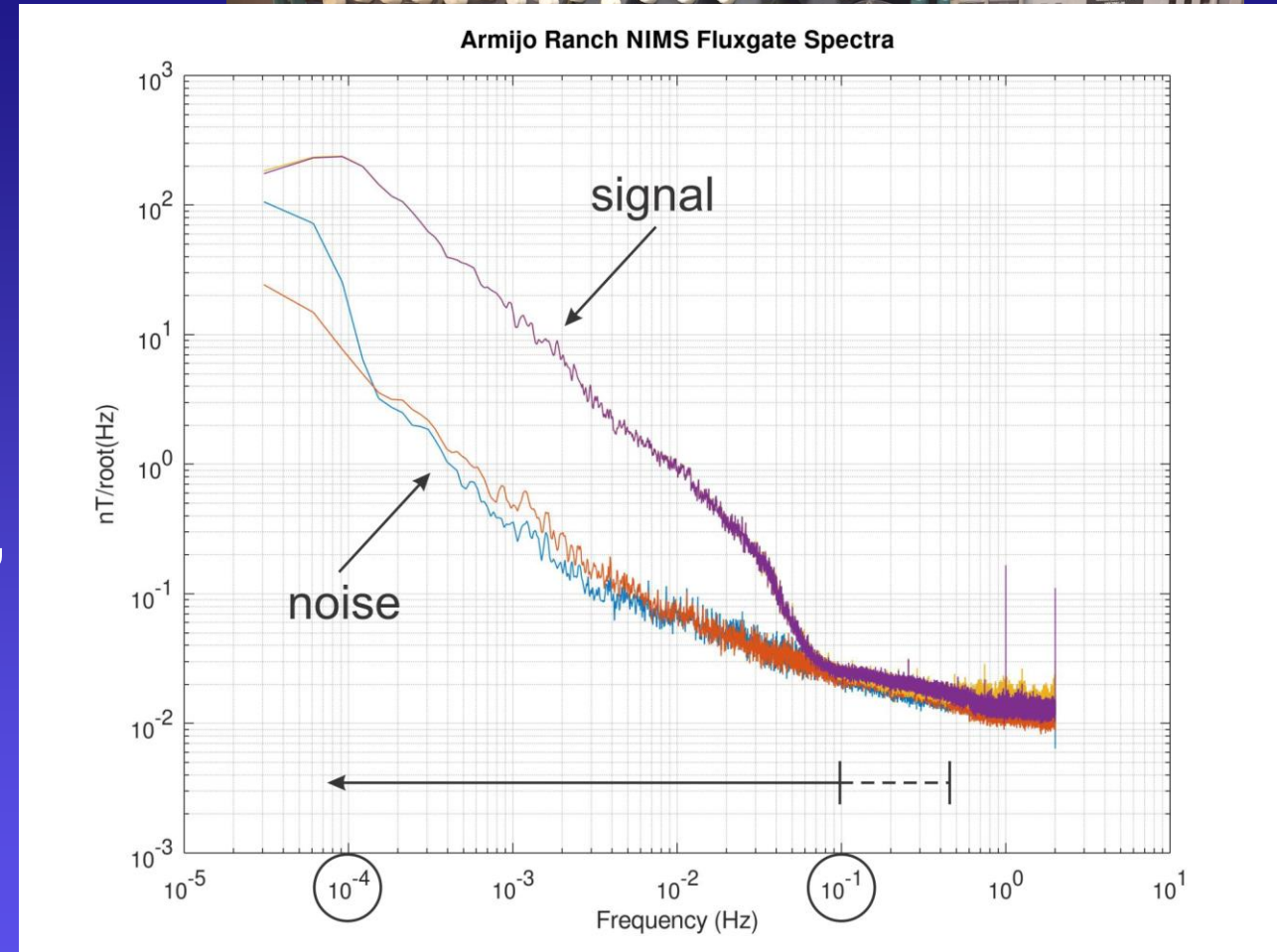
USArray components & MT

- Transportable array: 70 km spacing, long-period, 3+ week recording
- Backbone array: 7 stations, 2-year recording
- Flexible array: PI-driven science
- Research funding for PI-driven experiments
- Education & outreach



Instrumentation

- NIMS instrument (1 Hz sampling rate) start to finish
- Full 5-channel data MT data
- Instrument facility (NGF at OSU) with engineering support (repairs, upgrades, ancillary equipment)
- Low-noise fluxgate sensor



Permitting, QA/QC, site acceptance

- Site selection (cultural noise avoidance, spatial tolerance, etc.)
- In-field QA/QC, 10-day checkup, advanced processing
- Consensus-based site acceptance (10% in ρ_a , 5° in φ from 10-10,000 sec)
- Relocation of 'rejected' stations → 10% grid points relocated

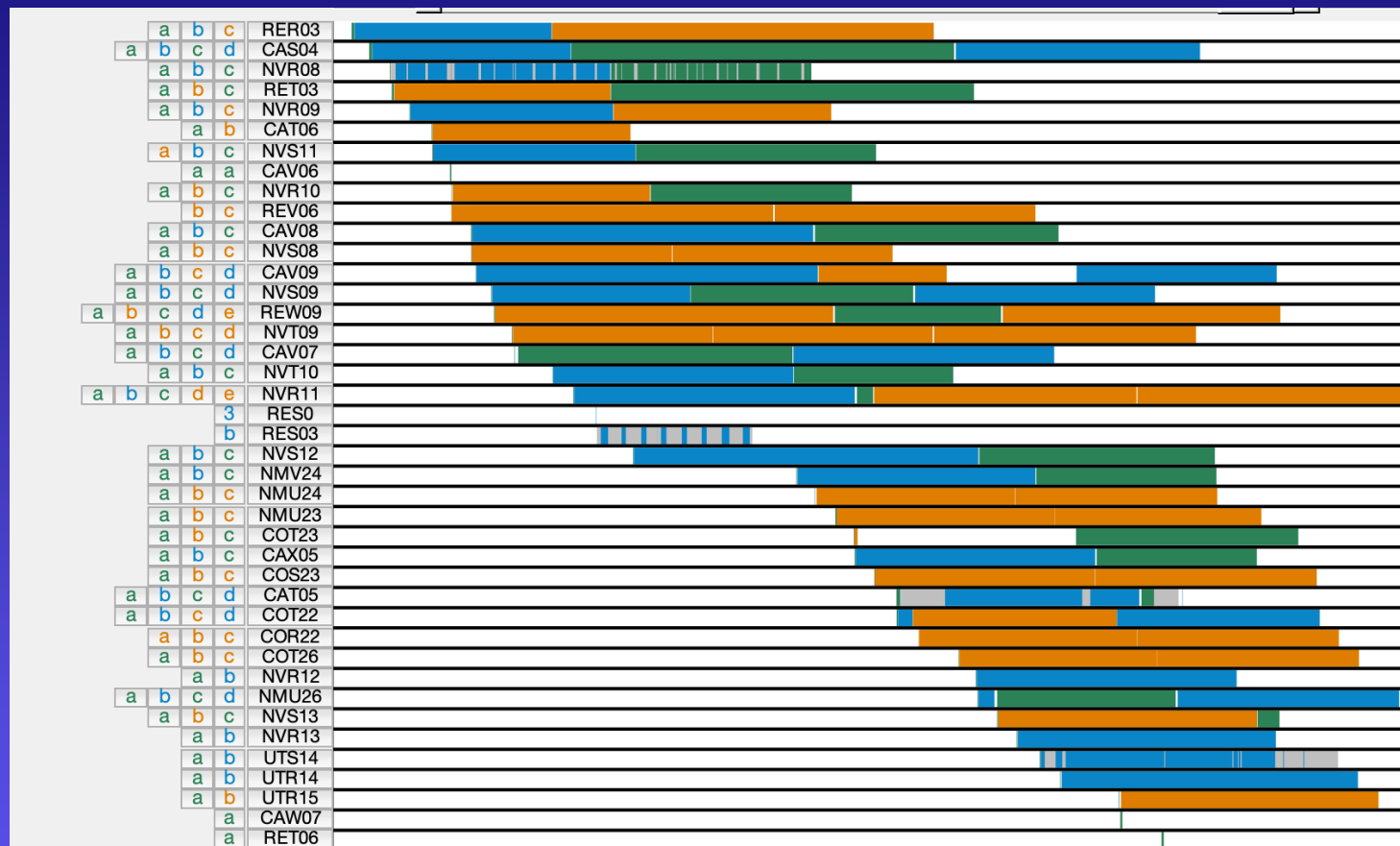
Data acquisition



preliminary data, subject to revision.
Not for citation or distribution

Definitive data processing

- EMTF processing suite (Dnff, TranMT, MMT)
- Standardized workflow w/ metadata tracking
- Remote-reference and multi-station responses
- Identify best short and long-period responses



→ merge to best composite response

Transfer Functions

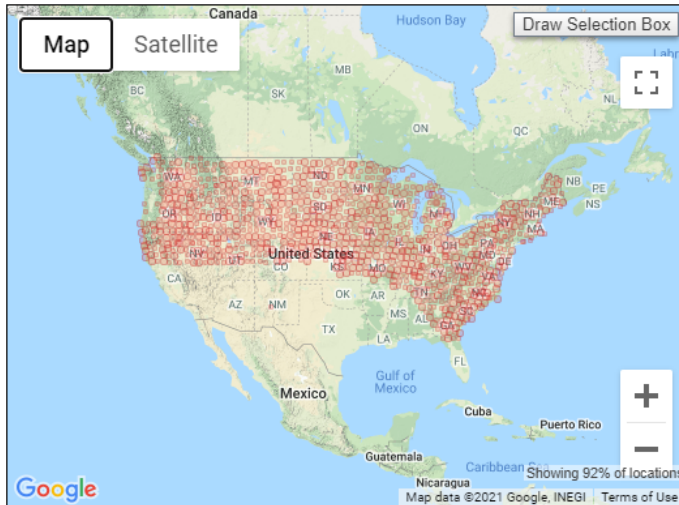
- 1216 stations and growing
- 5-20,000 sec
- <https://ds.iris.edu/spud/emtf>



Products ▾ Help ▾ Citations

EM Transfer Function Product Query

EM Transfer Function Query Parameters



Legend Data Quality Quality Warning Release Status Project Min I

Max Lat: 60.69 Start Date:

Min Lon: -142.40 -51.00 Max Lon: End Date:

Min Lat: 9.31 Modified after:

Site ID: Min Quality:

Project: USArray Period:

Survey: All Site Name:

Type: All Remote Site:

Author: Remote ID:

Tags: Release Status: All

Clear Download EDI

Item Details Source XML

Identification

Sub Type: MT_TF
Description: Magnetotelluric Transfer Functions
Product ID: USArray.CON27.2018
Tags: impedance,tipper

Download EDI

Download XML

Citation Info

Survey Reference: Schultz, A., G. D. Egbert, A. Kelbert, T. Peery, V. Clote, B. Fry, S. Erofeeva and staff of the National Geoelectromagnetic Facility (2018). USArray Magnetotelluric Transfer Functions. <https://doi.org/10.7927/H4T9-7098>

Specific Site Reference: Schultz, A., G. D. Egbert, A. Kelbert, T. Peery, V. Clote, B. Fry, S. Erofeeva and staff of the National Geoelectromagnetic Facility (2018). USArray Magnetotelluric Transfer Functions. <https://doi.org/10.7927/H4T9-7098>

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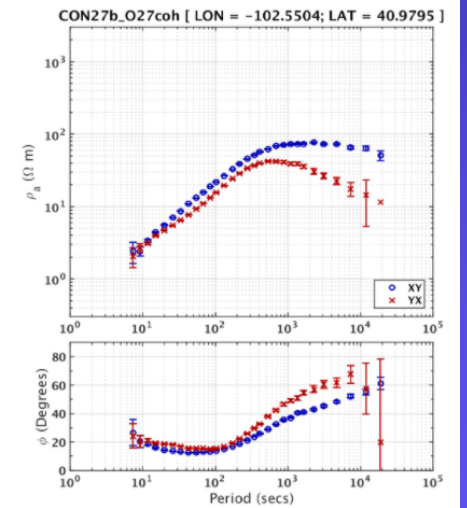
Selected Publications: Schultz, A. (2009). EMScope: a continental scale magnetotelluric observatory and data discovery resource. *Data in Brief*, 4, 1-10. doi:10.1016/j.dib.2009.11.001. Meqbel, N. M., Egbert, G. D., Wannamaker, P. E., Kelbert, A., & Schultz, A. (2014). Deep electrical resistivity structure of the central United States from magnetotelluric data. *Journal of Geophysical Research*, 119, 1-15. doi:10.1002/jgrb.12401. Yang, B., Egbert, G. D., Kelbert, A., & Meqbel, N. M. (2015). Three-dimensional electrical resistivity of the north-central United States from magnetotelluric data. *Journal of Geophysical Research*, 120, 1-15. doi:10.1002/jgrb.12401.

Release Status: Unrestricted Release

Conditions of Use: All data and metadata for this survey are available free of charge and may be copied freely, duplicated and further processed for research purposes. While the author(s) strive to provide data and metadata of best possible quality, neither the author(s) of this data set nor the quality or limitations of the data and metadata, as obtained from the author(s), are included for informational purposes.

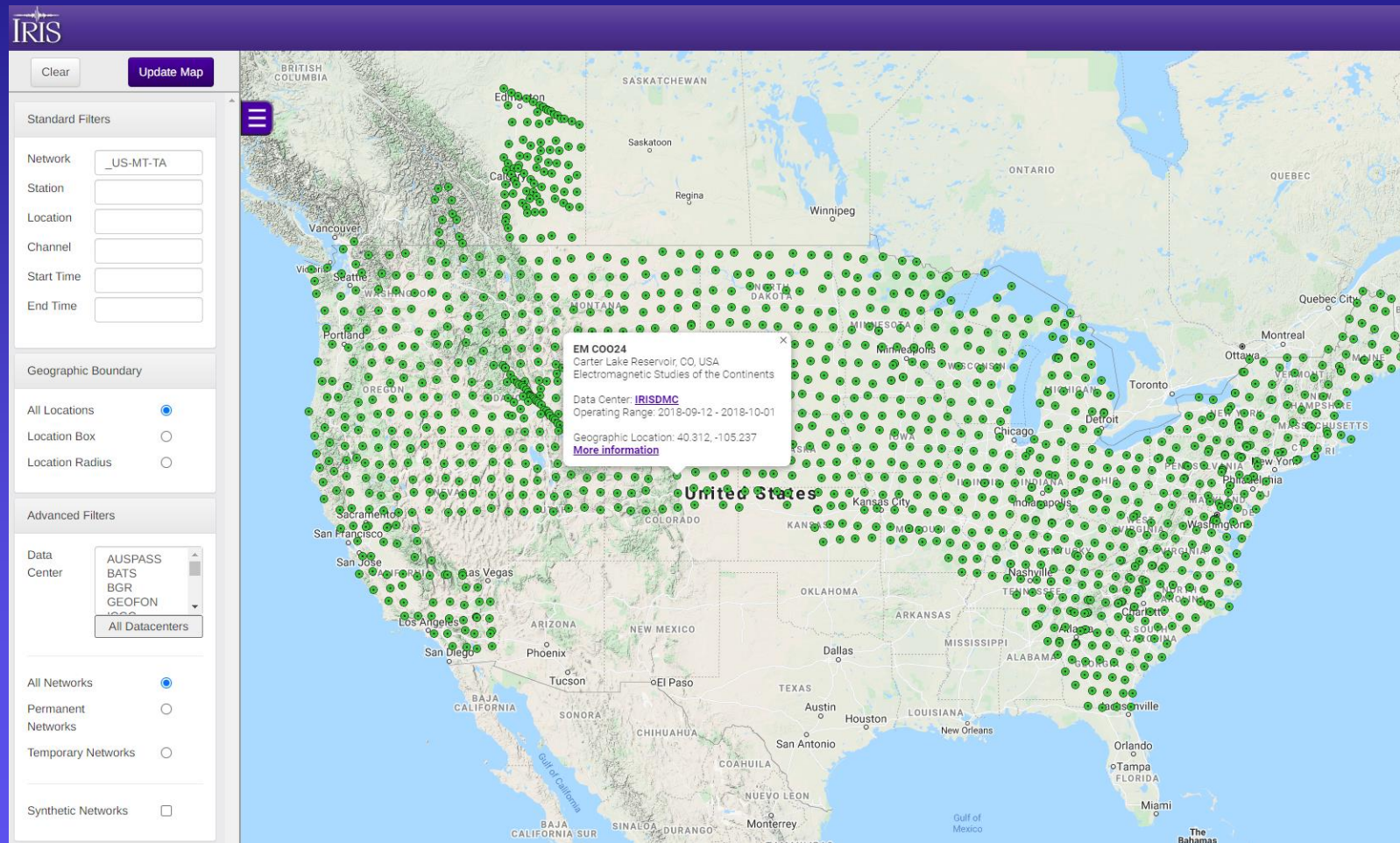
Site Info

Project: USArray
Survey: Transportable Array
Year Collected: 2018
ID: CON27
Name: Sedgwick, CO, USA
Elevation: 1155.05
Latitude: 40.97947
Longitude: -102.55042
Declination: 8.6
Declination Epoch: 1995.0
Orientation: orthogonal
Angle To GG North: 0.000
Release Status: Unrestricted Release
Acquired By: National Geoelectromagnetic Facility
Data Quality Rating: 5
Data Quality Comments: great TF from 10 to 10000 secs (or longer)
Runlist: CON27a CON27b
Start Date: 2018-10-31 20:06:31
End Date: 2018-11-10 19:29:56

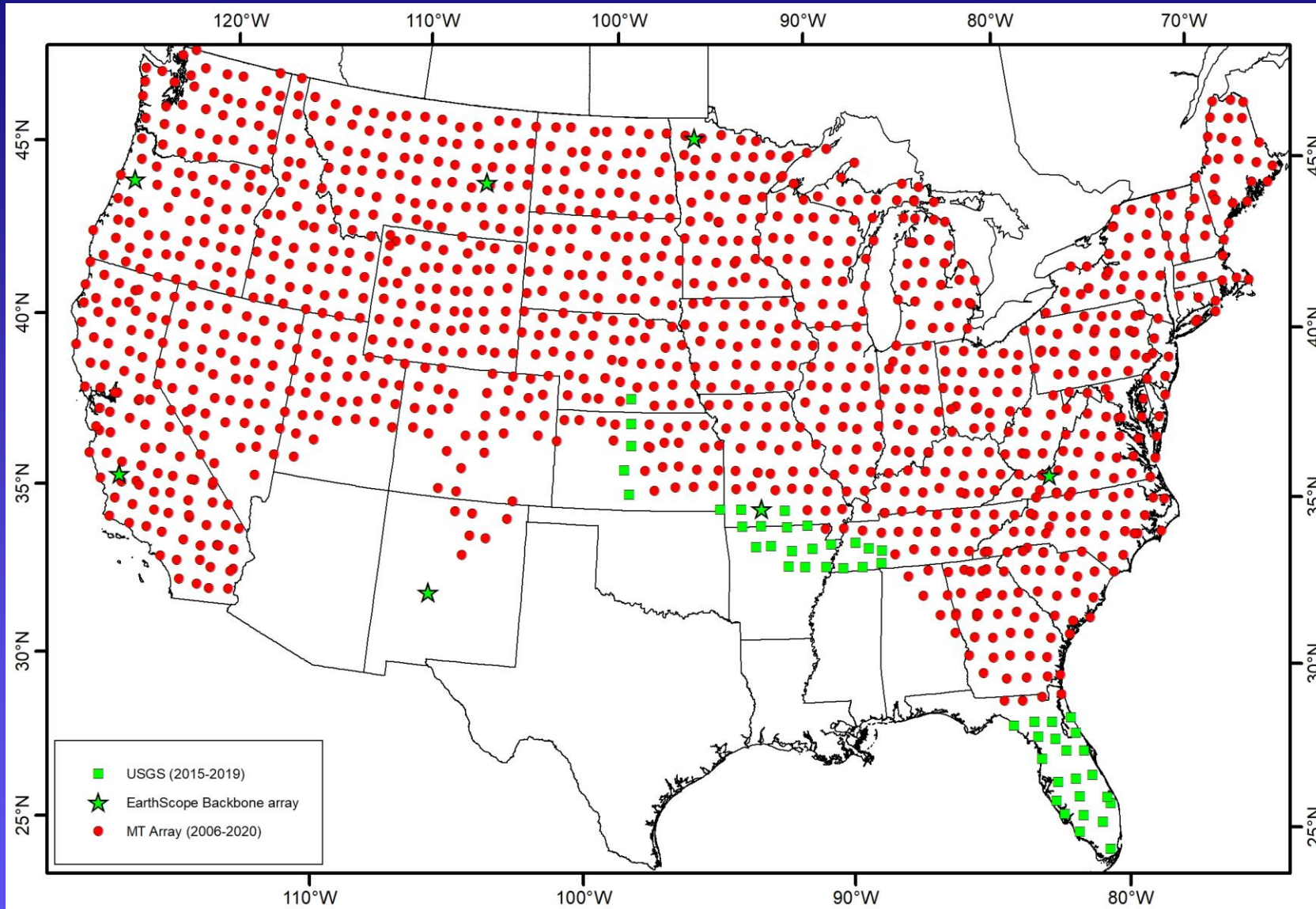


Time Series

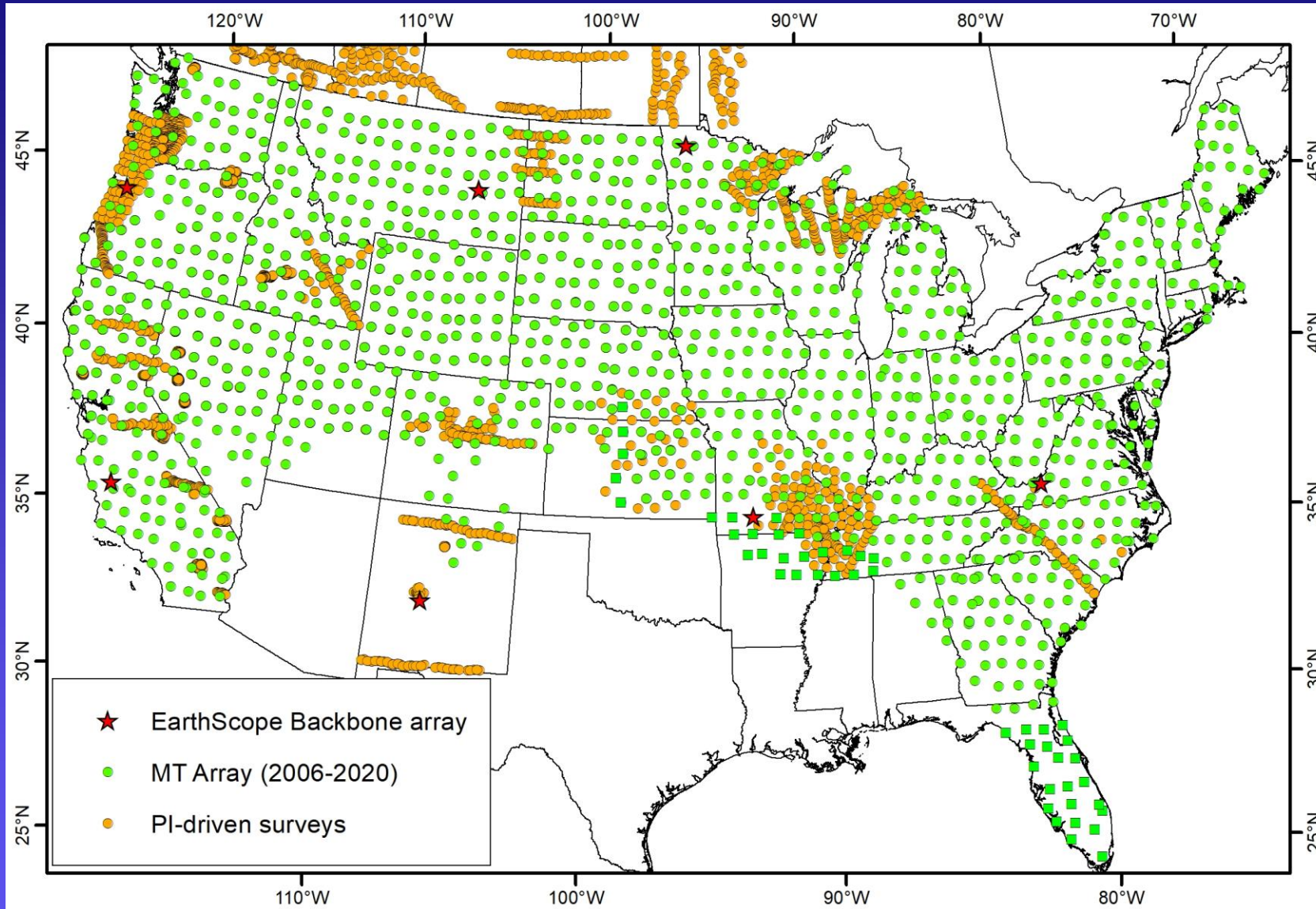
- <https://ds.iris.edu/gmap>, network code: **_US-MT-TA**



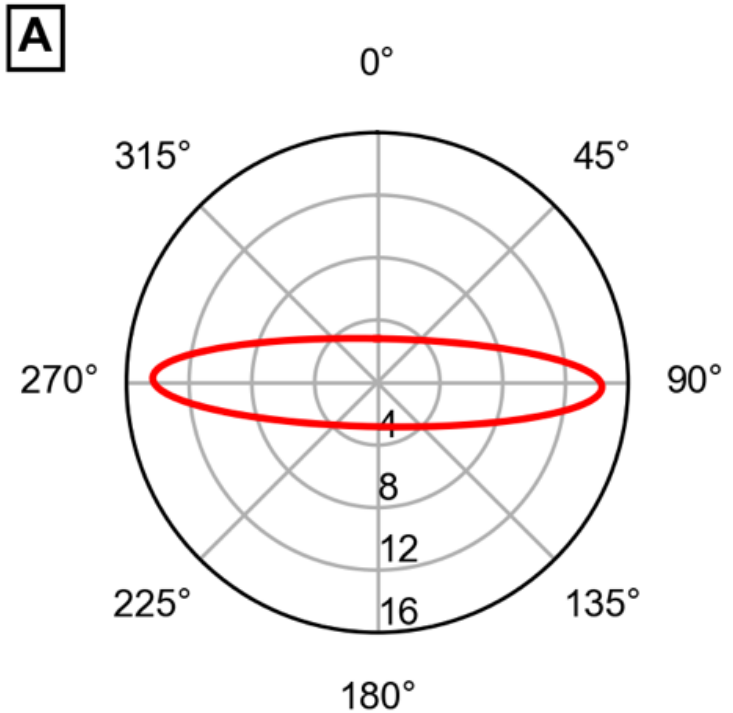
Building the US MT Array → 2006-present



A consistent framework to build upon

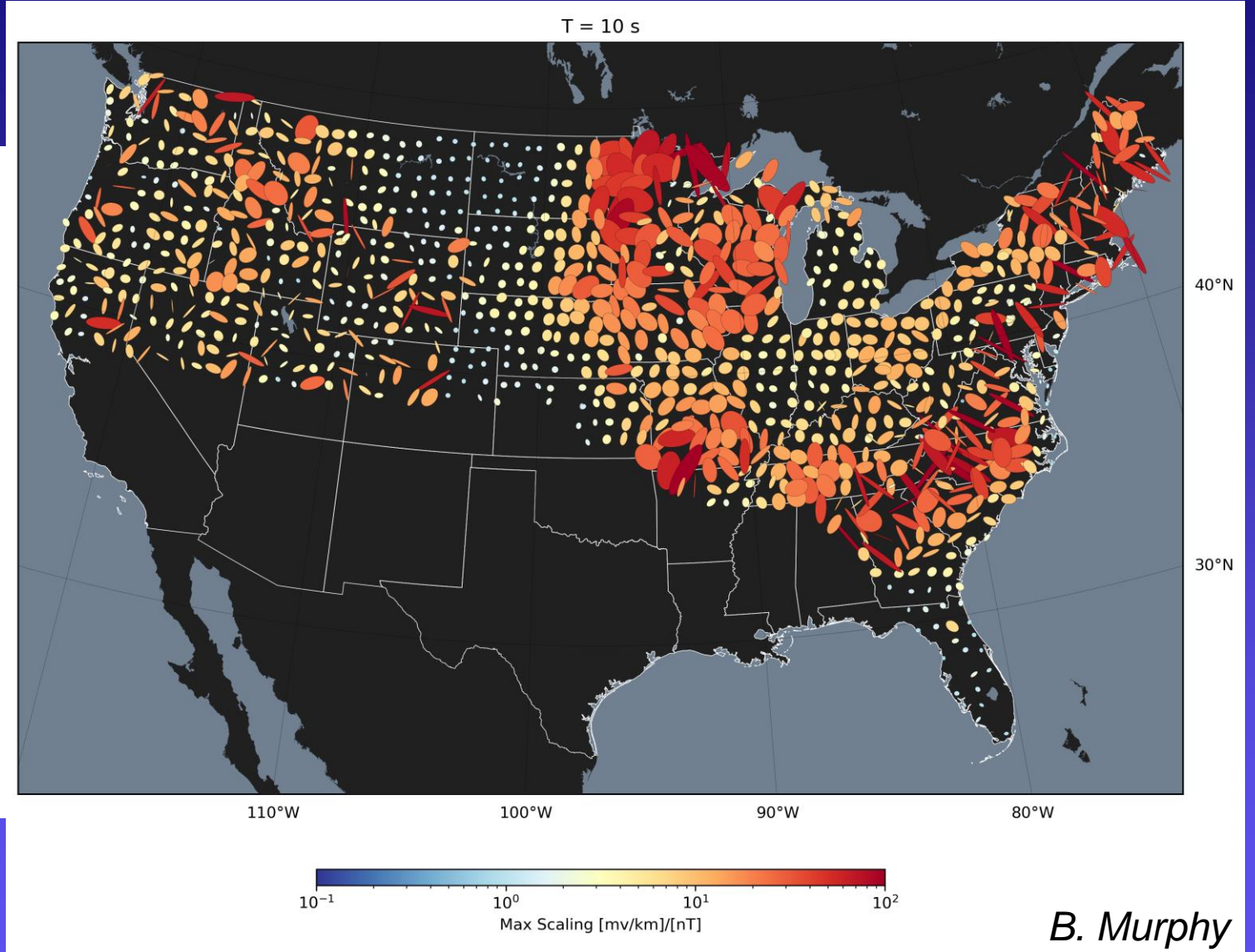


Electric field polarization ellipses → 10 sec



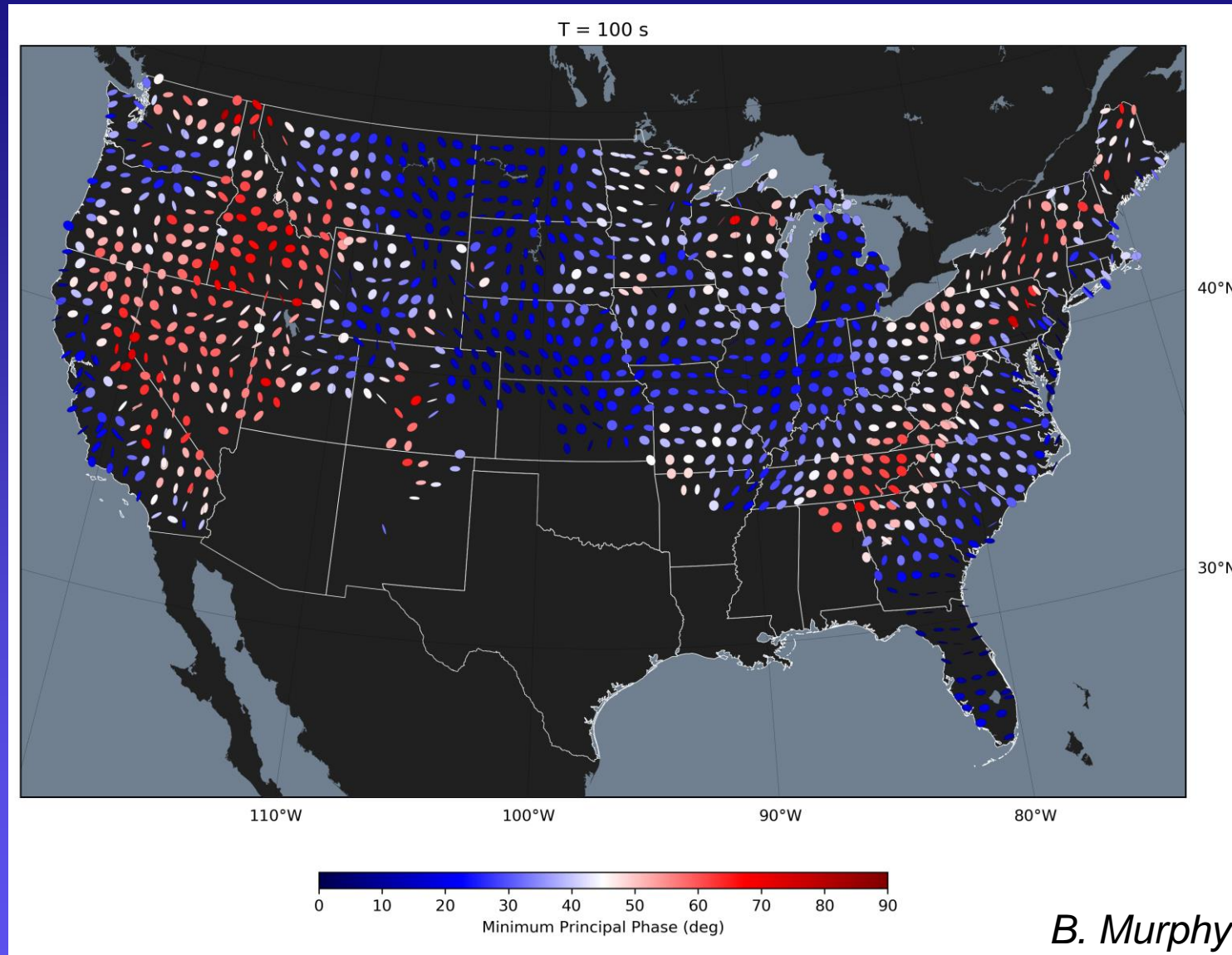
Impedance E-Polarization State (WAA10)

Berdichevsky & Dmitriev, 2008

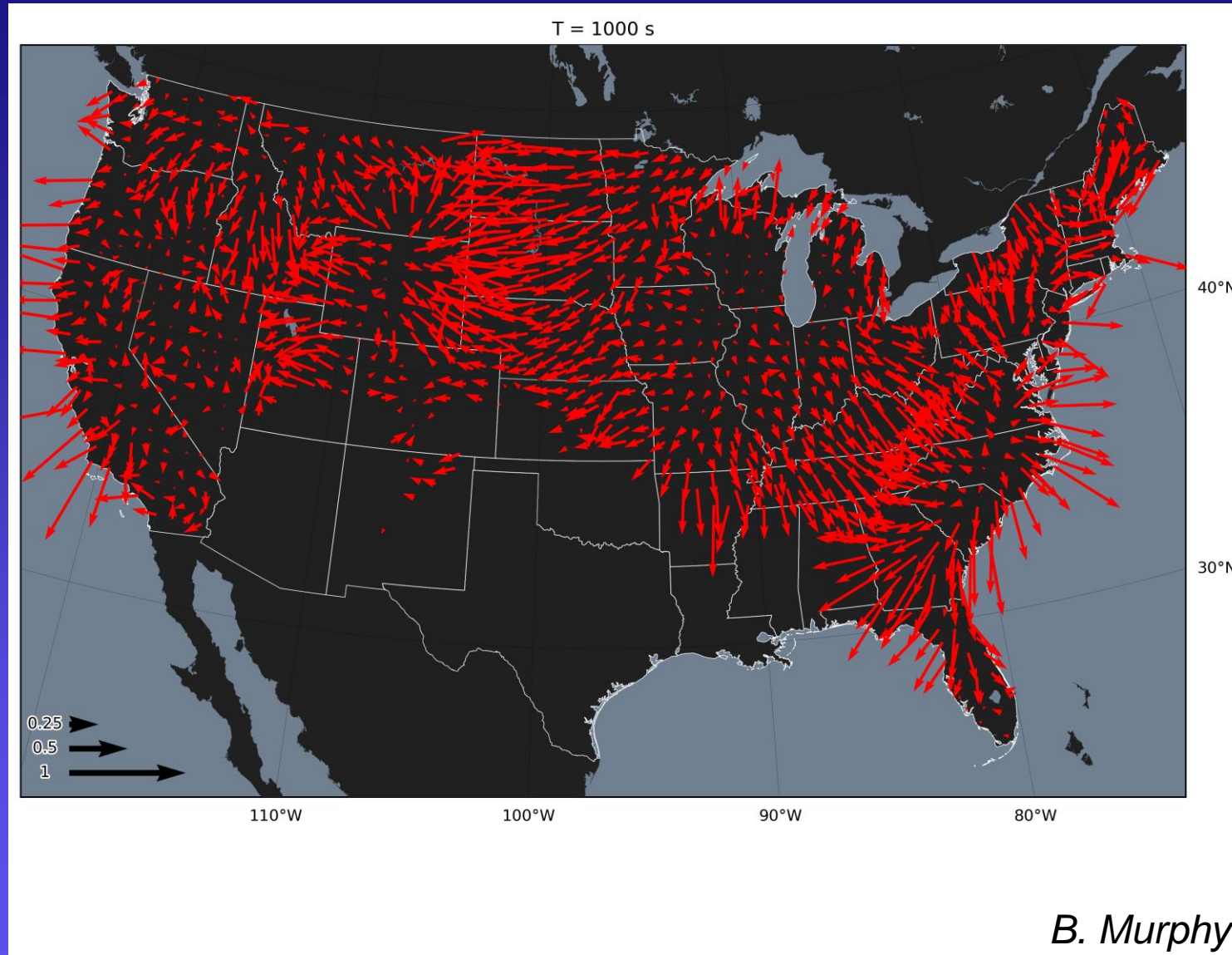


B. Murphy

Phase tensors, minimum principal phase \rightarrow 100 sec

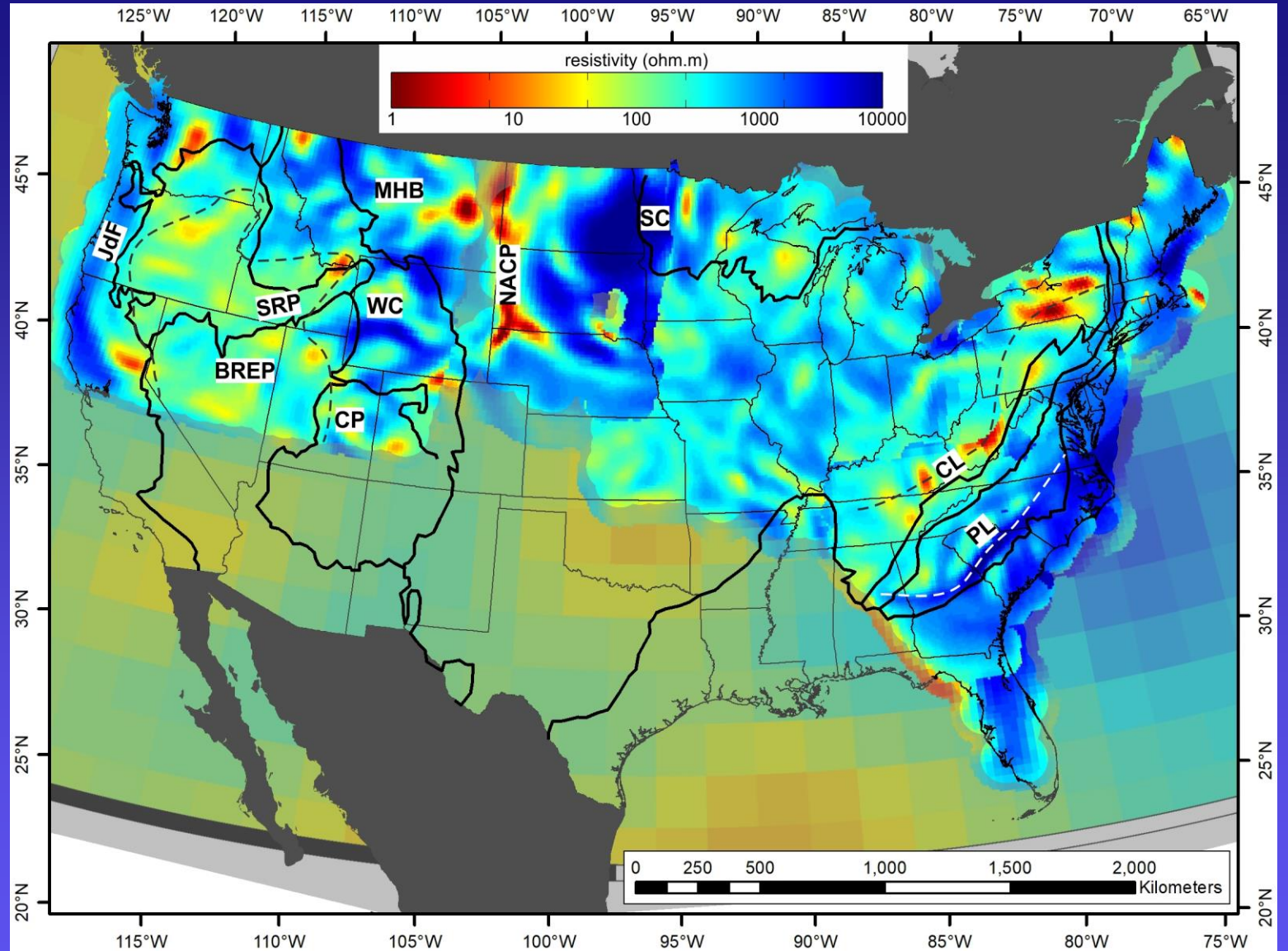
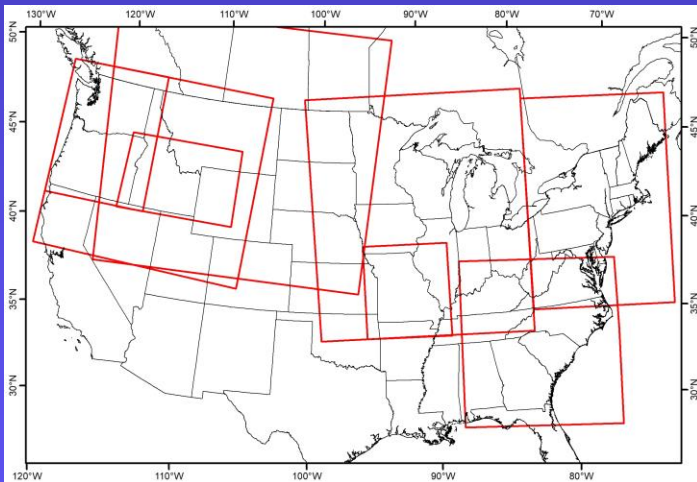


Real induction vectors, Parkinson convention → 1000 sec



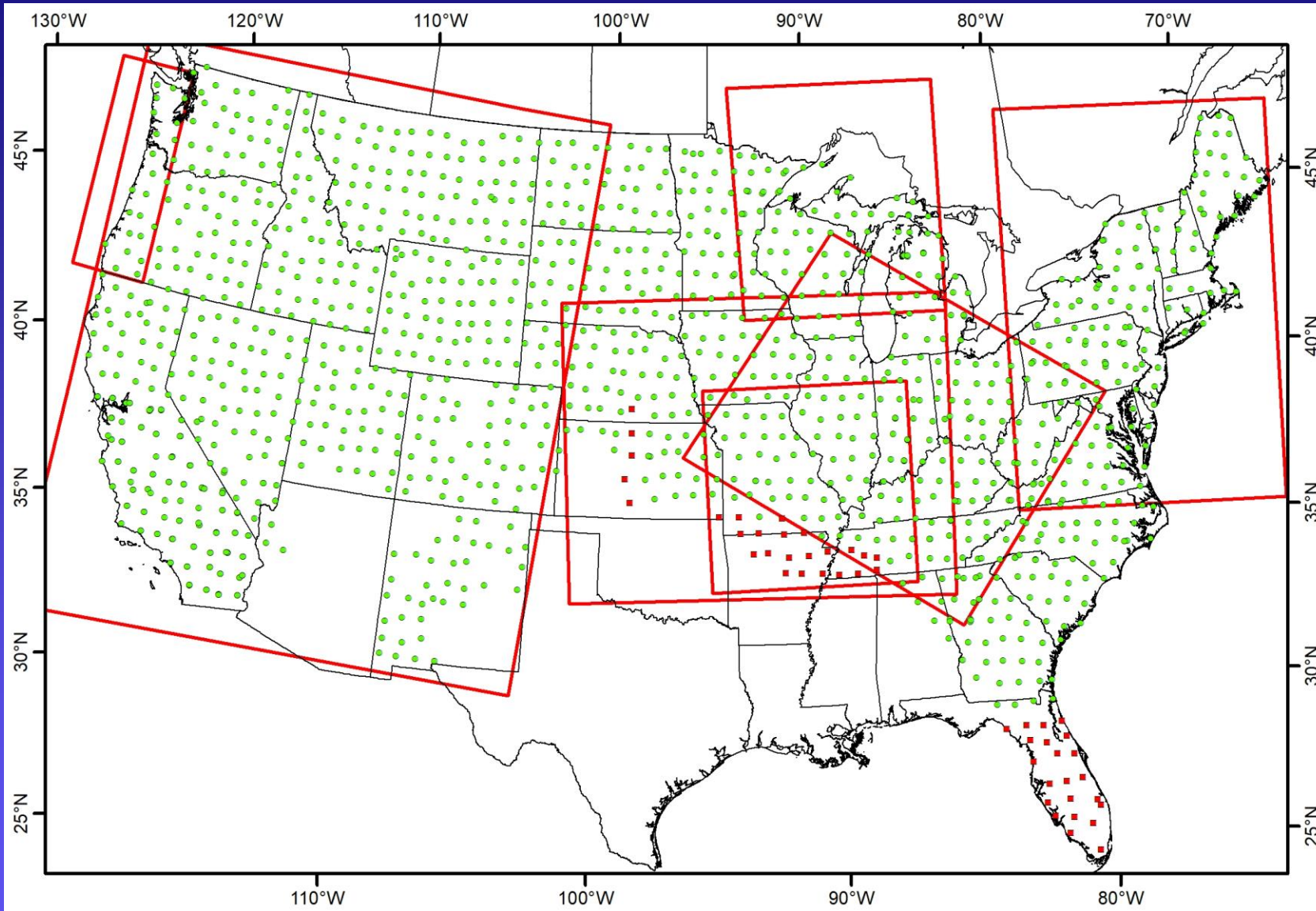
Conductivity model of the contiguous United States (v1.0)

- 3 km
- 30 km
- 100 km

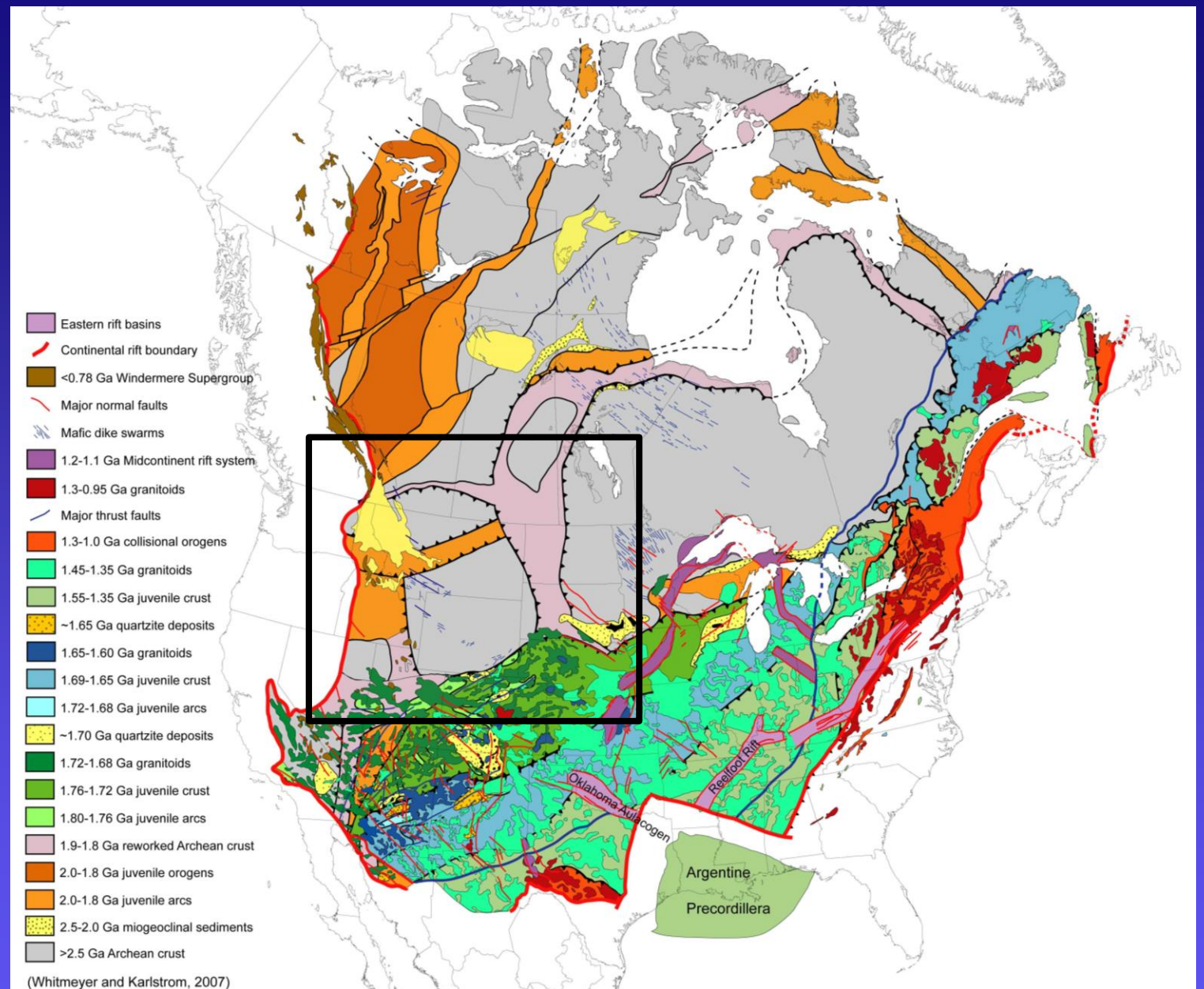


Framework Tectonics

Geologic/tectonic studies using MT Array data

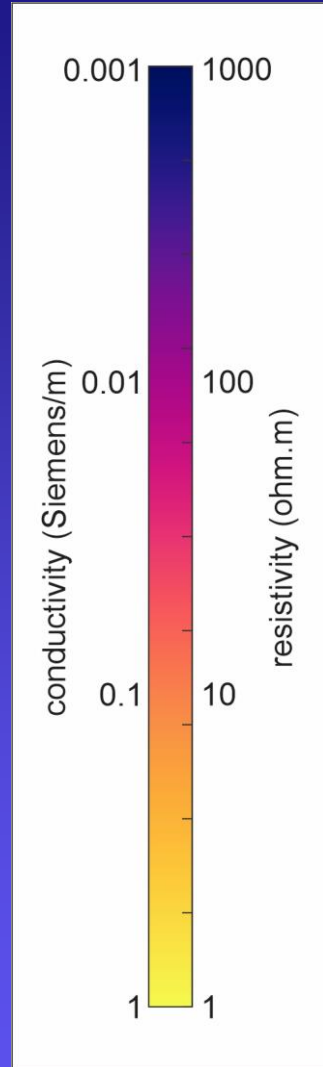
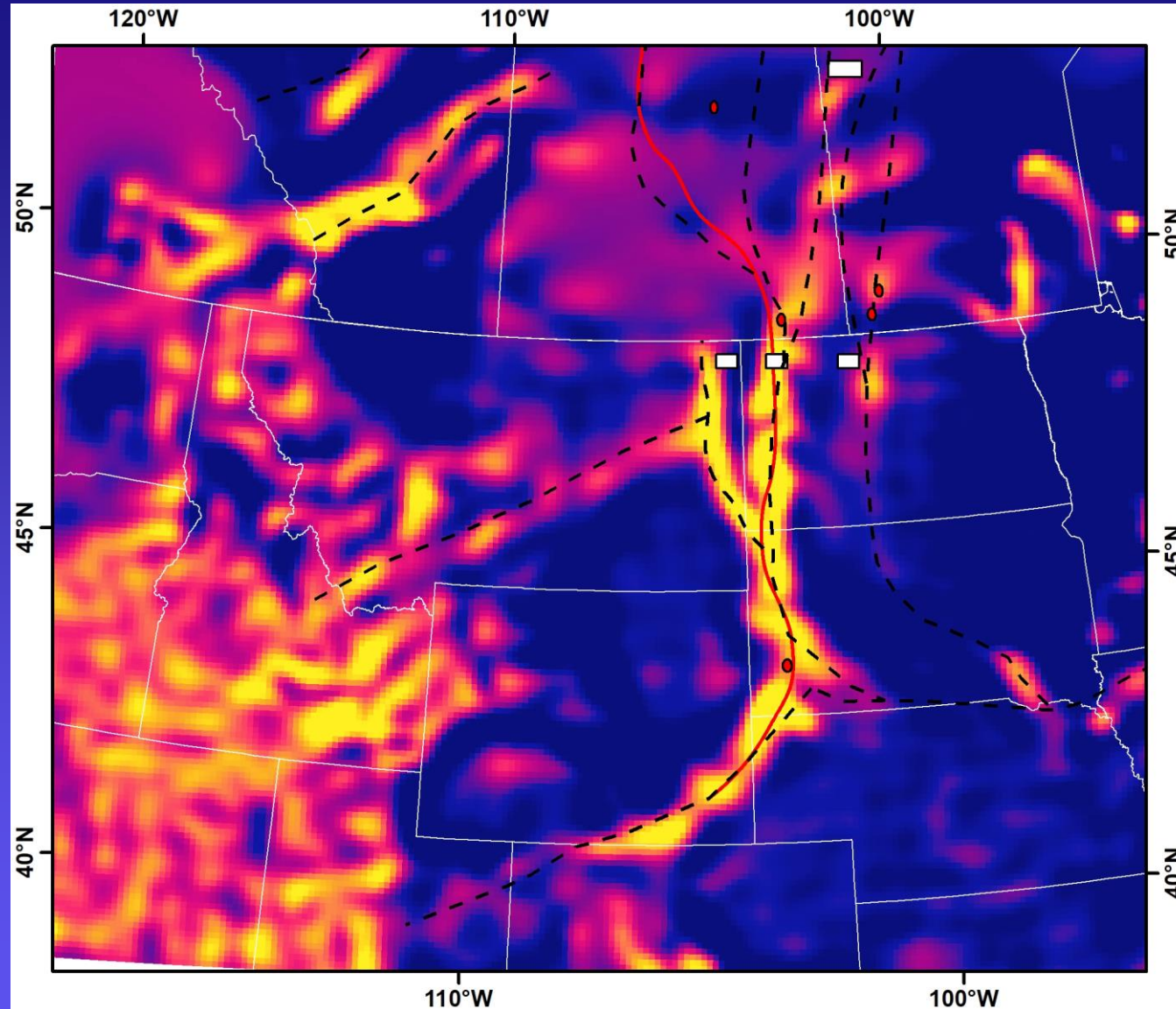


North American framework

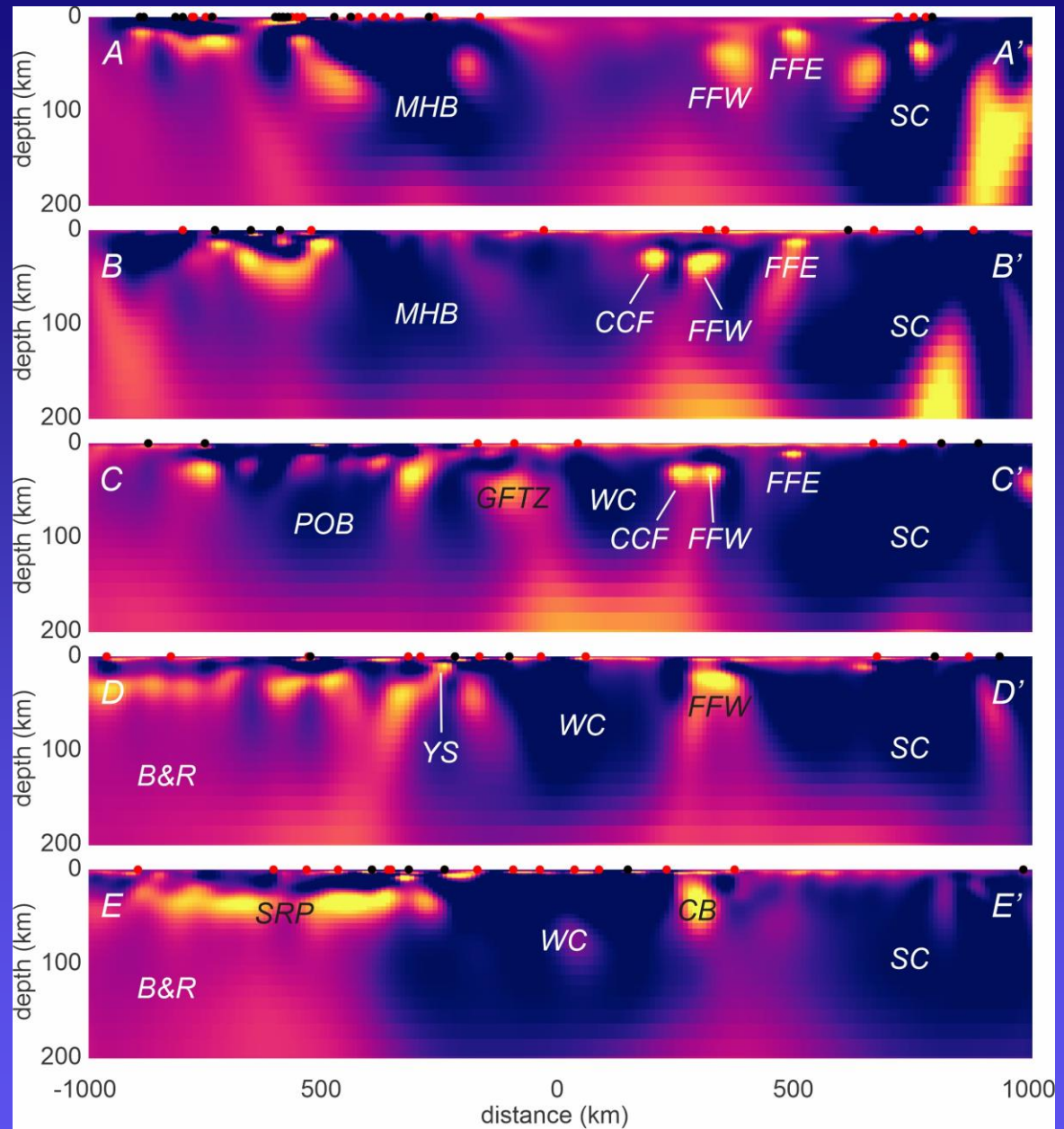
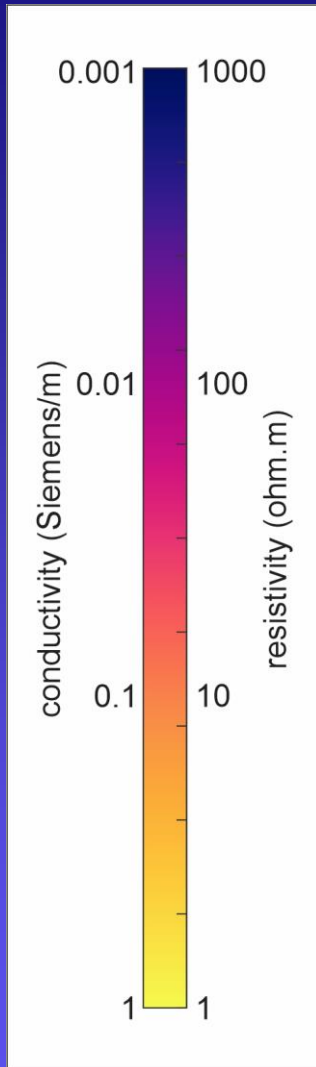


Tectonic architecture

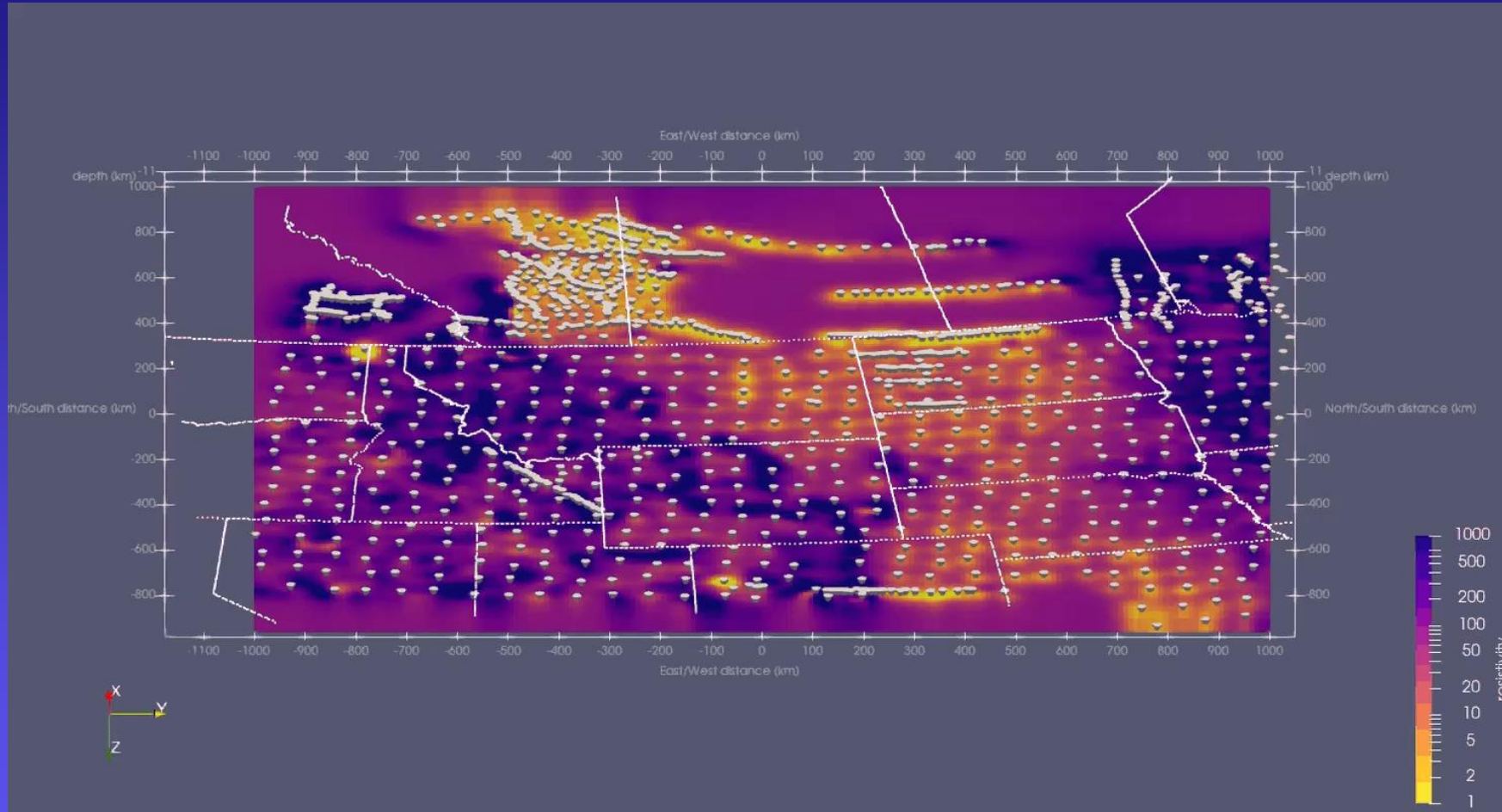
- 2 km
- 15 km
- 30 km



Tectonic architecture

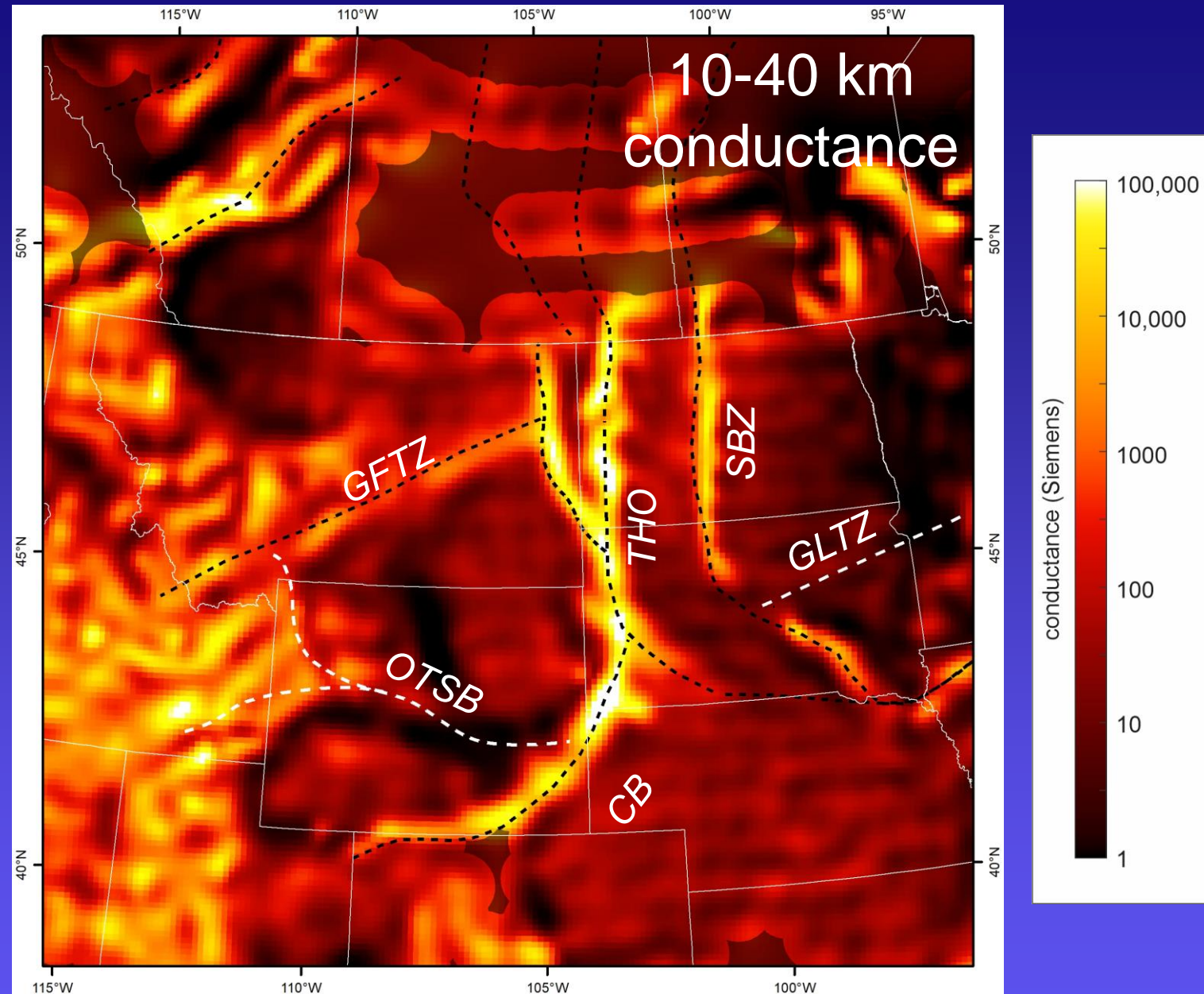


Forest for the trees & building upon a backbone



Archean vs Paleoproterozoic subduction

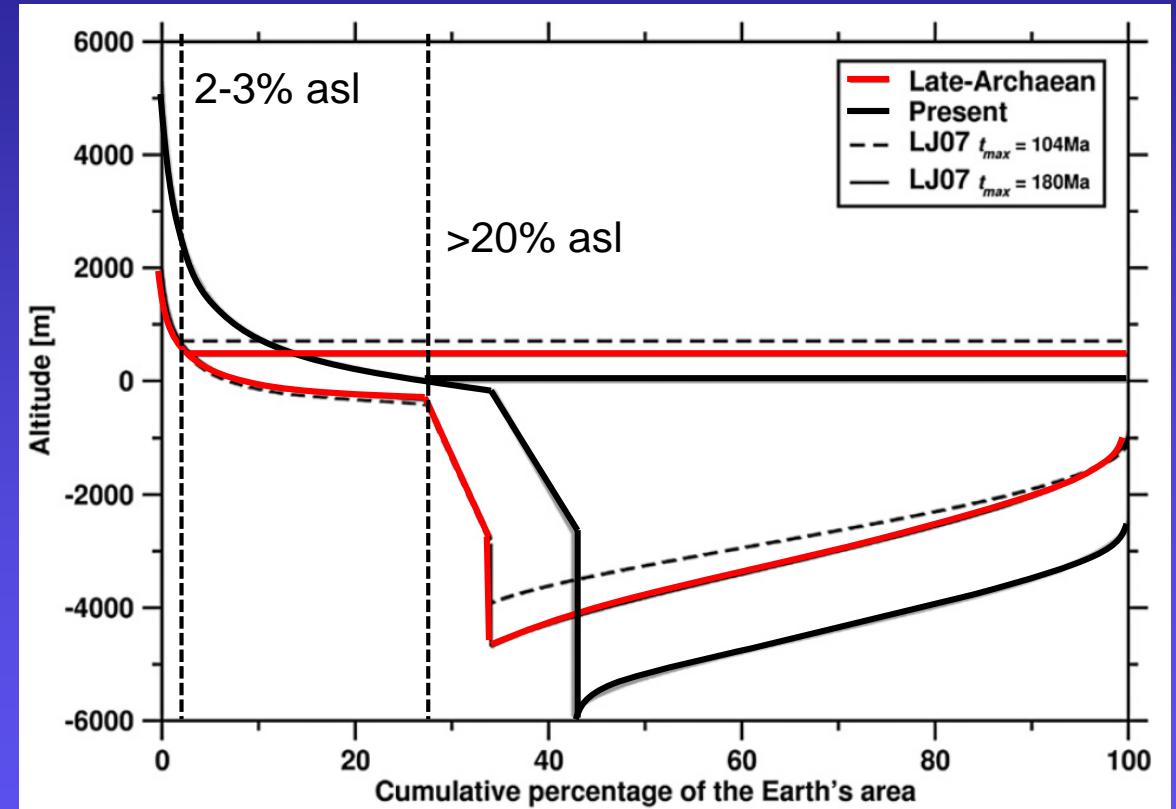
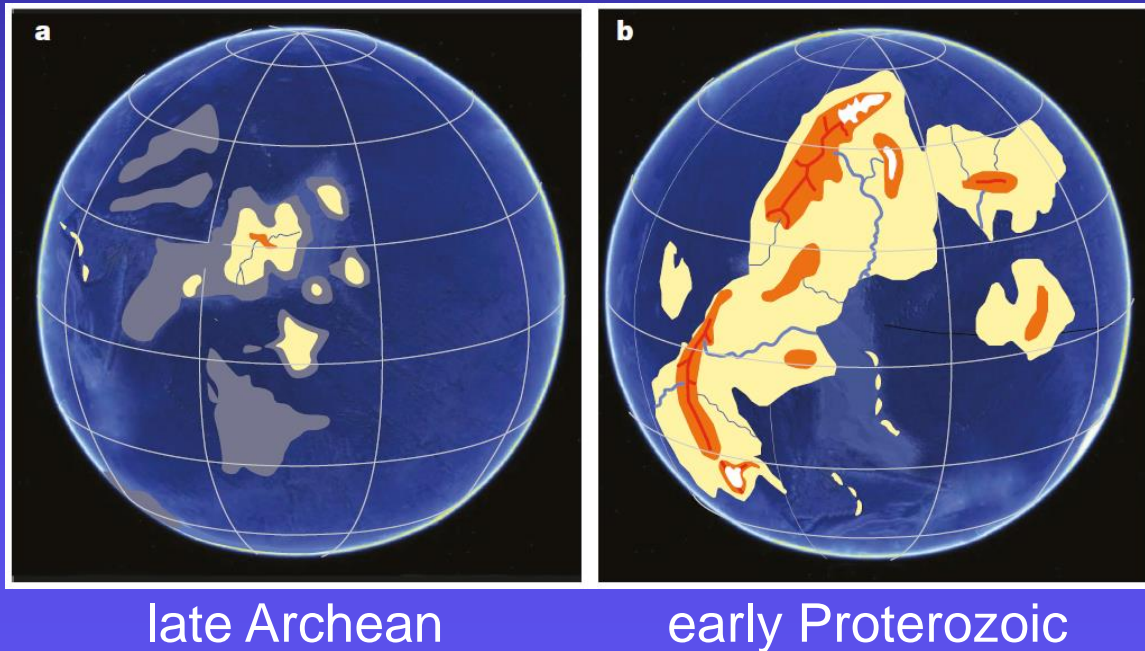
- Paleoproterozoic sutures have conductance values that range from 1000-100,000 Siemens
- OTSB is low conductance: 1000x less than Paleoproterozoic sutures
- Other Archean sutures have similarly low conductance



Sediment-starved subduction in the Archean?

- What's missing in the Archean? → passive margin sediments
- Consistent with rapid emergence of the continents at the end of the Archean and accompanying increases in subaerial weathering

Bindeman et al. (2018)



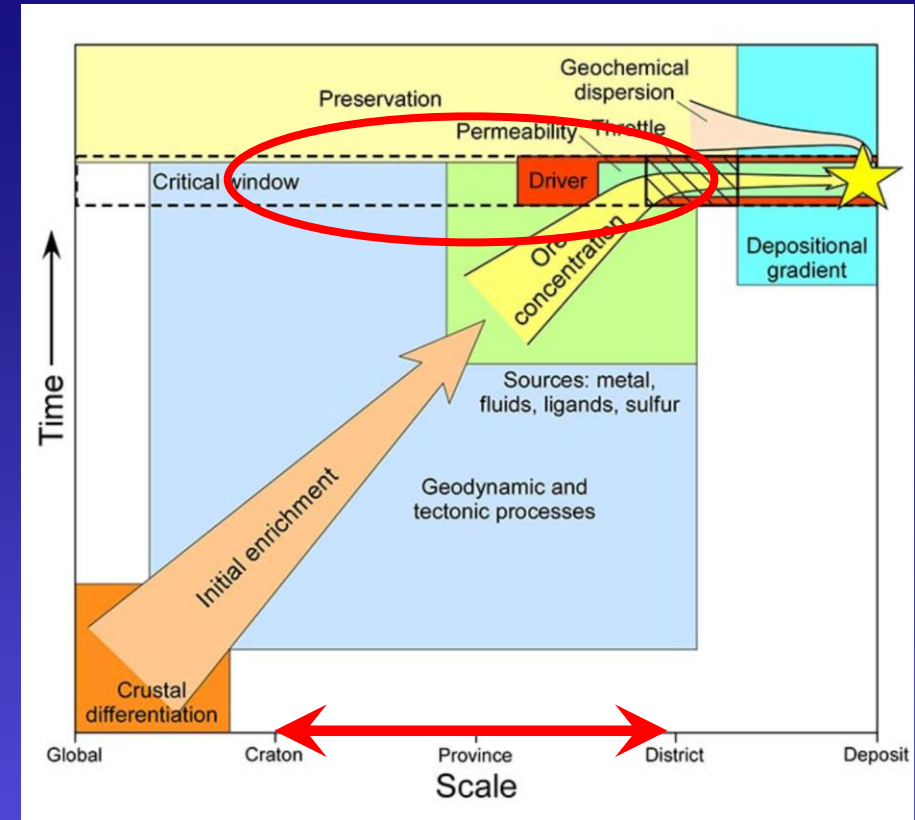
Flament et al. (2008)

Mineral Resources

'Mineral Systems' framework

All geologic processes that control the formation and preservation of genetically-related ore deposits

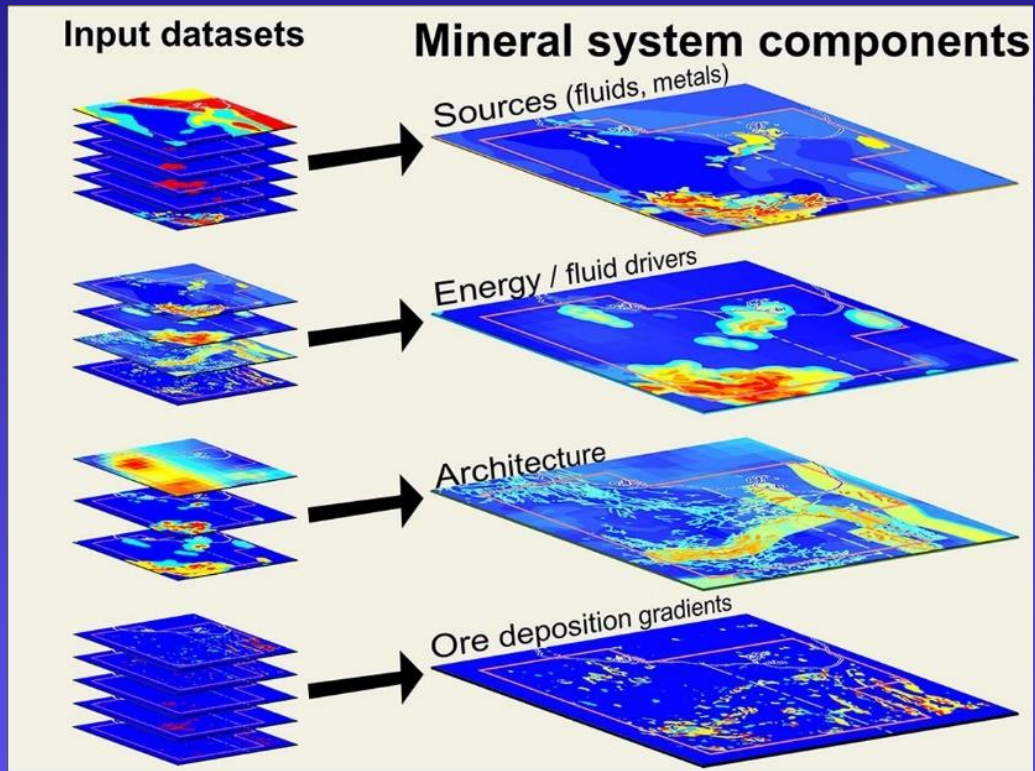
- Energy drive (e.g. topography, geothermal gradient, magma)
- Source (metals)
- Transport media (melts, aqueous fluids, petroleum)
- Transport pathways (permeable structures/lithologies)
- Physical and chemical traps (basins, lithologies, redox changes)



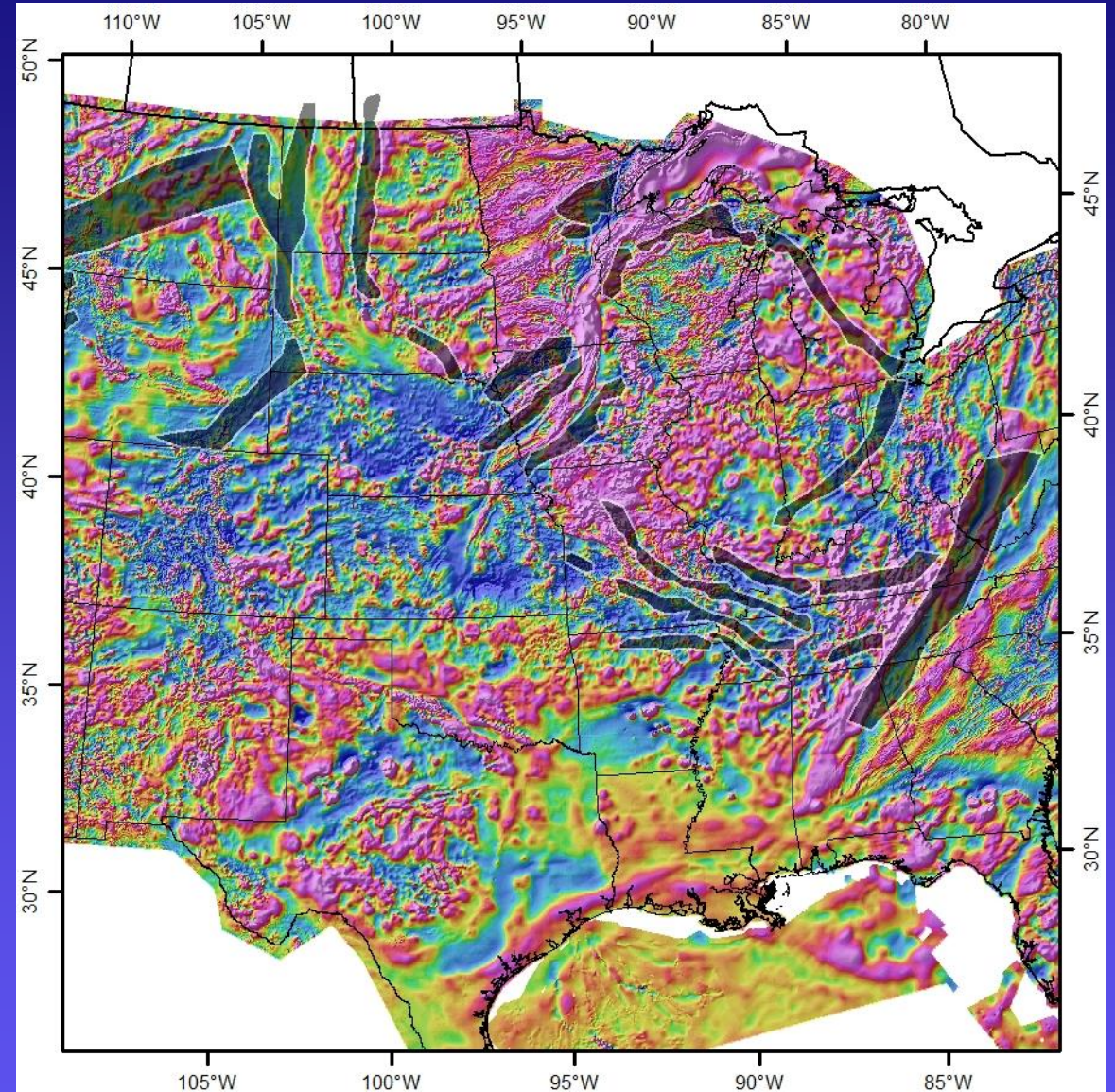
Huston et al. (2016)

→ ***Mineral systems have much larger and deeper geologic and geophysical footprints than deposits.***

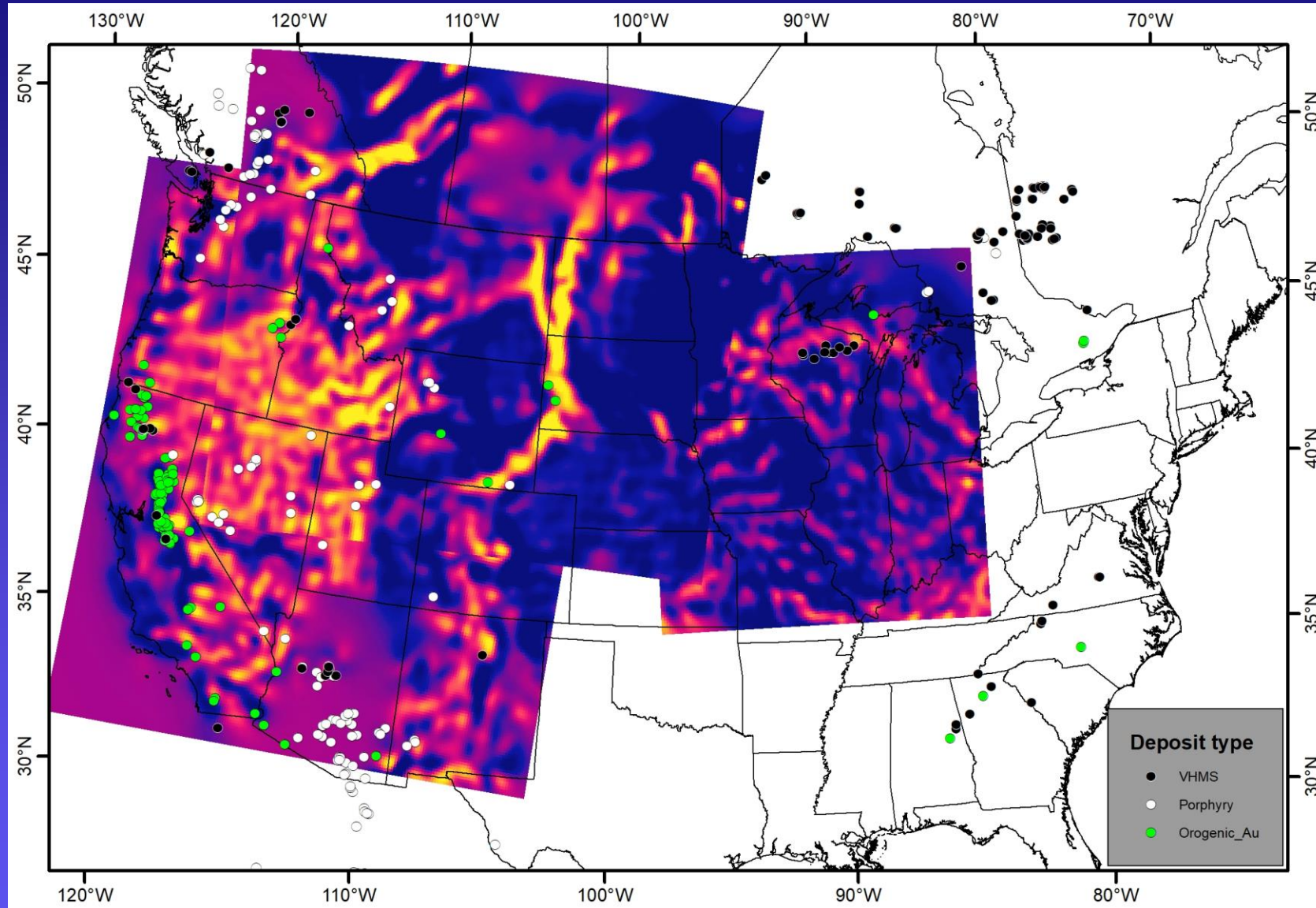
Prospectivity analysis



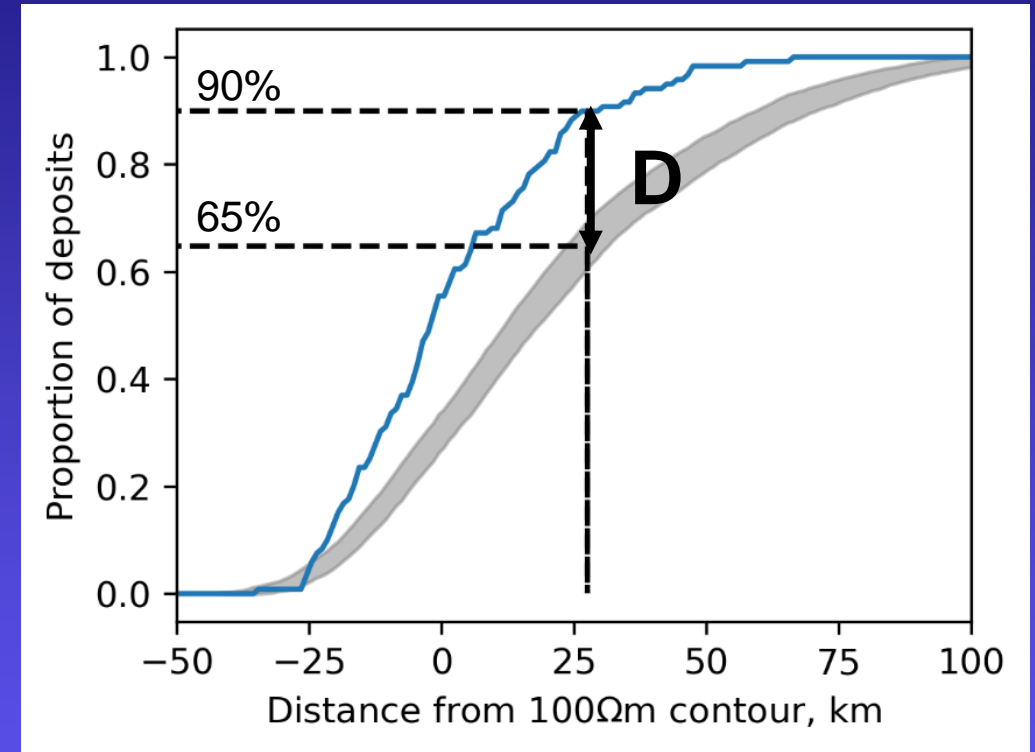
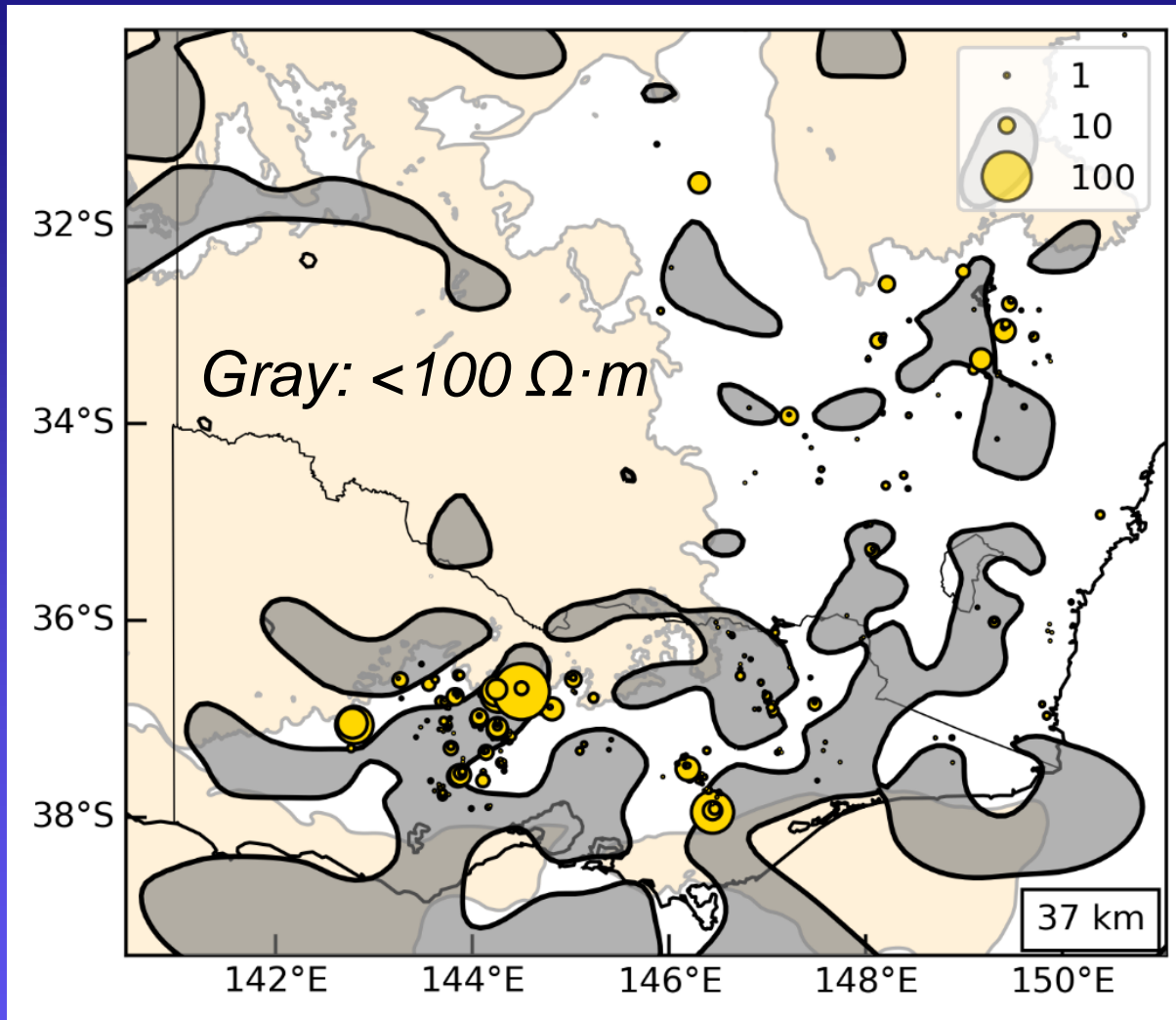
Skirrow et al. (2019)



Resistivity at 30 km + deposit locations

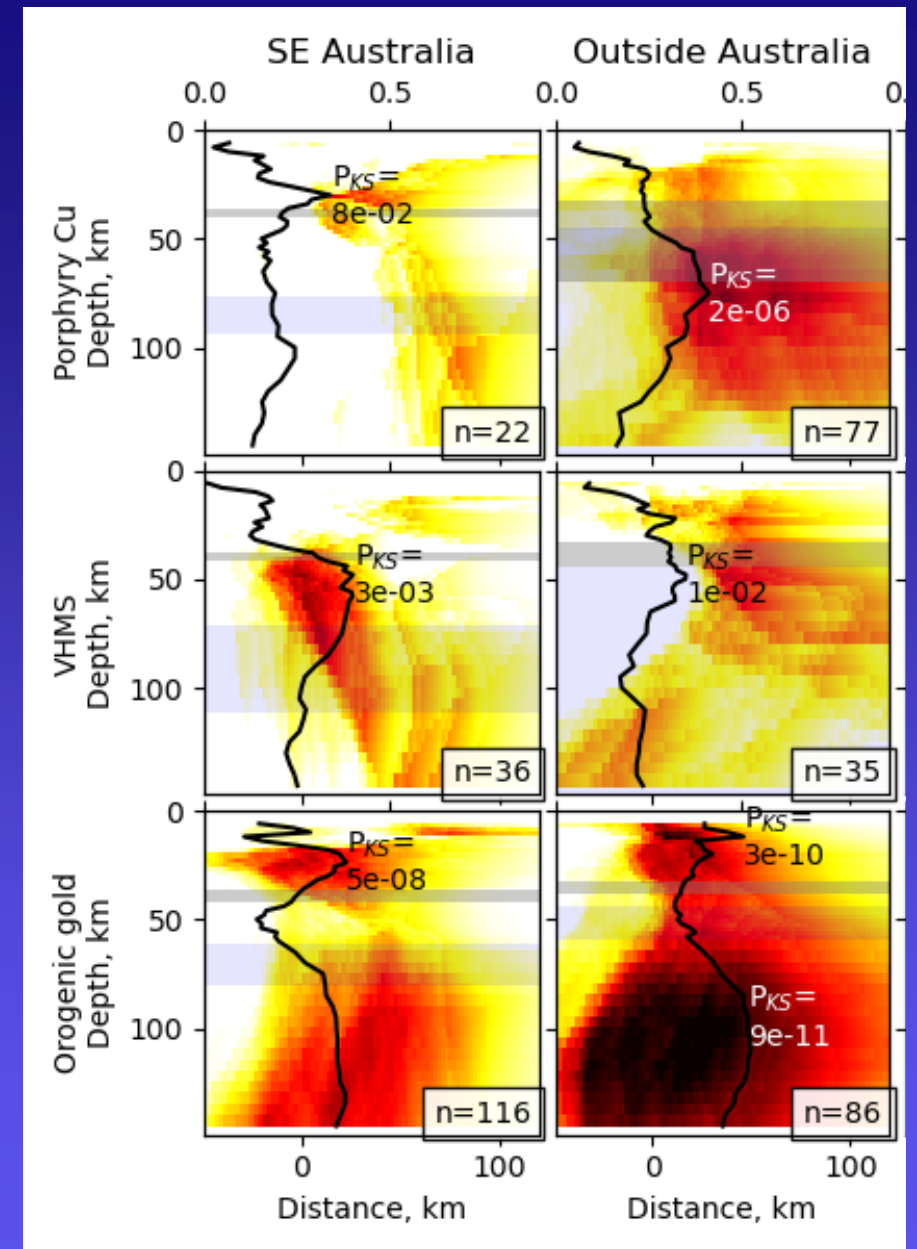


Spatial relationship between deposits & conductors

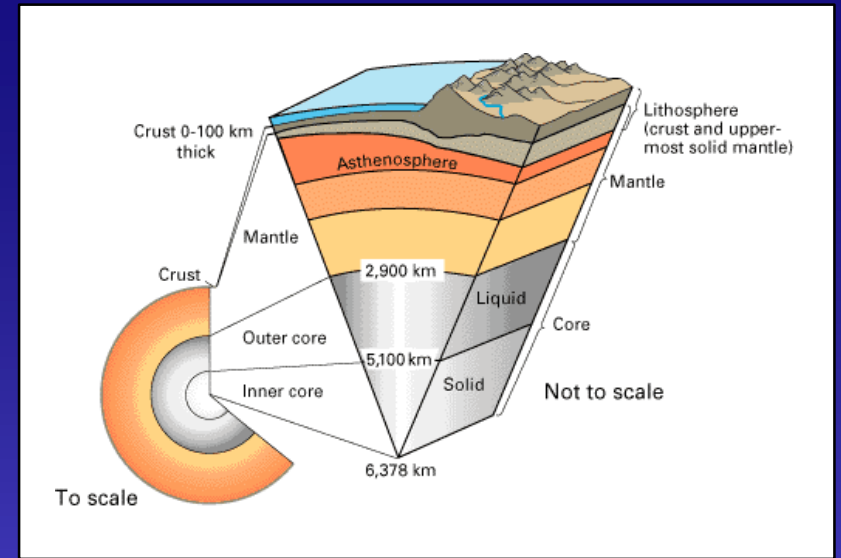
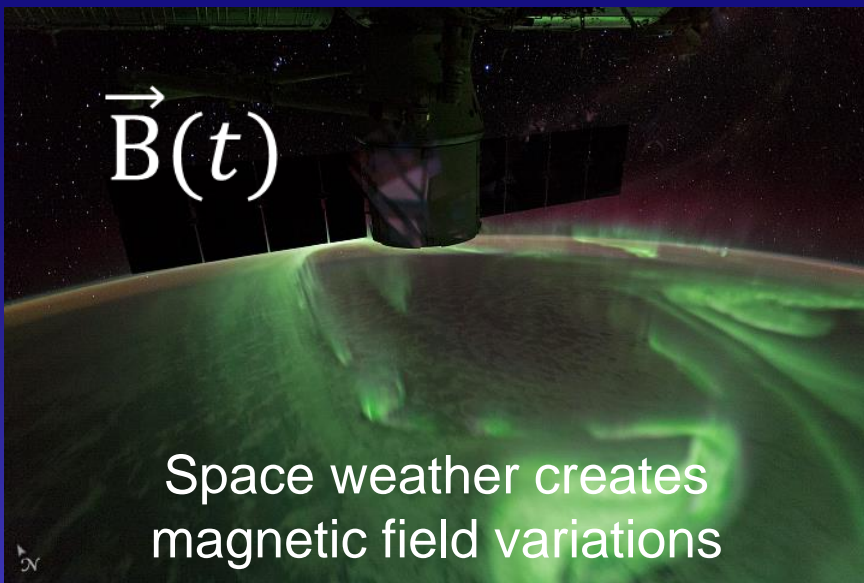


Correlation as heat maps

- Probability that deposits and conductors are spatially related as a function of depth
- Different spatial/depth relationships for different deposit types
- Reflect different genetic models and positions within convergent margins



Space Weather

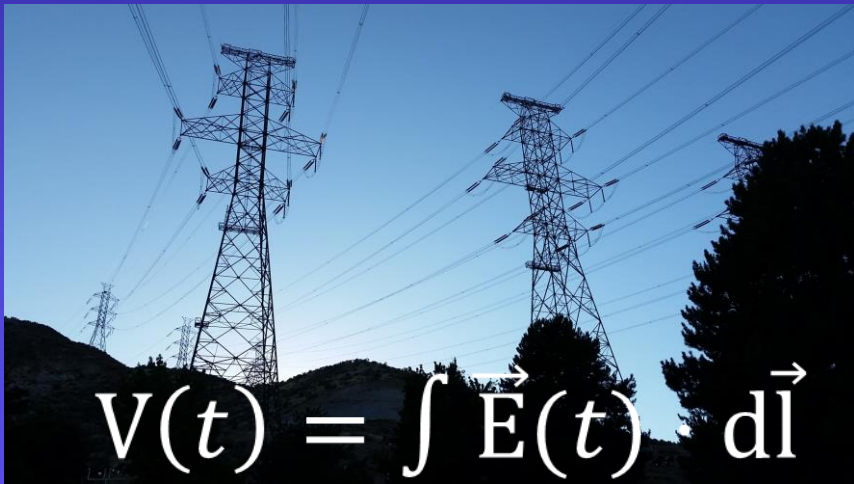


\vec{Z}



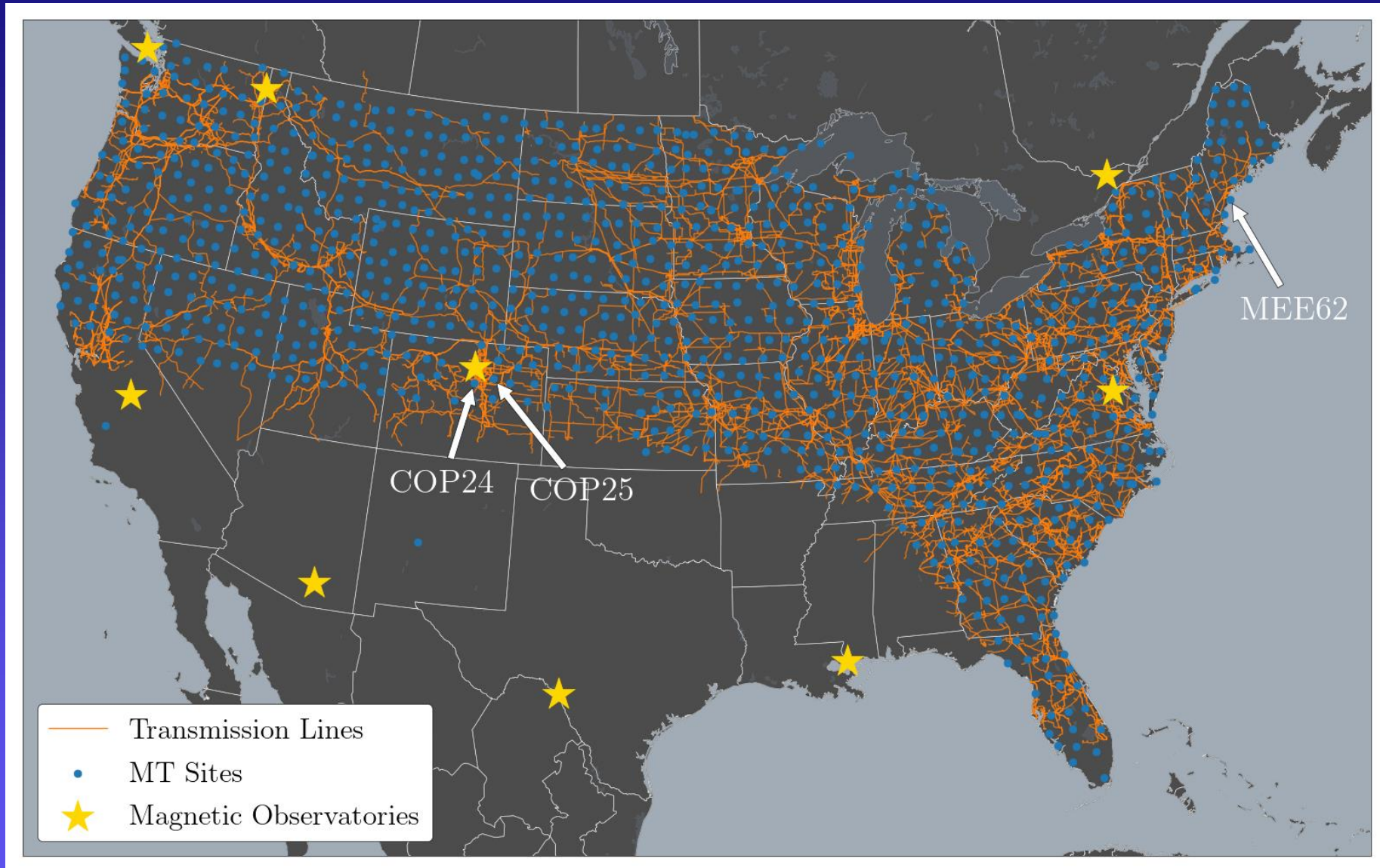
changing magnetic field induces geoelectric fields in the Earth

$$\vec{E}(t) = \vec{Z} * \vec{B}(t)$$

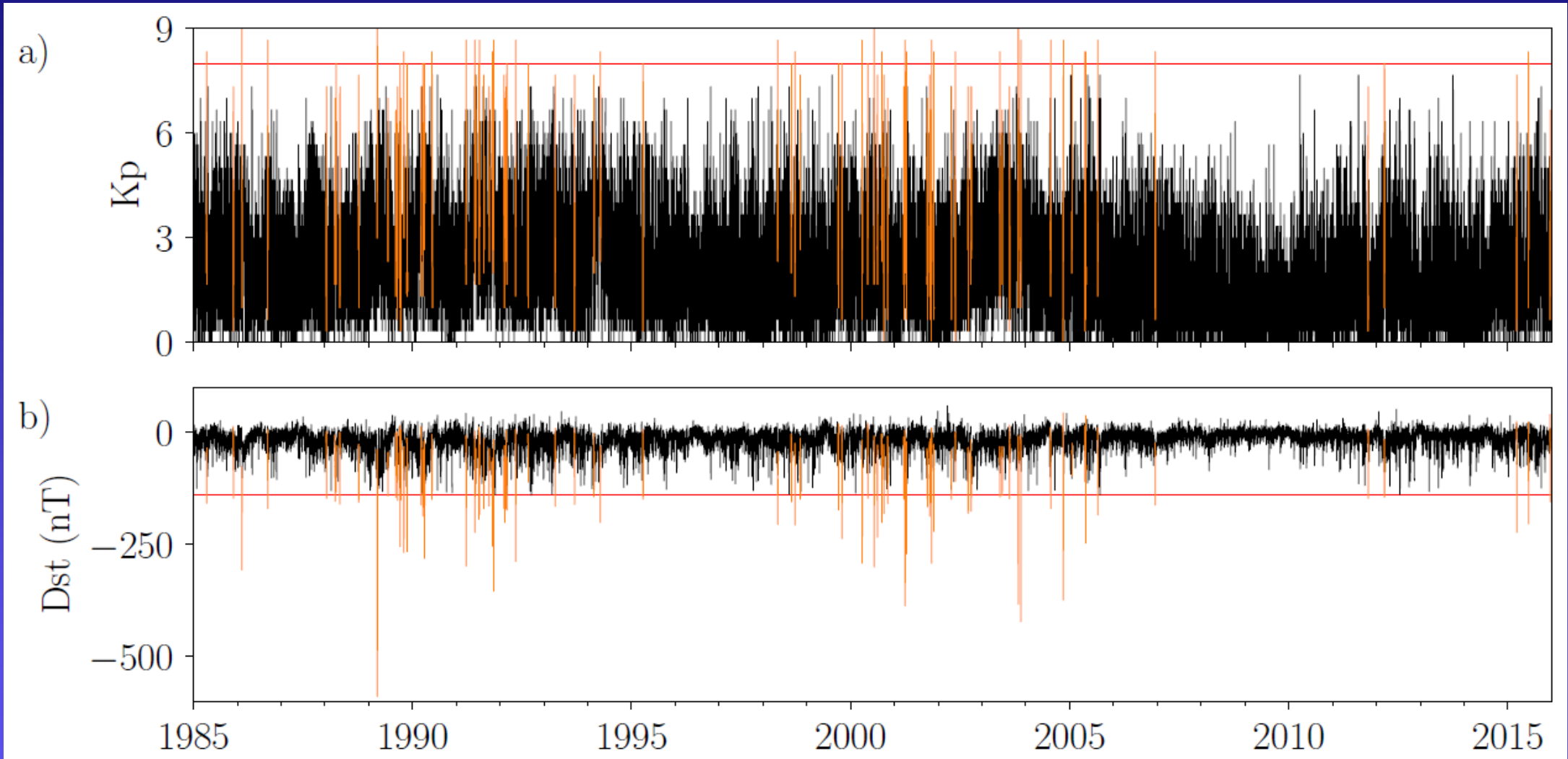


Electric fields generate voltages (and quasi-DC currents) in transmission lines

MT Array data + mag observatories + transmission lines

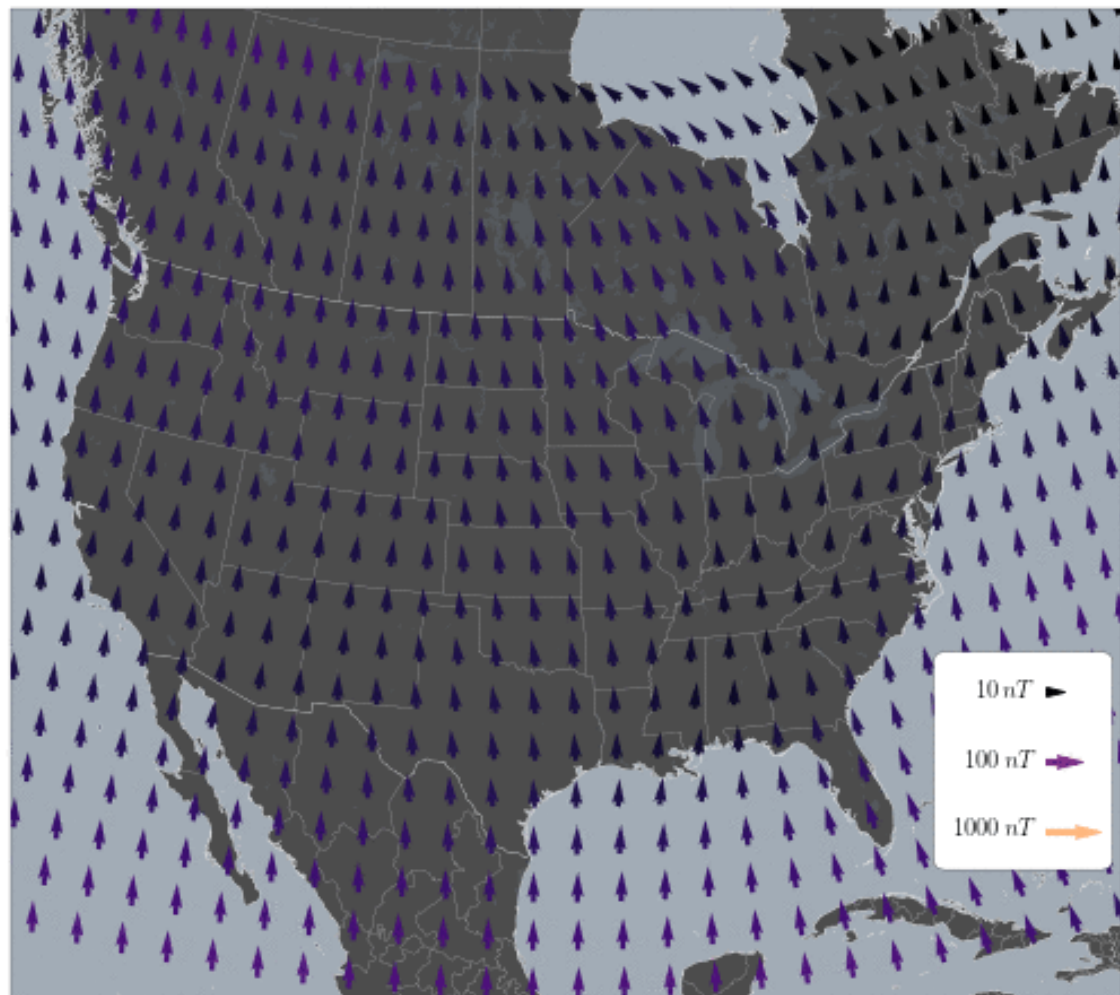


Geomagnetic storm identification from magnetic indices



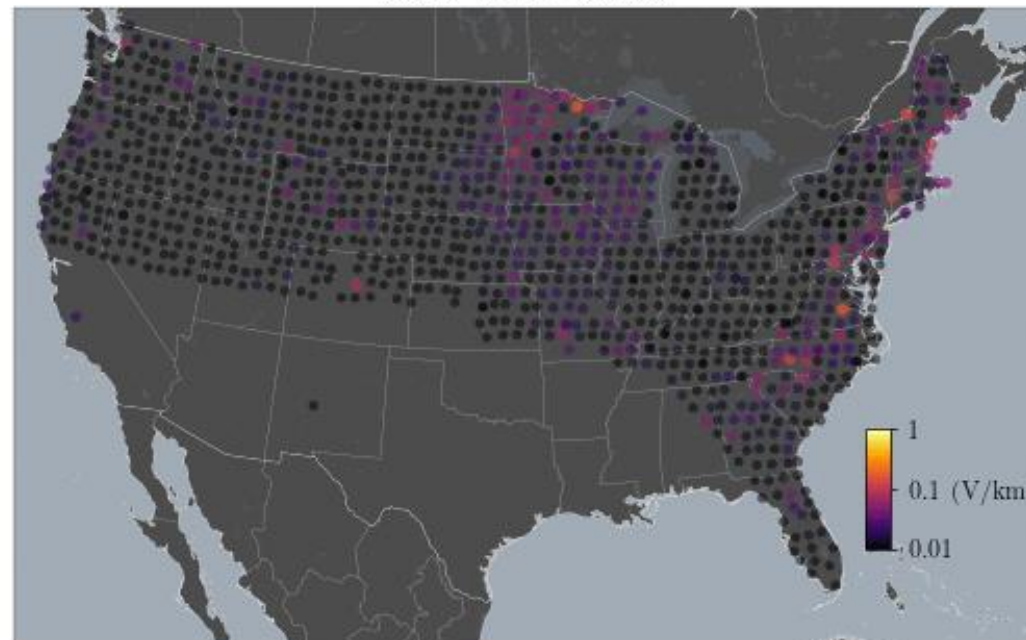
Magnetic field

2015-03-17 06:00



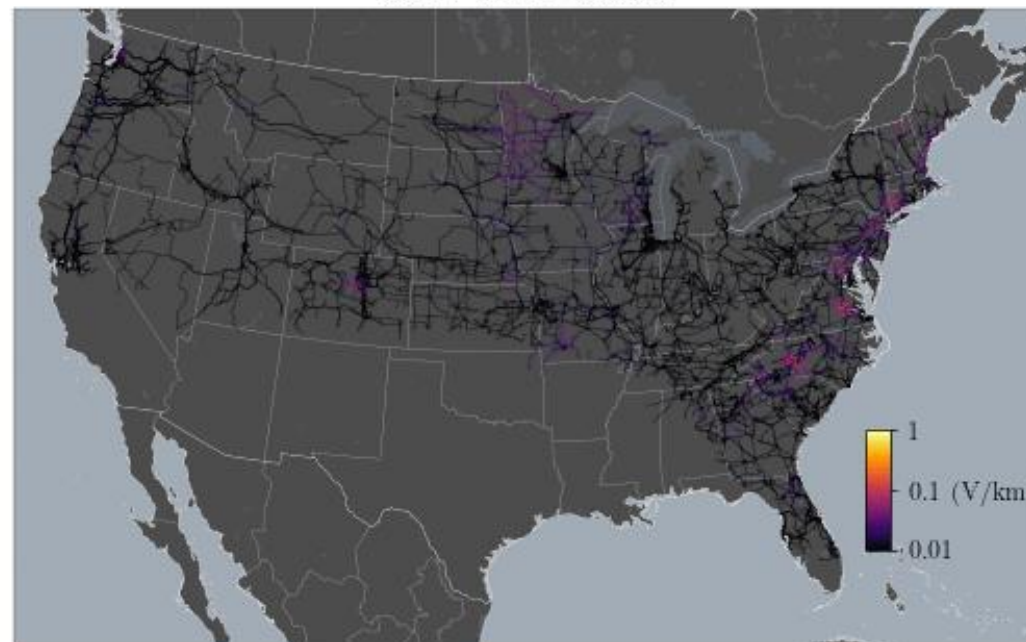
Electric field

2015-03-17 06:00



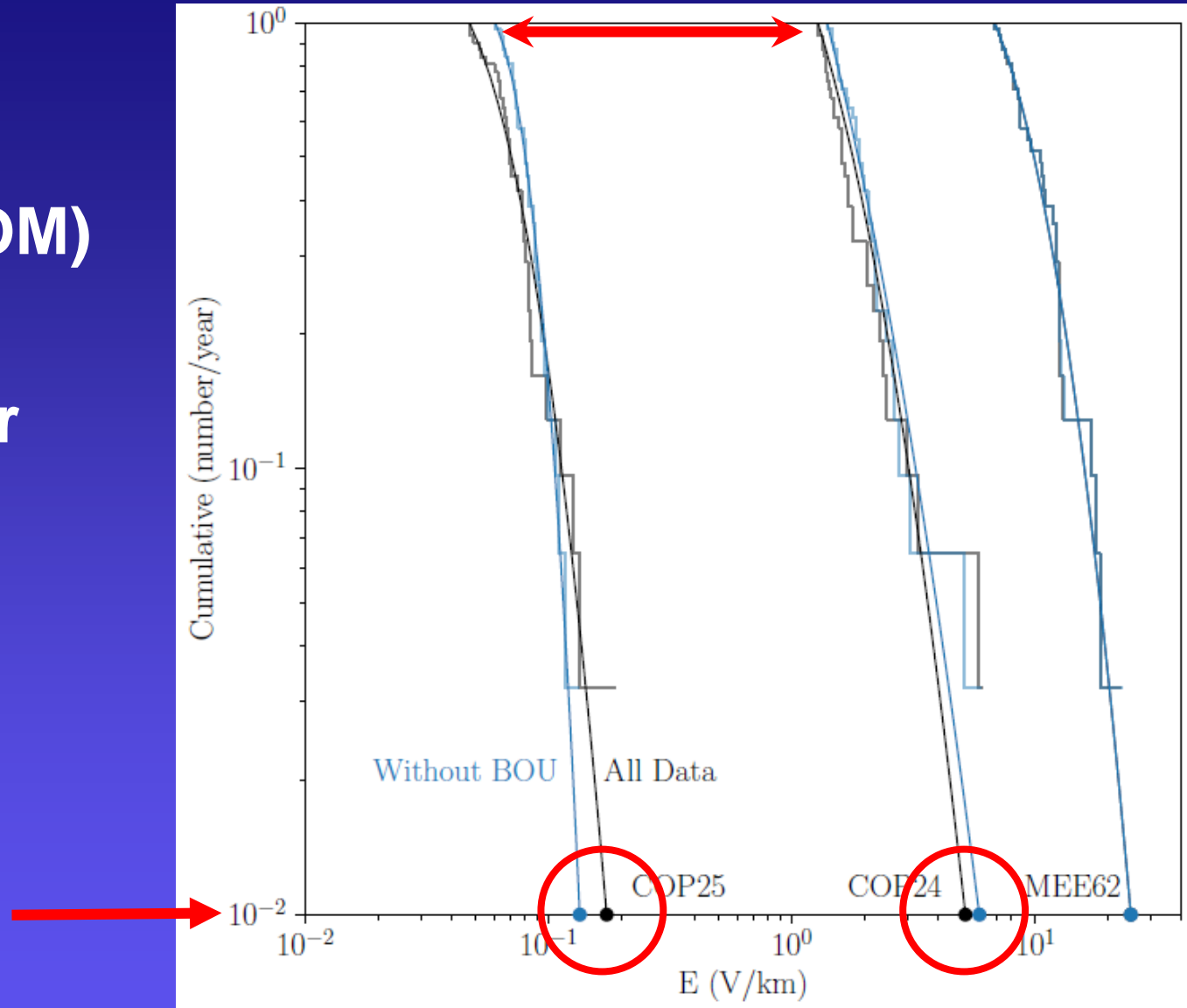
Normalized line voltage

2015-03-17 06:00



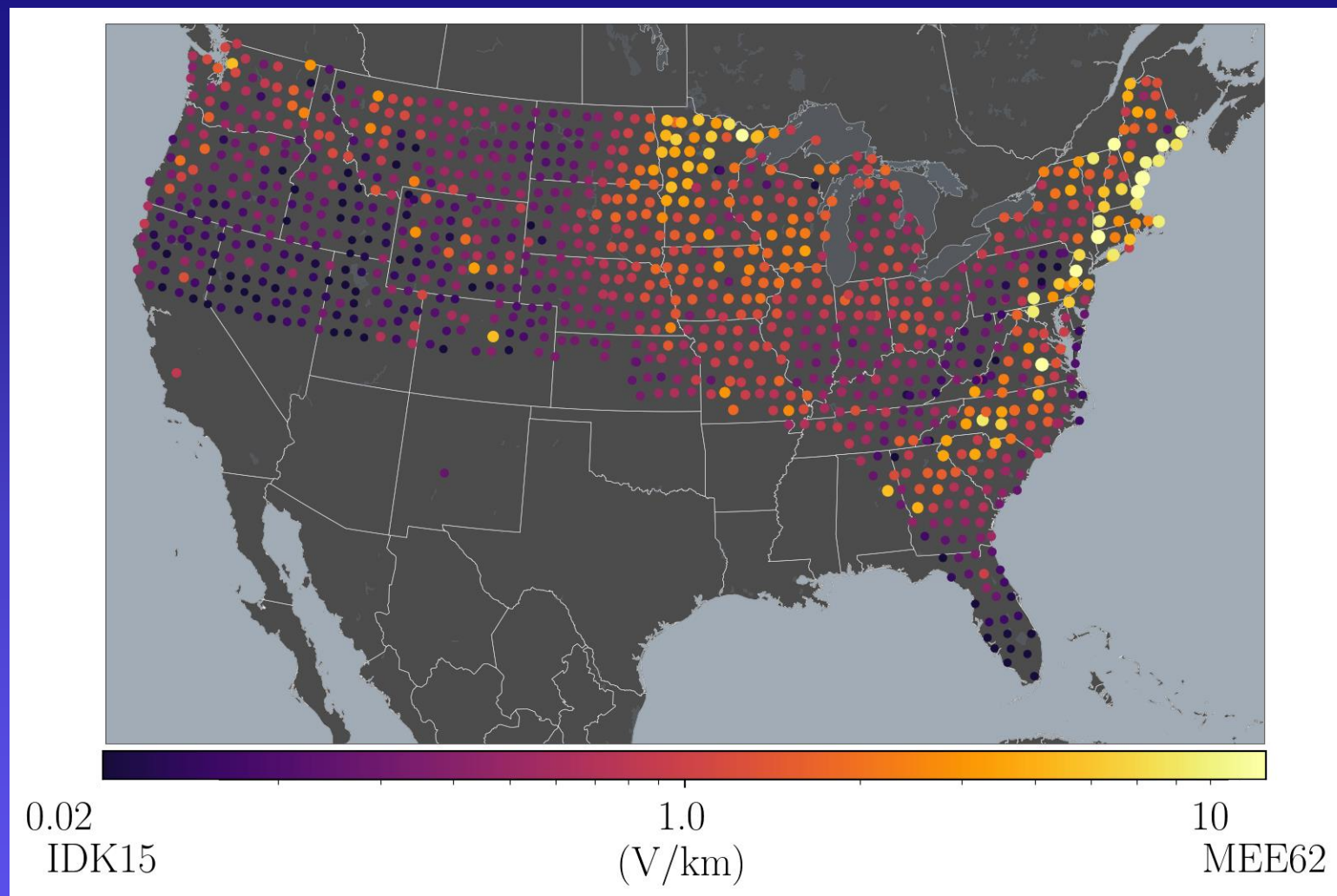
Statistics – peak geoelectric field for all storms

- Strong differences between sites (> 2 OOM)
- Extrapolated to 100-yr exceedance field



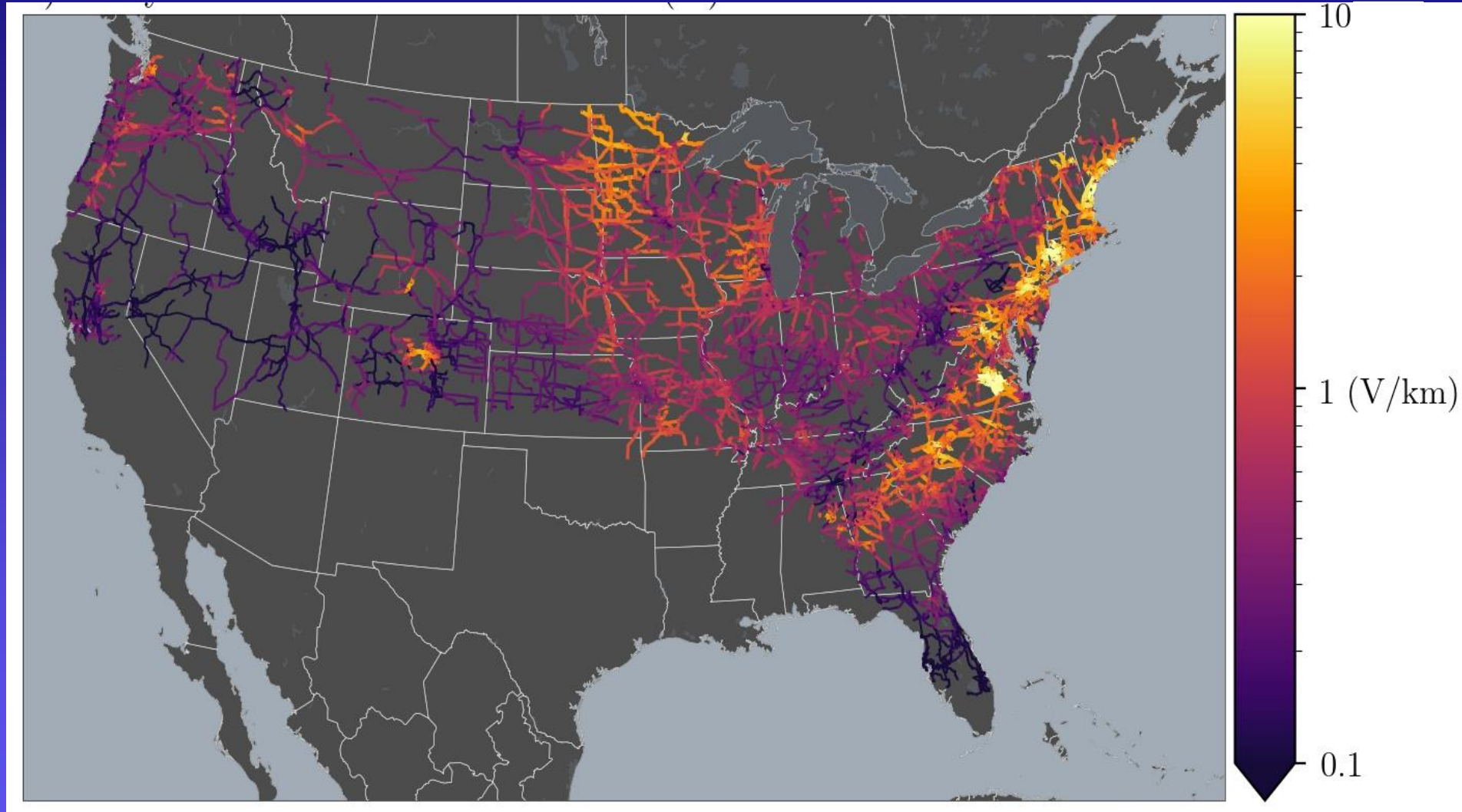
100-yr geoelectric field exceedance map

- Independent of human infrastructure
- Primarily geologically driven
- Secondary magnetic overprint



100-yr exceedance map

- Added imprint of power network
- Polarization effects due to geologic polarization and network geometry



Conclusions

- *The U.S. MT Array is a consistent, publicly-available long-period data set nearing completion of the contiguous U.S.*
- *MT Array data and the models derived from them are advancing our understanding of active tectonics, North American assembly, and space weather hazards*
- *The MT Array program has increased the prominence of MT in the Earth Science community and exposed a new generation of students to magnetotellurics*

Acknowledgements

- US National Science Foundation: Kaye Shedlock, Greg Anderson, Maggie Benoit
- Oregon State University: Adam Schultz, Gary Egbert, Lana Erofeeva, Esteban Bowles-Martinez, Naoto Imamura, Tristan Peery, Valerie Clote
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- Chaytus Engineering: Brady Fry
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