Unveiling a Continent: The US Array Magnetotelluric Program

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MTNet EMinar, January 20, 2021

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)

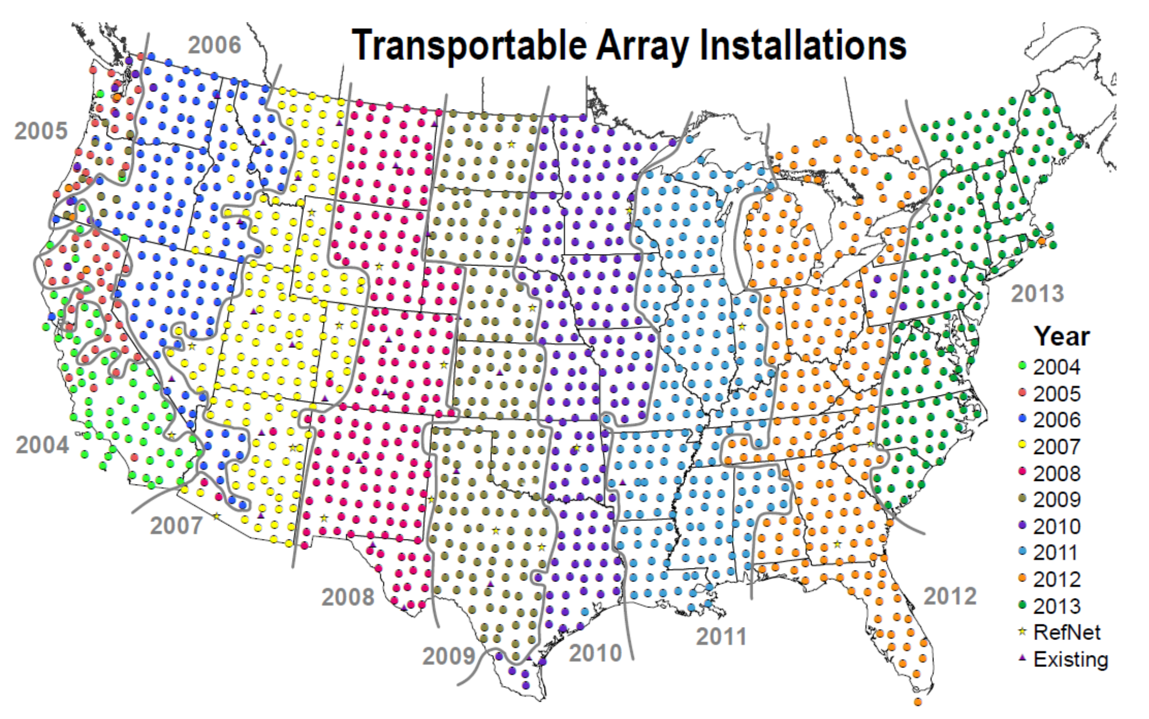
- USGS (2020-?)

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

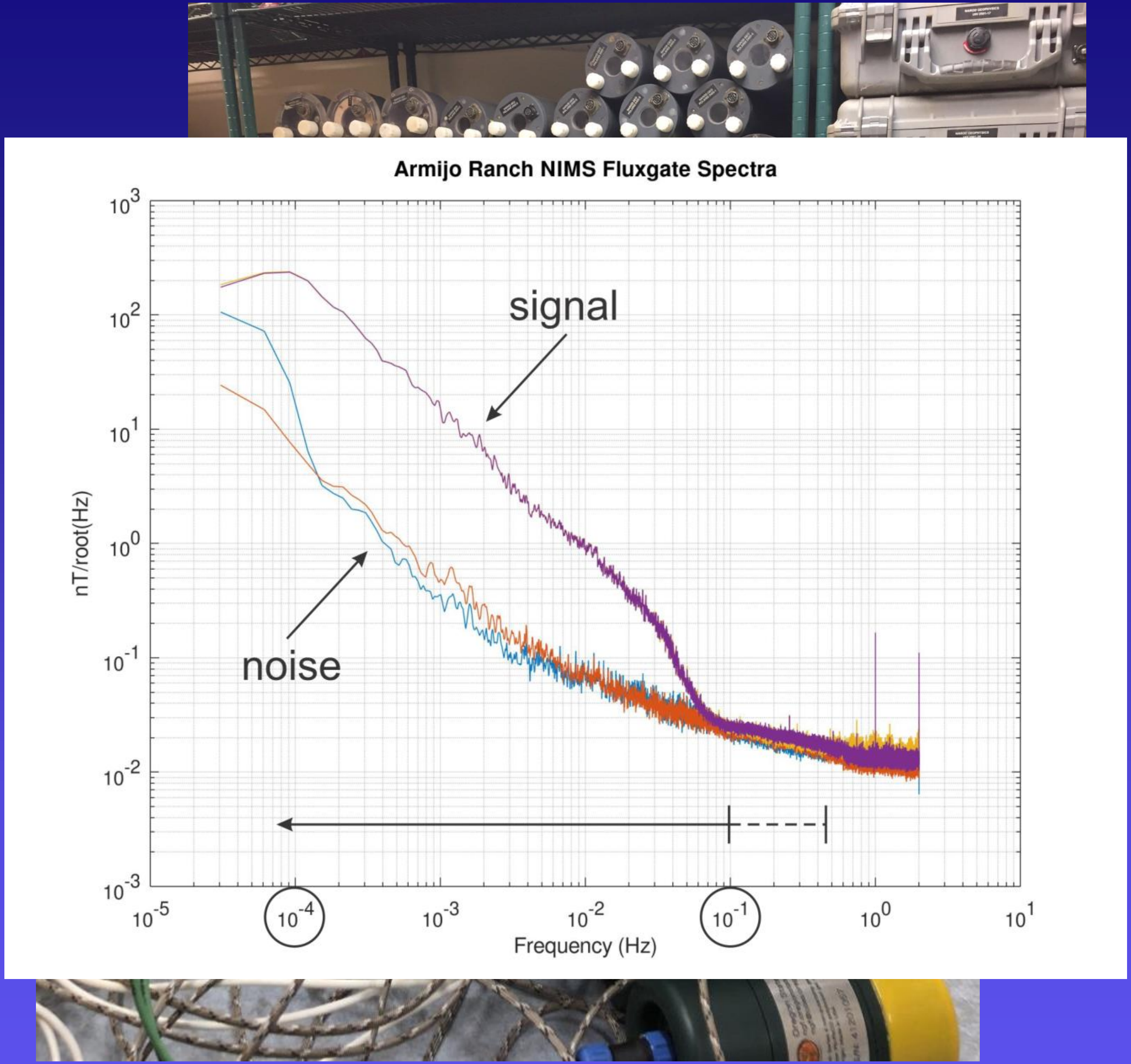
USArray components & MT

- 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

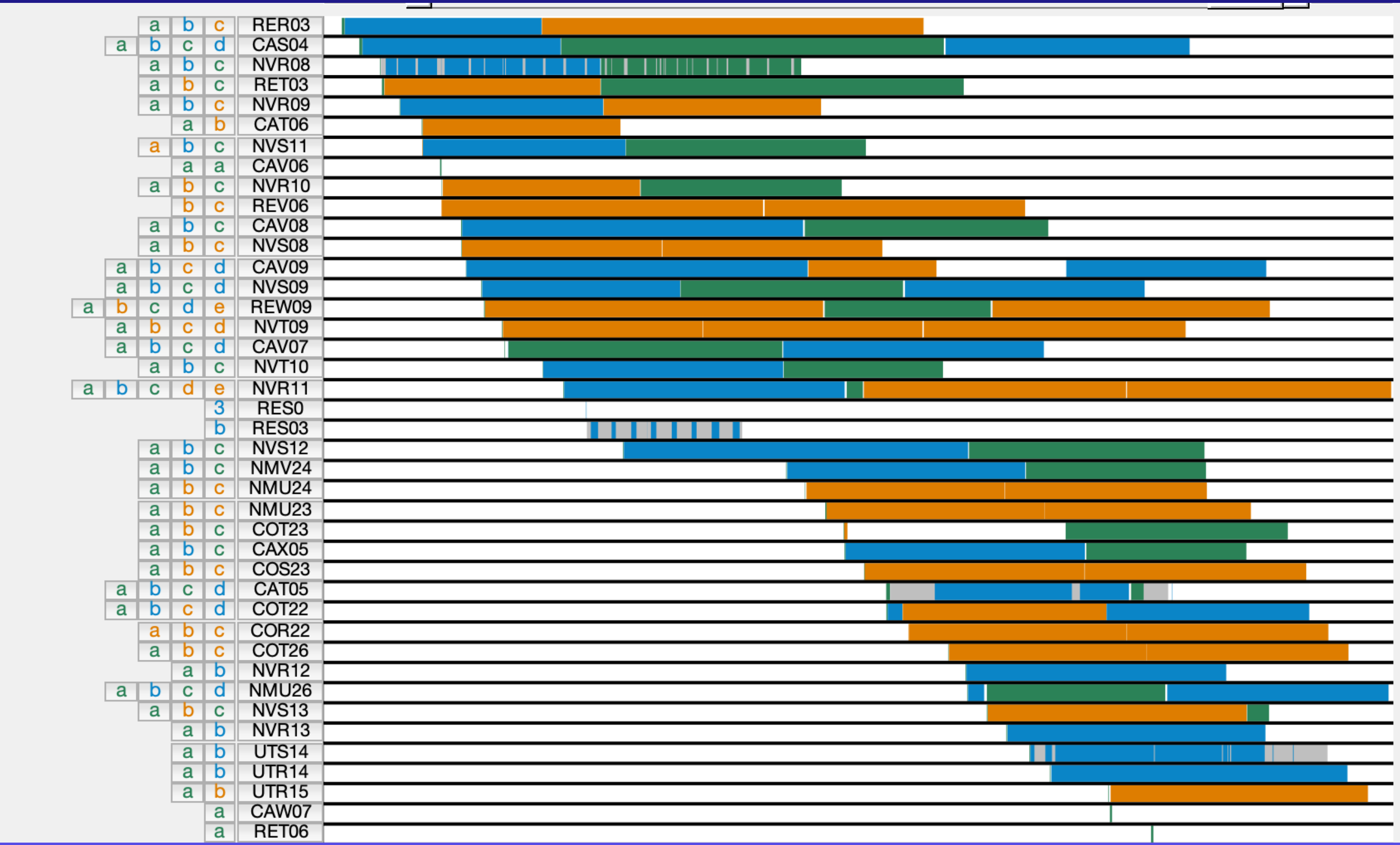
- Site selection (cultural noise avoidance, spatial tolerance, etc.)
- In-field QA/QC, 10-day checkup, advanced processing
- Consensus-based site acceptance (10% in ρ_a , 5° in φ from 10-10,000 sec)
- Relocation of ‘rejected’ stations → 10% grid points relocated

Data acquisition

USGS

Definitive data processing

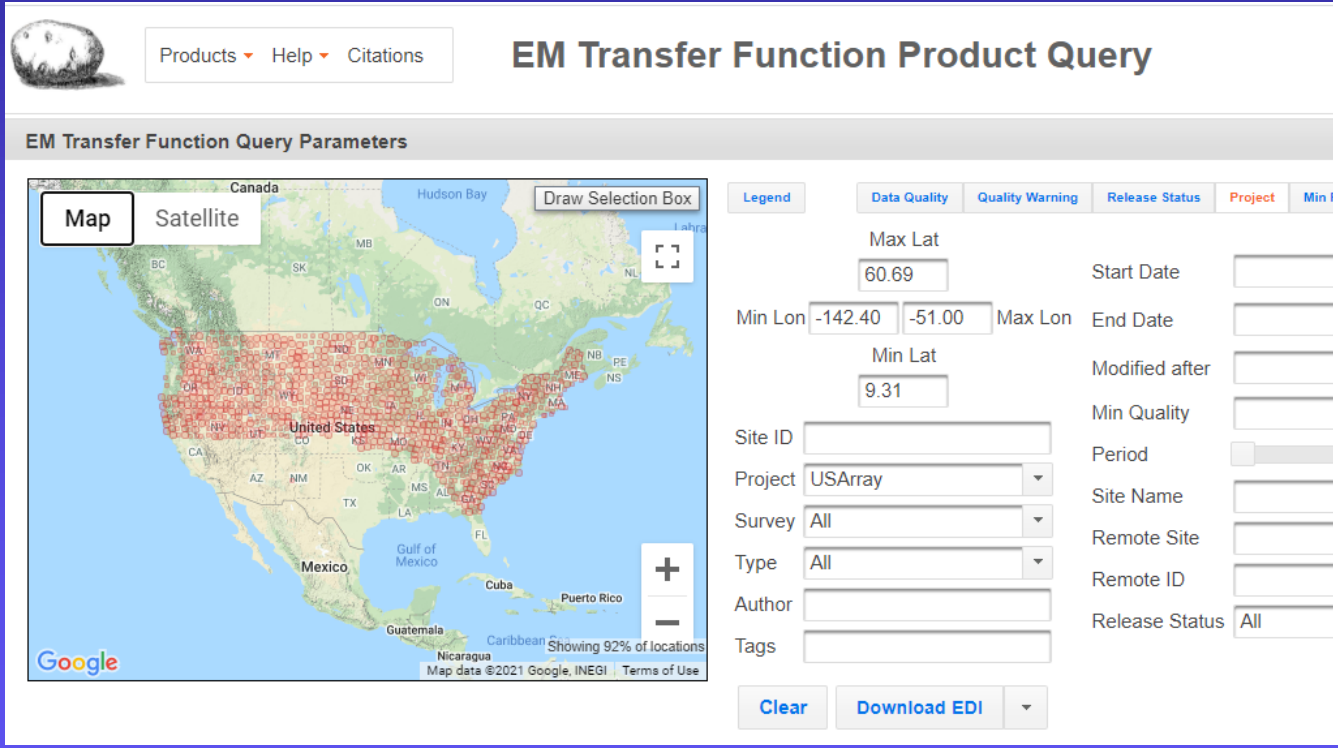
- EMTF processing suite (Dnff, TranMT, MMT)
- Standardized workflow w/ metadata tracking
- Remote-reference and multi-station responses
- Identify best short and long-period responses

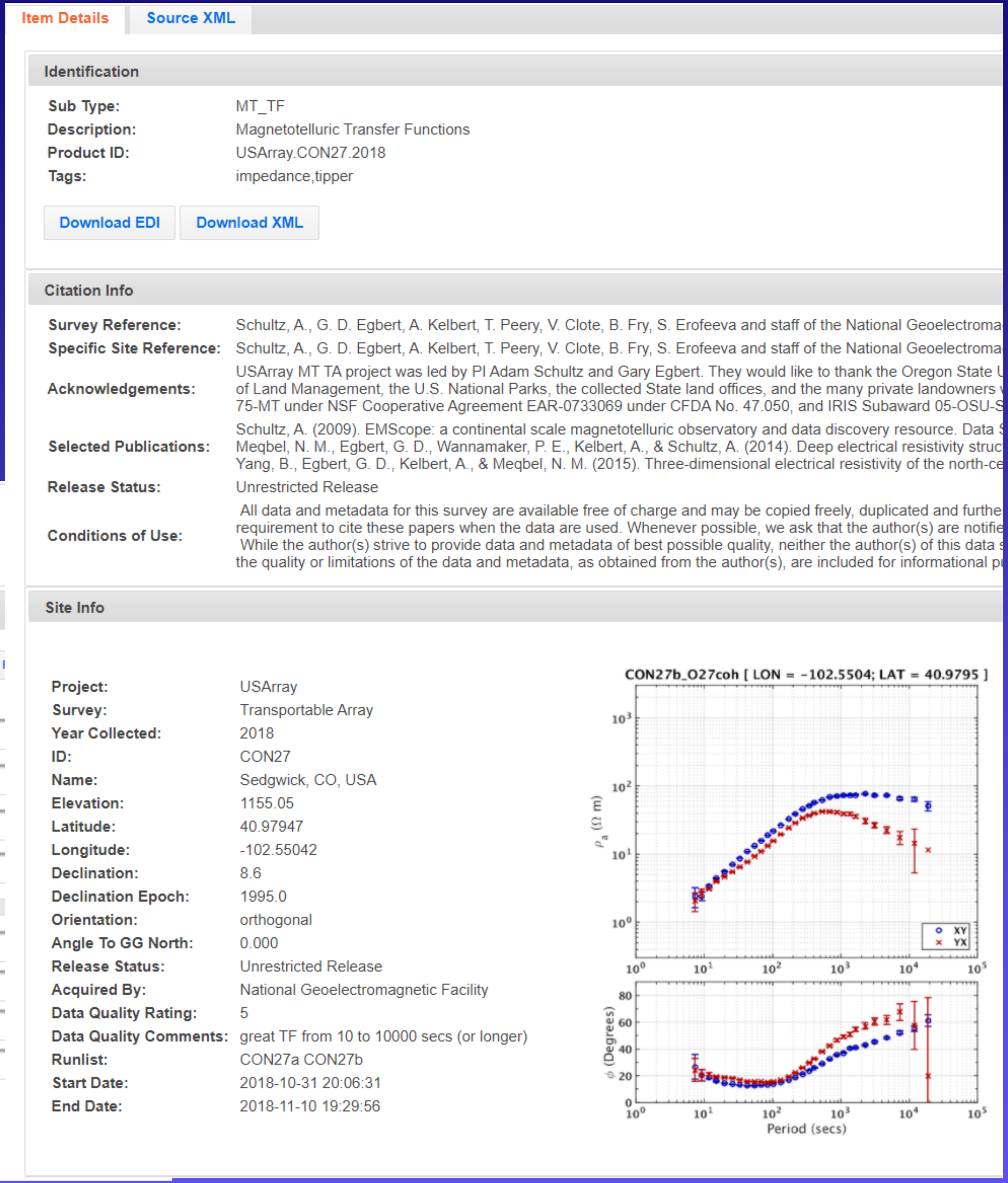


→ merge to best composite response

Transfer Functions

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



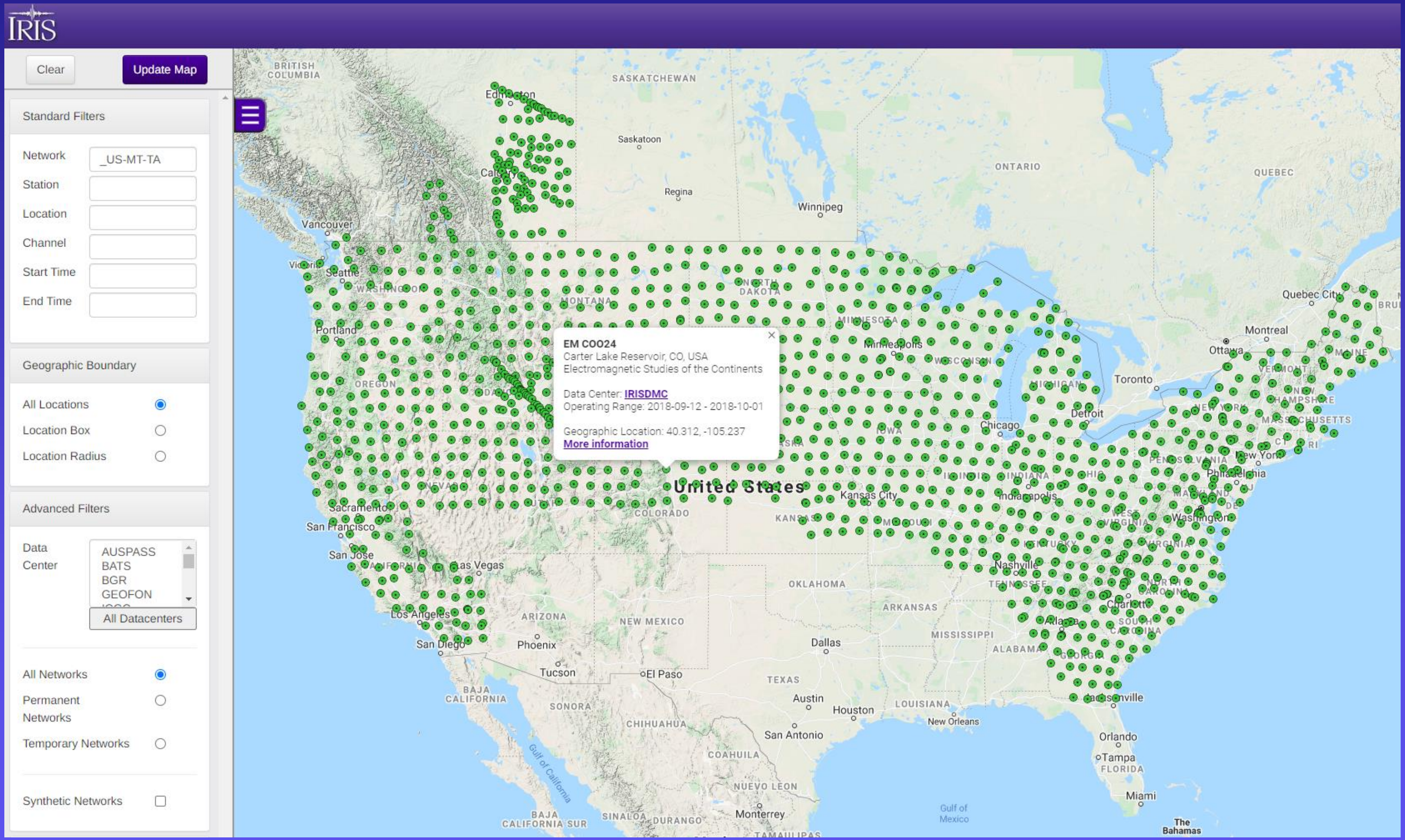


preliminary data, subject to revision.
Not for citation or distribution

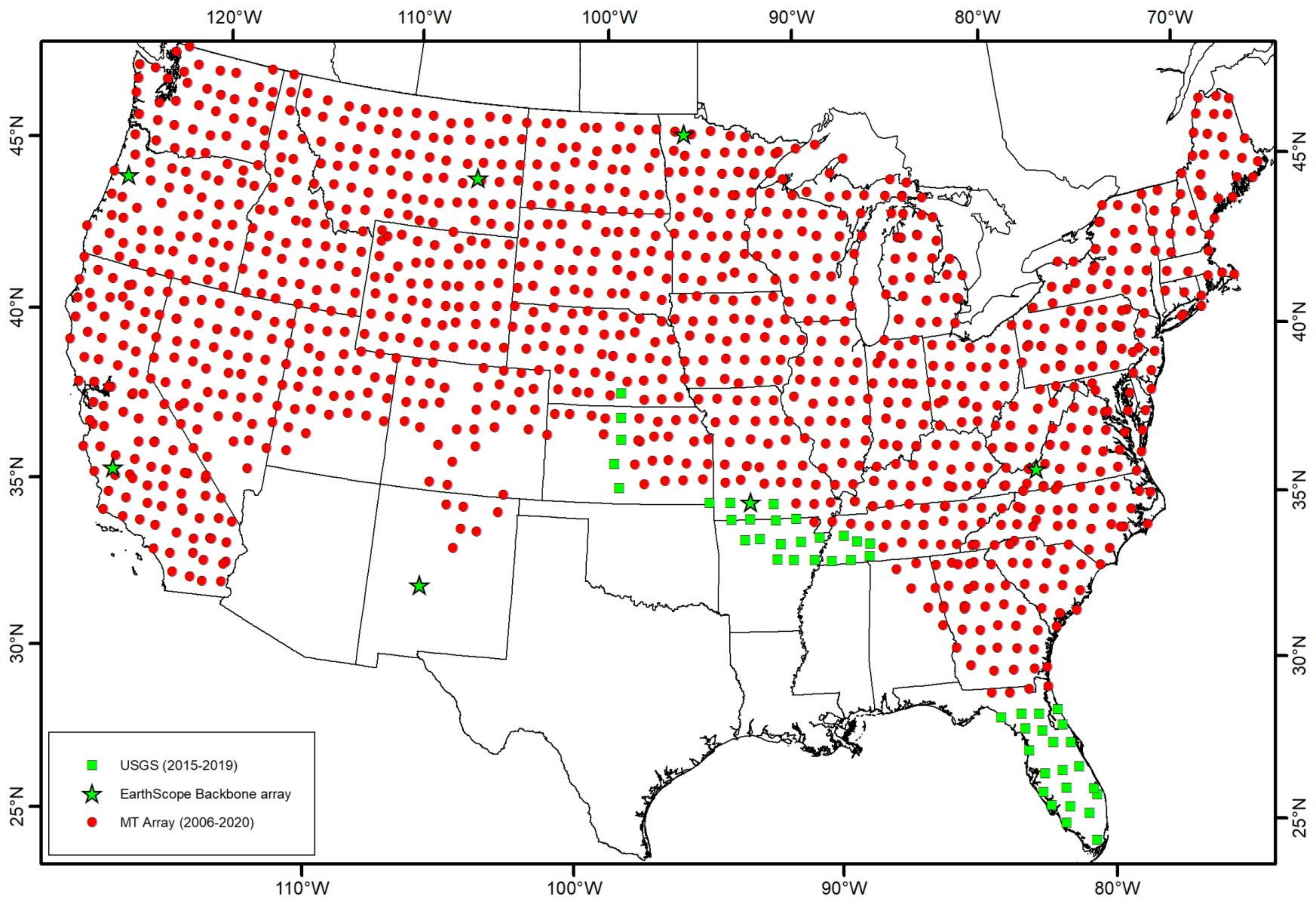
Kelbert et al. (2011); Kelbert (2020)

Time Series

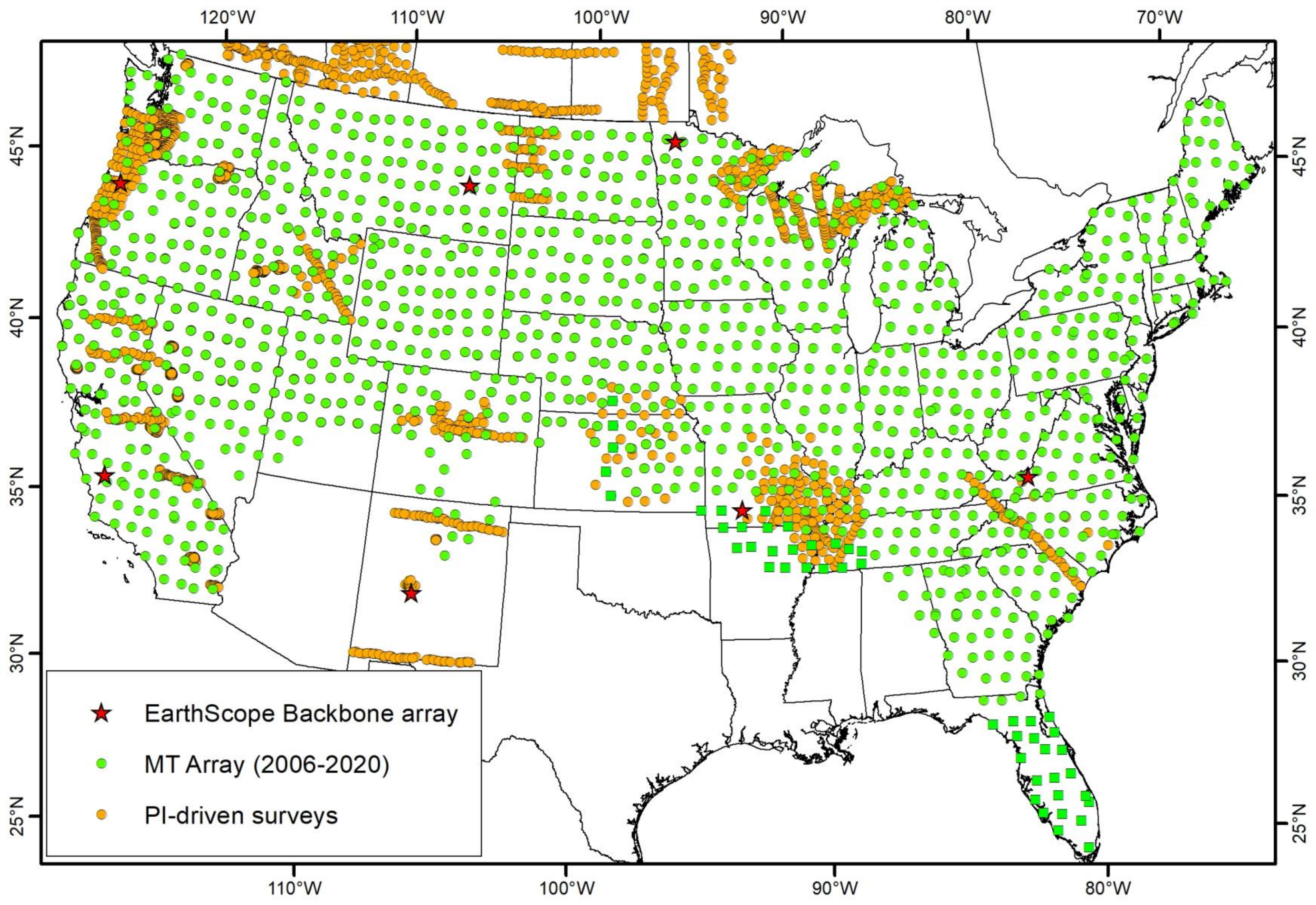
- https://ds.iris.edu/gmap, network code: _US-MT-TA



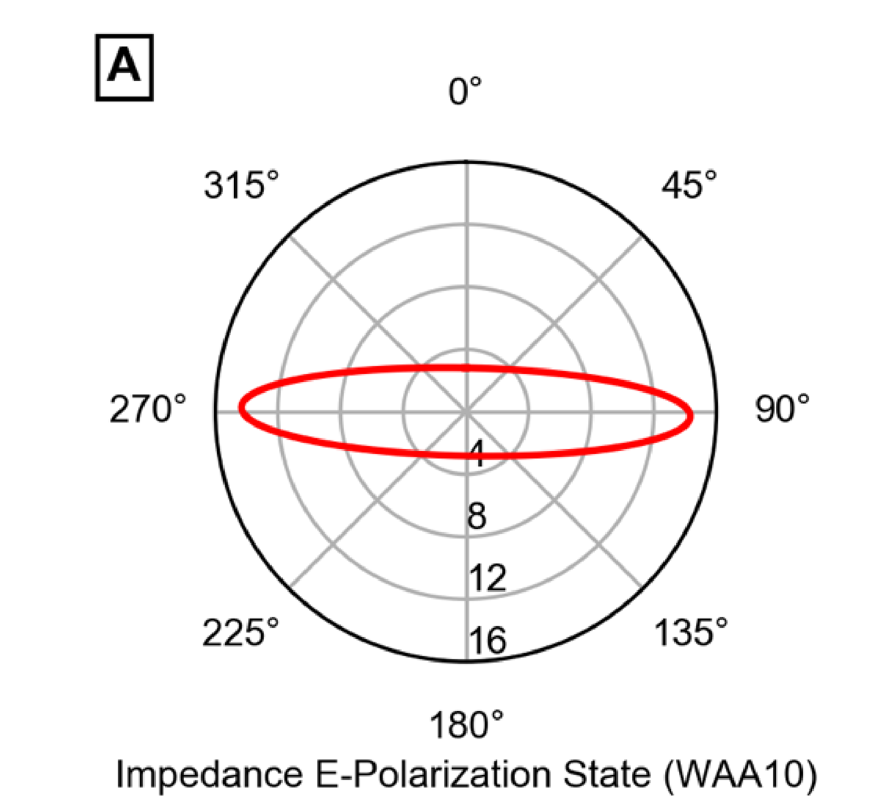
Building the US MT Array → 2006-present



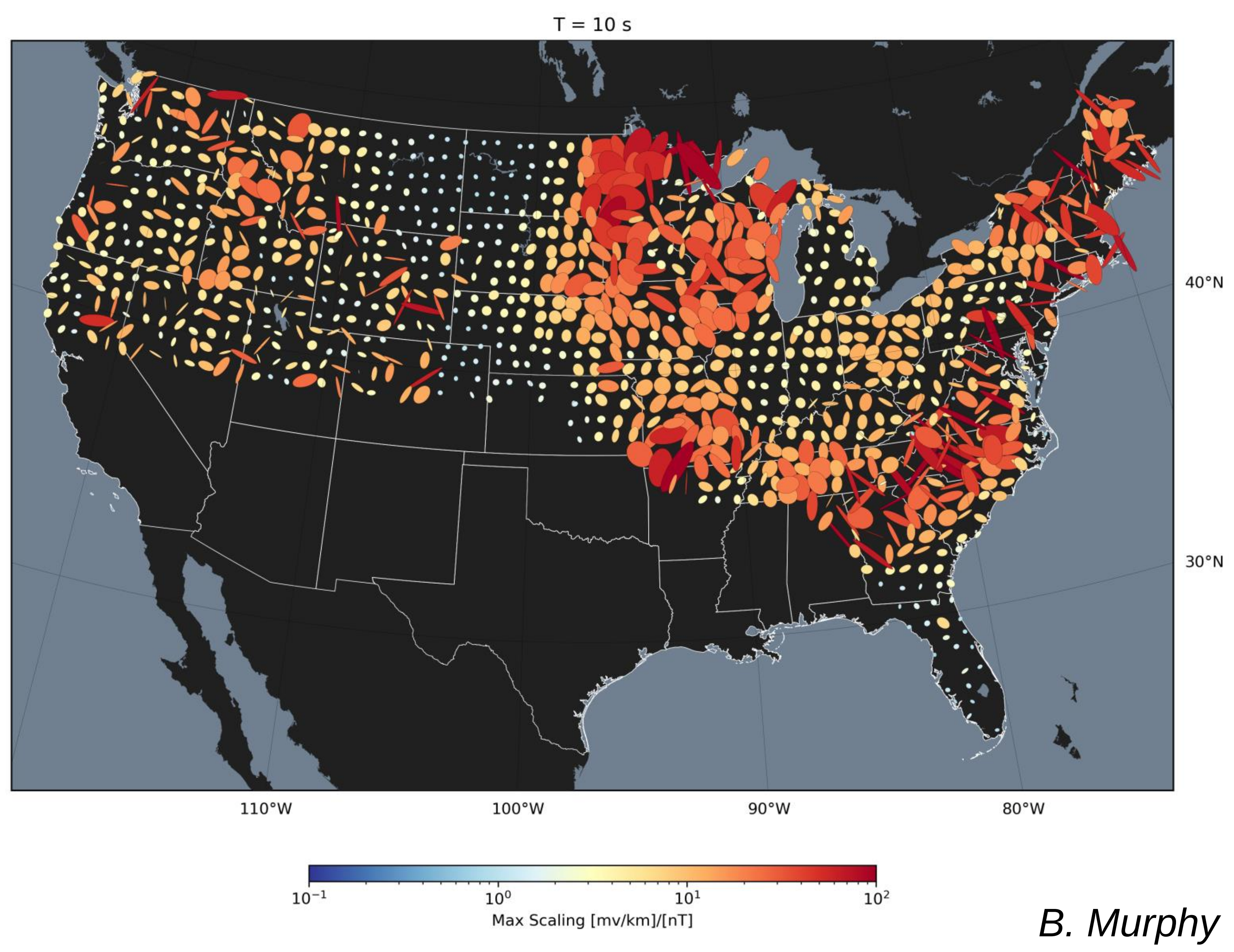
A consistent framework to build upon



Electric field polarization ellipses → 10 sec

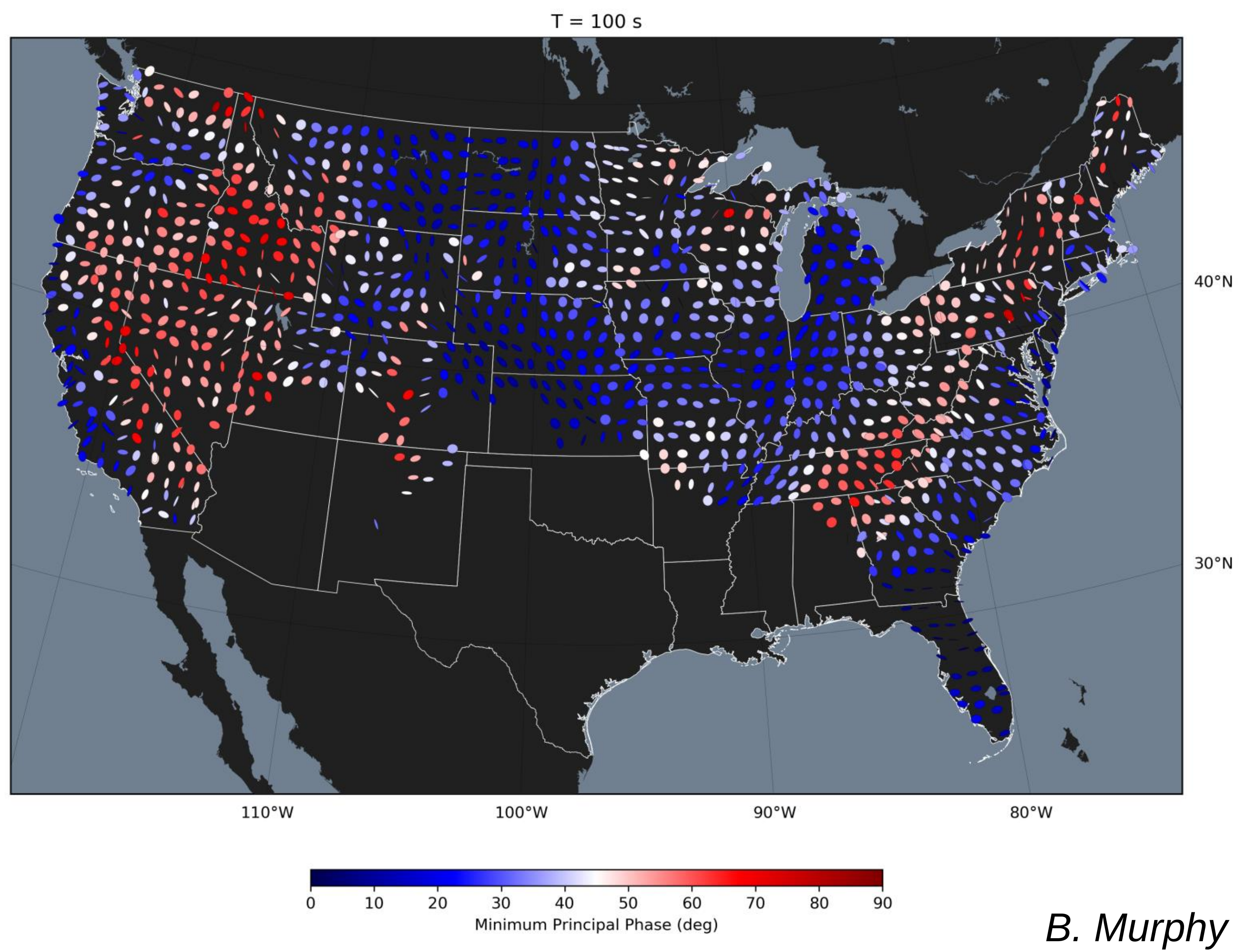


Berdichevsky & Dmietriev, 2008



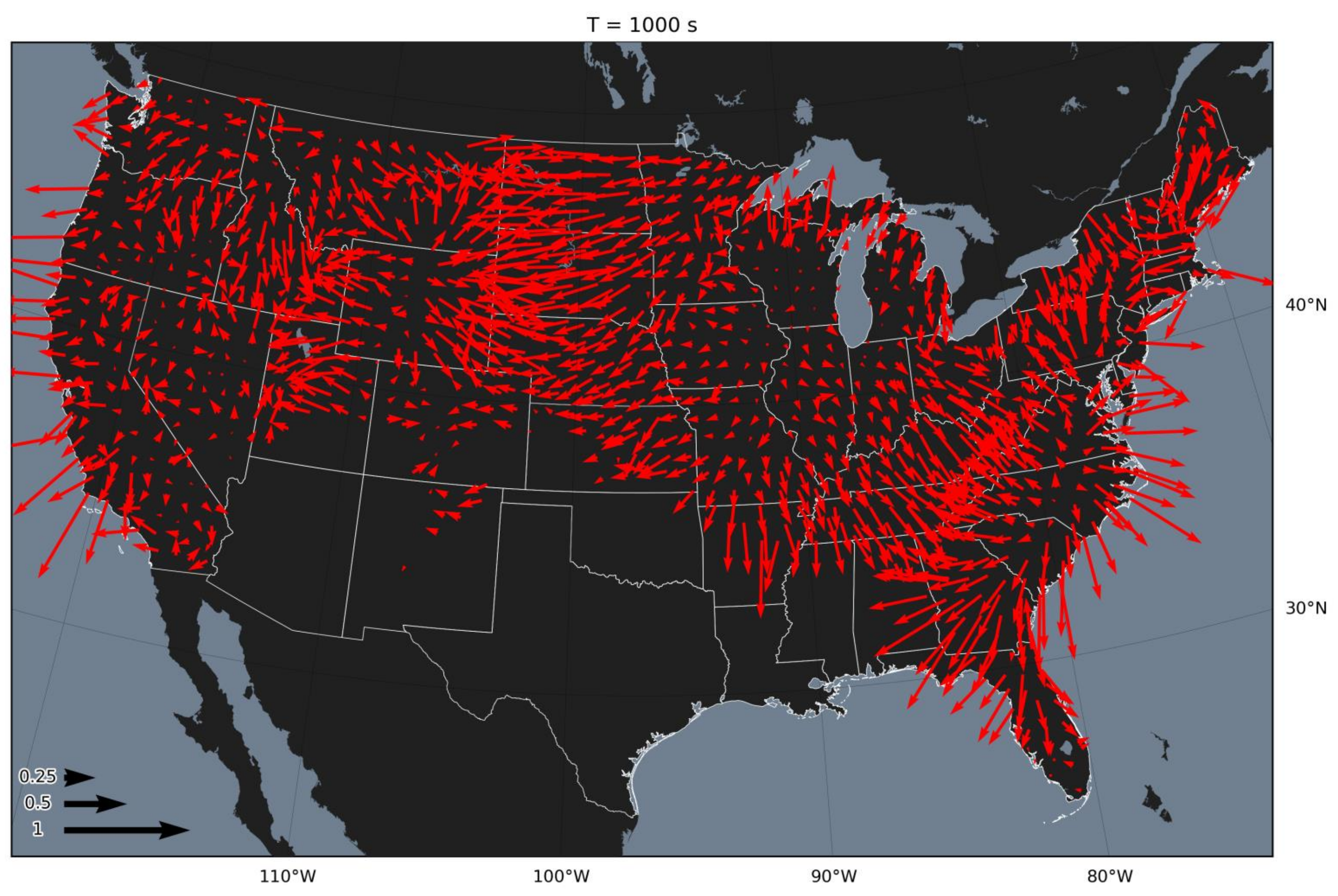
B. Murphy

Phase tensors, minimum principal phase → 100 sec



B. Murphy

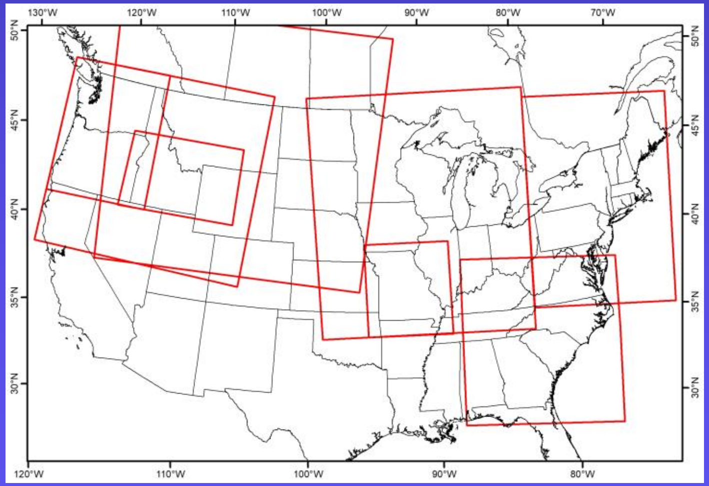
Real induction vectors, Parkinson convention → 1000 sec

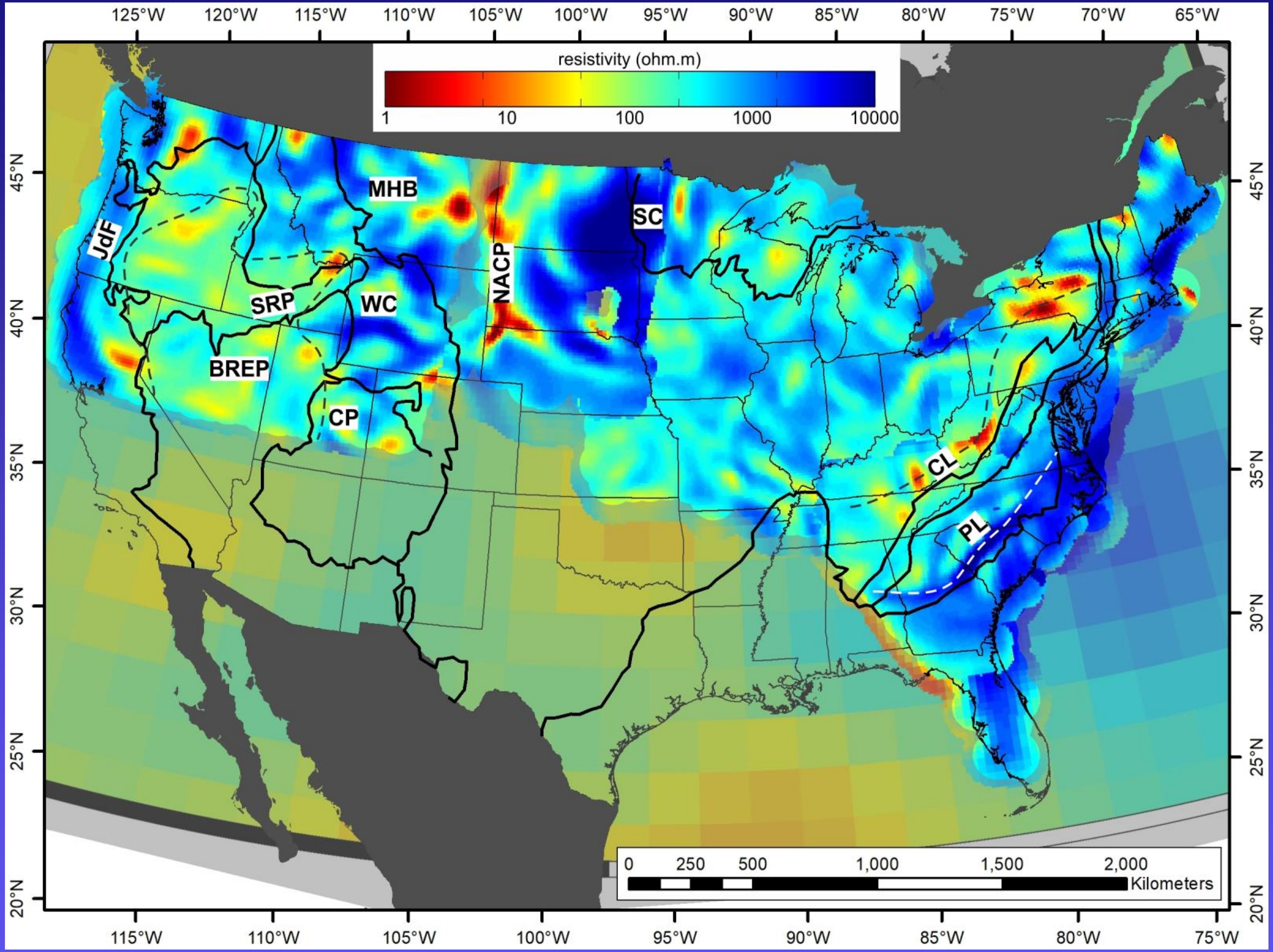


B. Murphy

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

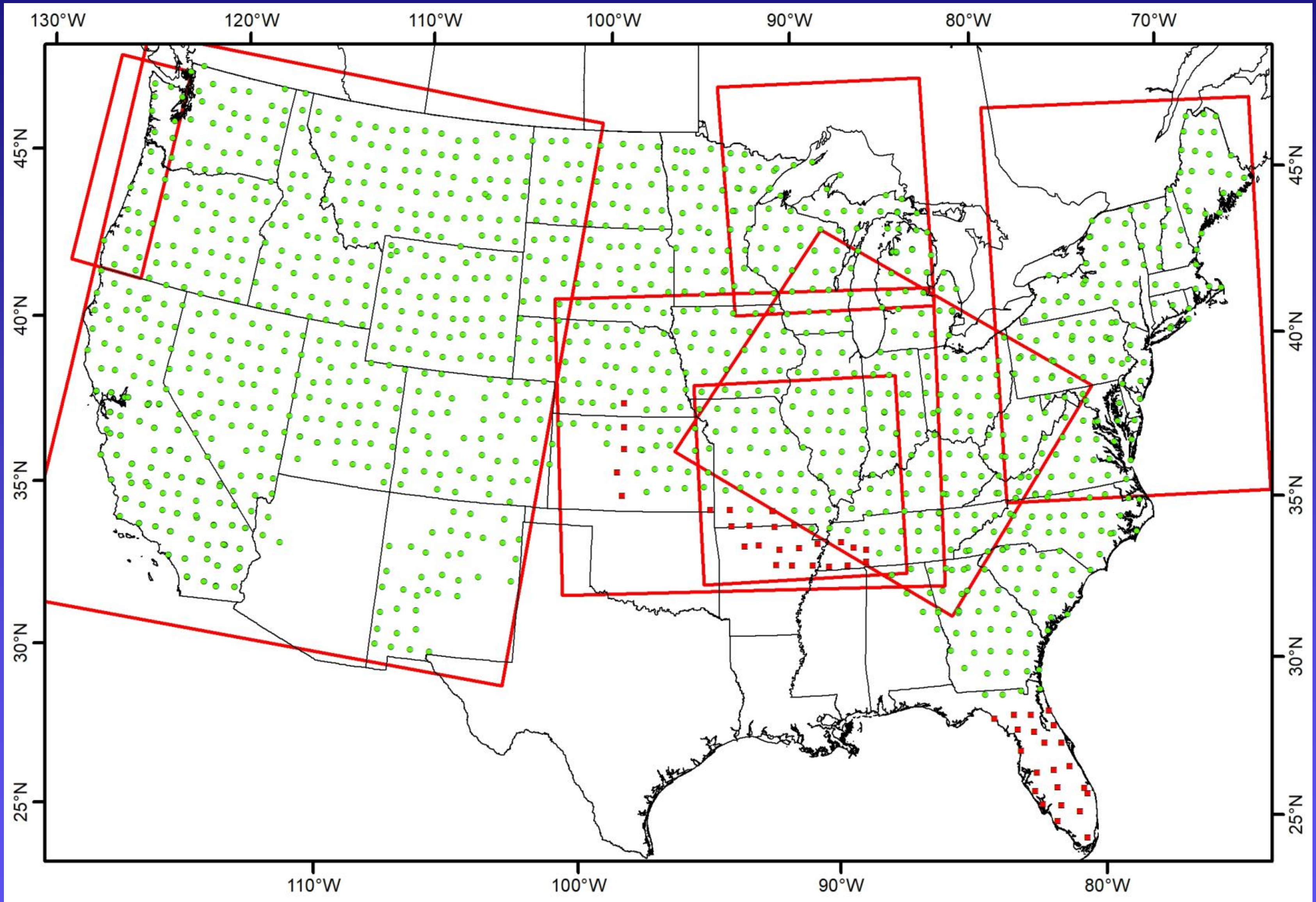
- 3 km
- 30 km
- 100 km





Framework Tectonics

Geologic/tectonic studies using MT Array data



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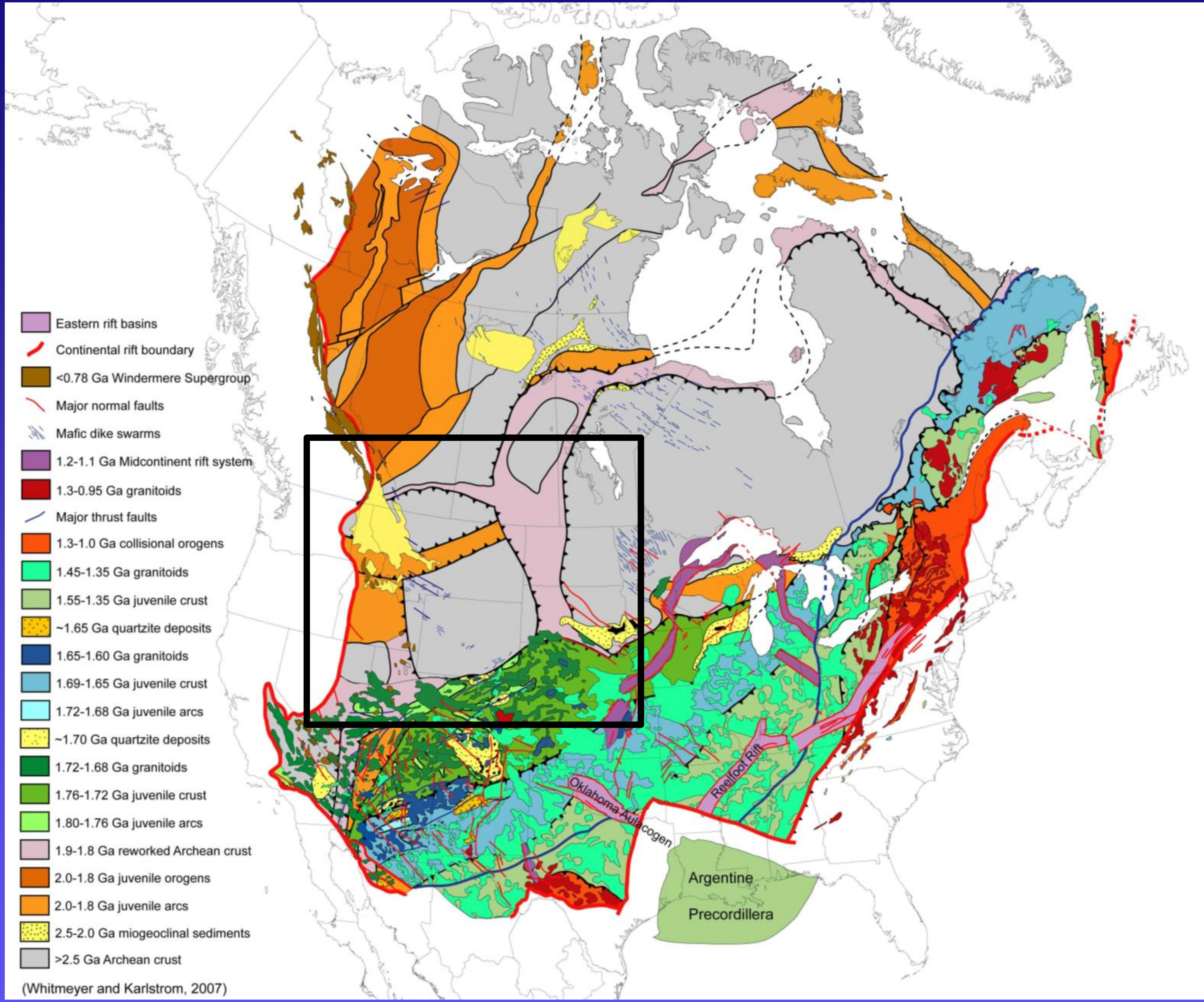
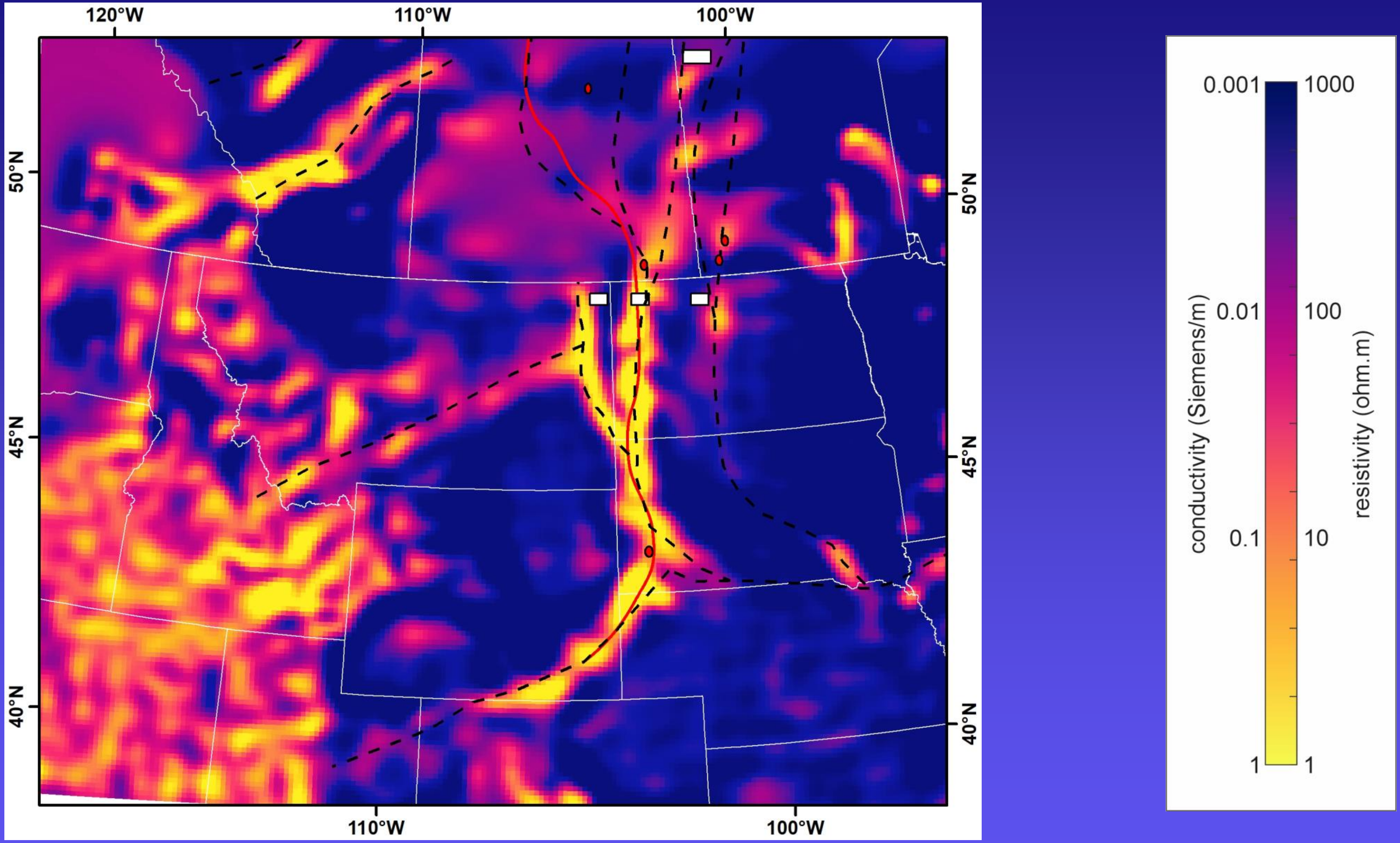
North American framework

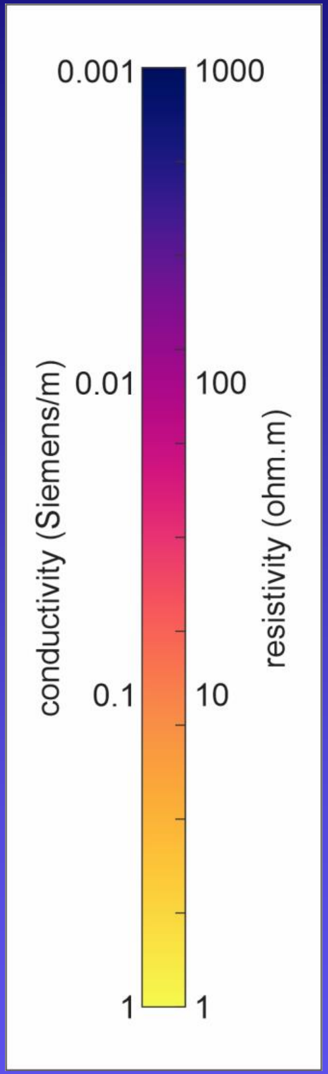


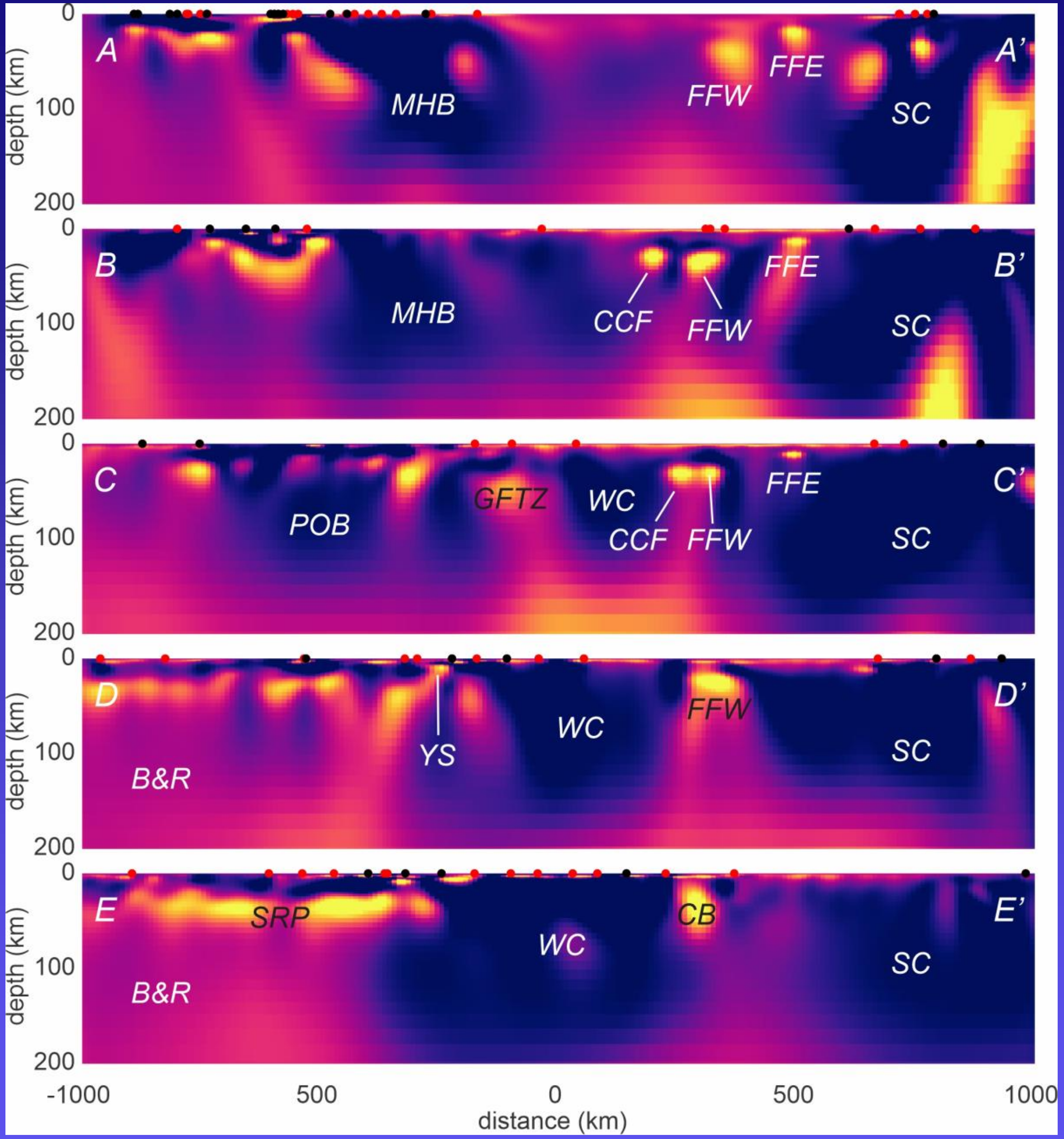
Tectonic architecture

- 2 km
- 15 km
- 30 km



Tectonic architecture



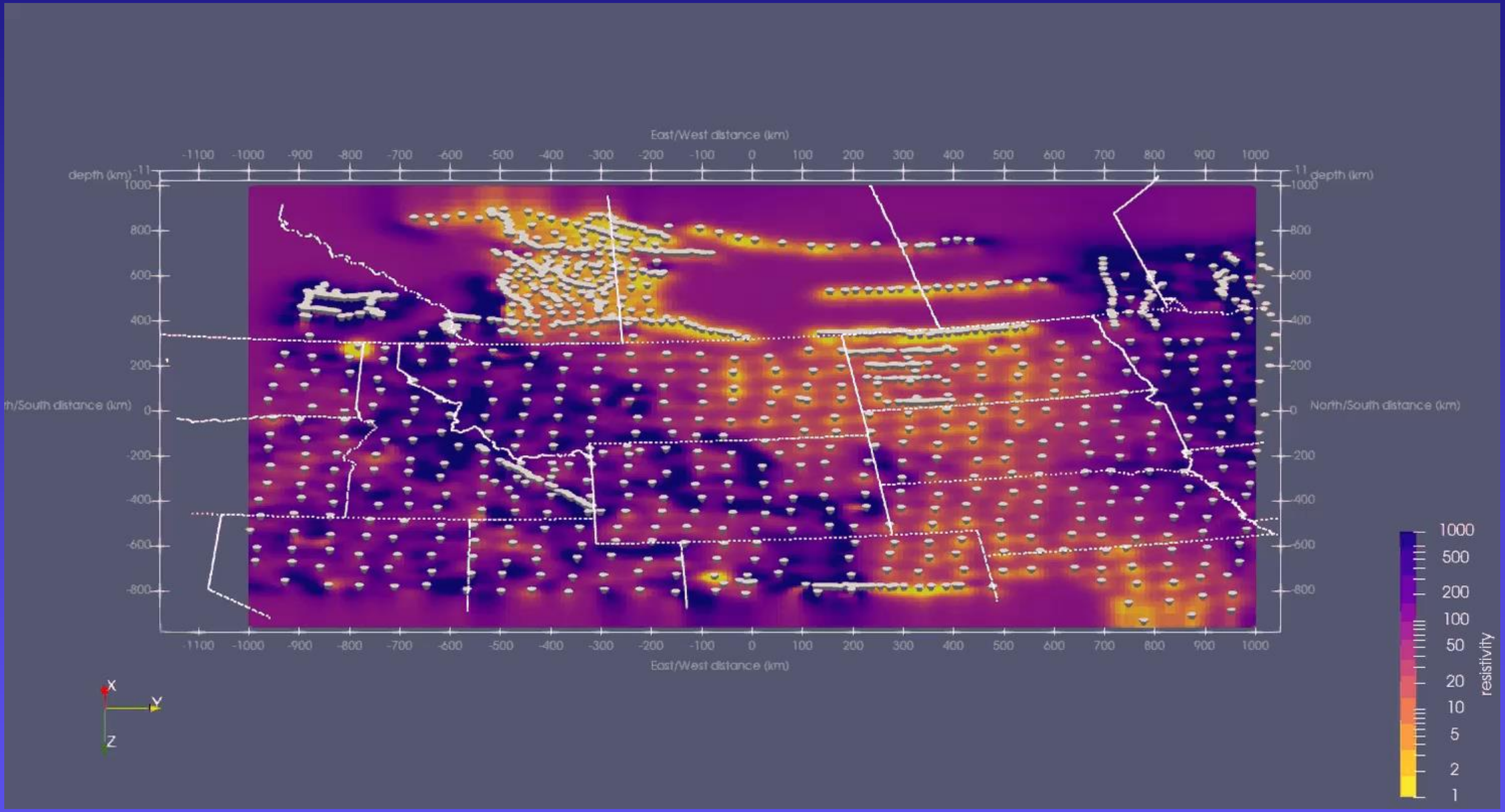


USGS

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

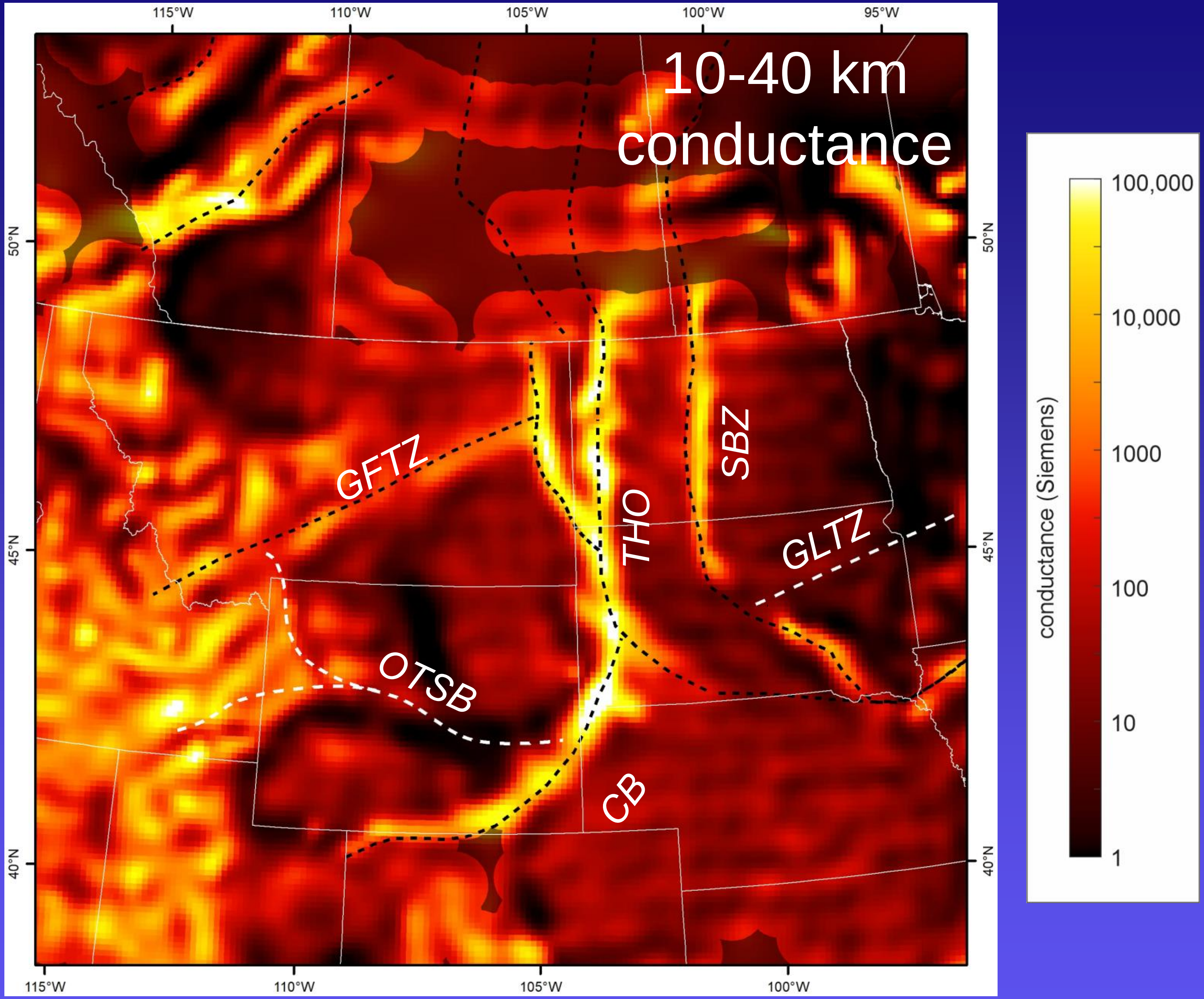
Bedrosian & Finn, in review

Forest for the trees & building upon a backbone



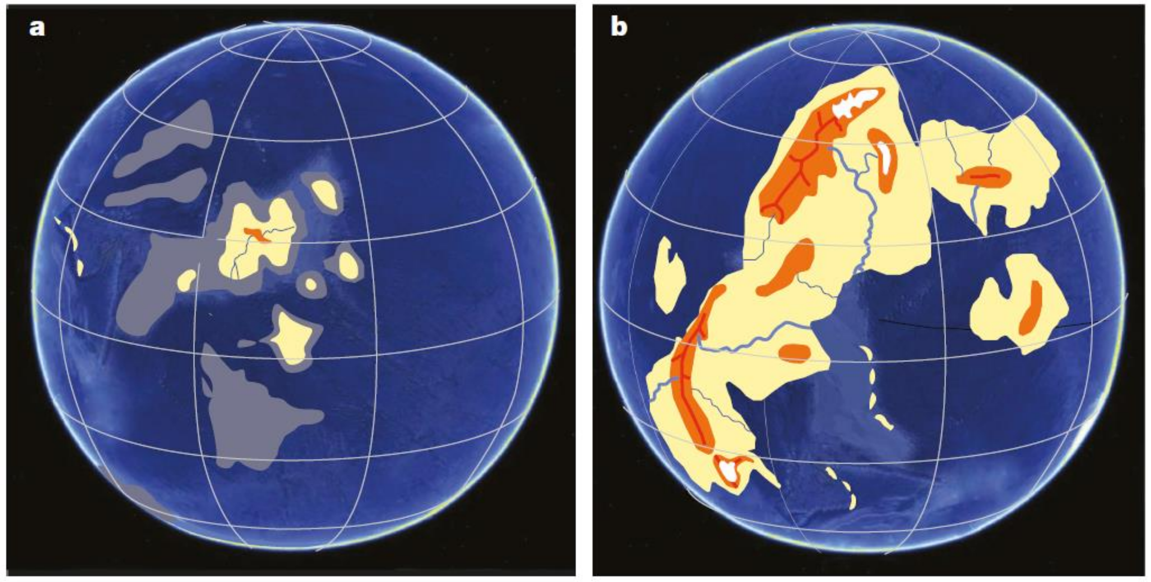
Archean vs Paleoproterozoic subduction

- 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



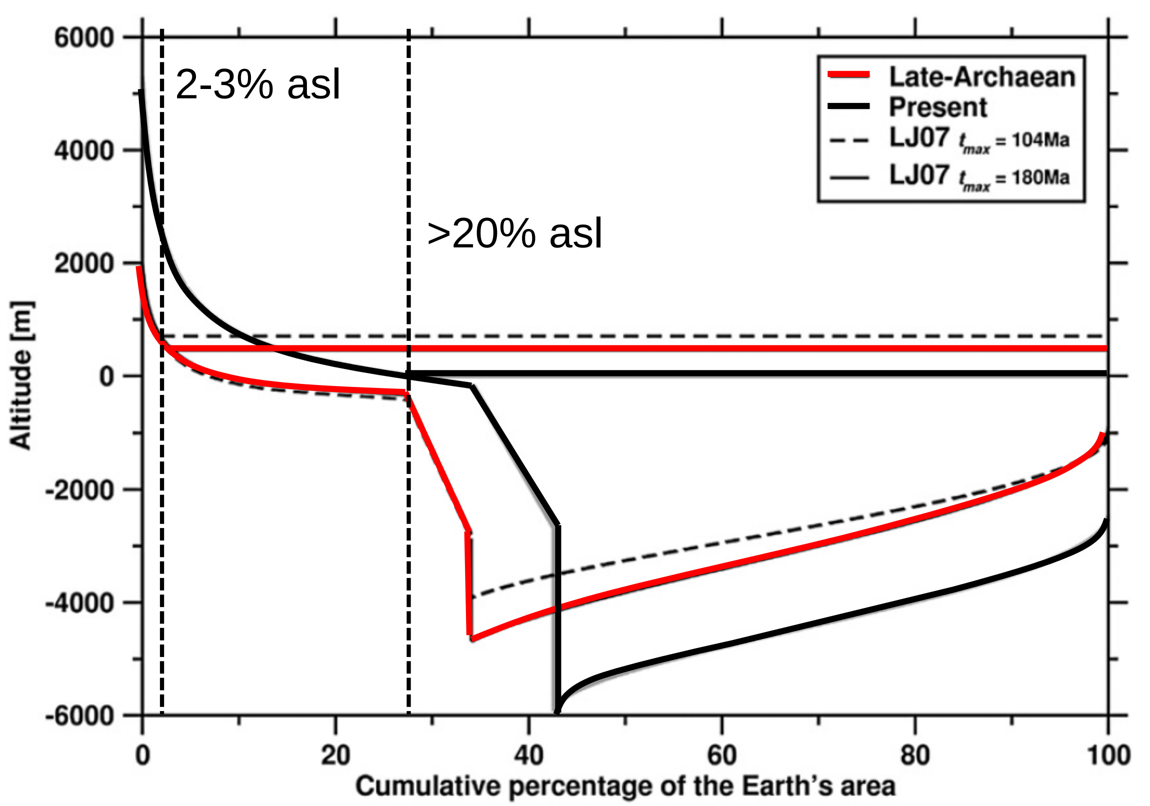
Sediment-starved subduction in the Archean?

- **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)

late Archean early Proterozoic



Flament et al. (2008

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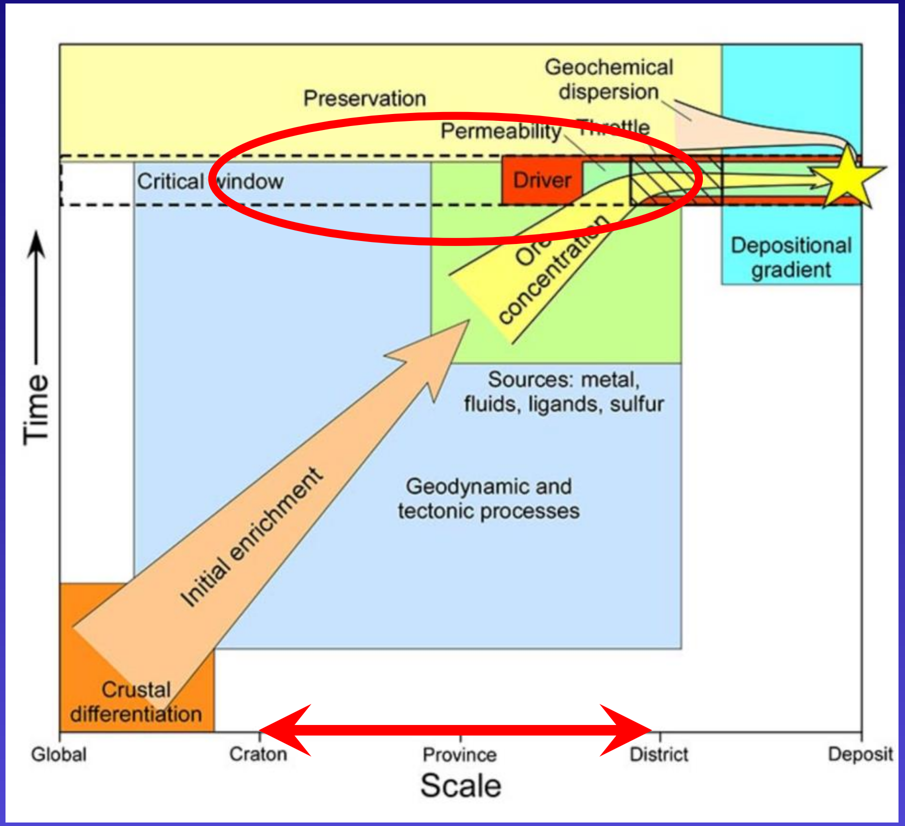
Mineral Resources

‘Mineral Systems’ framework

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

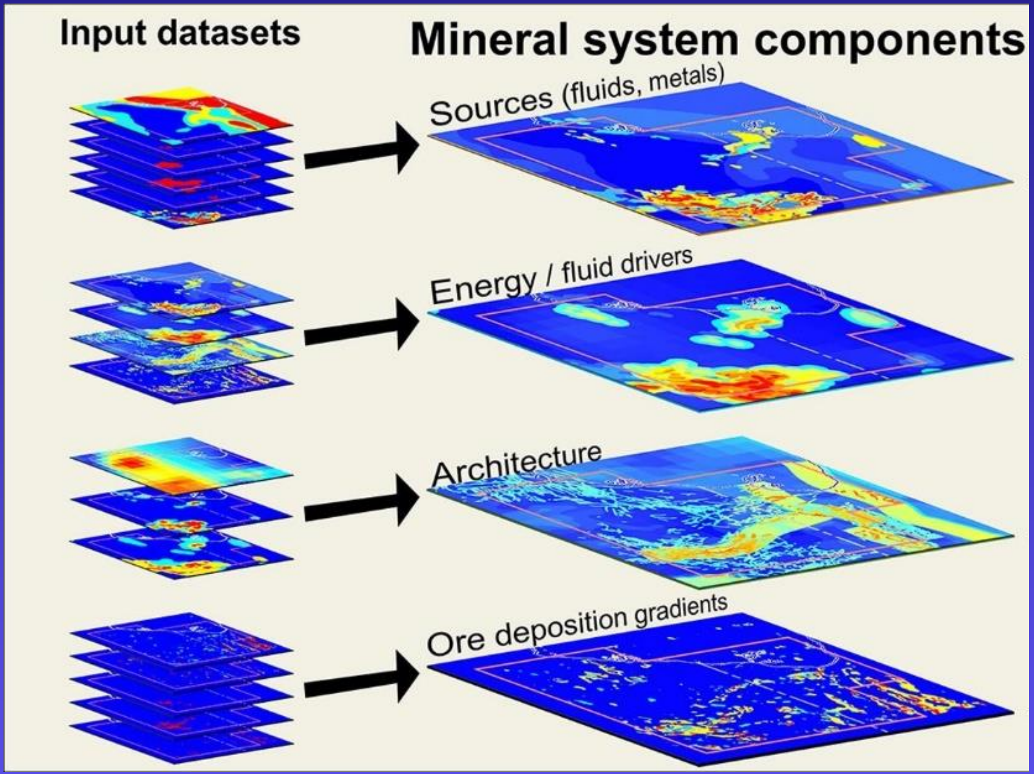
- Energy drive (e.g. topography, geothermal gradient, magma)
- Source (metals)
- Transport media (melts, aqueous fluids, petroleum)
- Transport pathways (permeable structures/lithologies)
- Physical and chemical traps (basins, lithologies, redox changes)



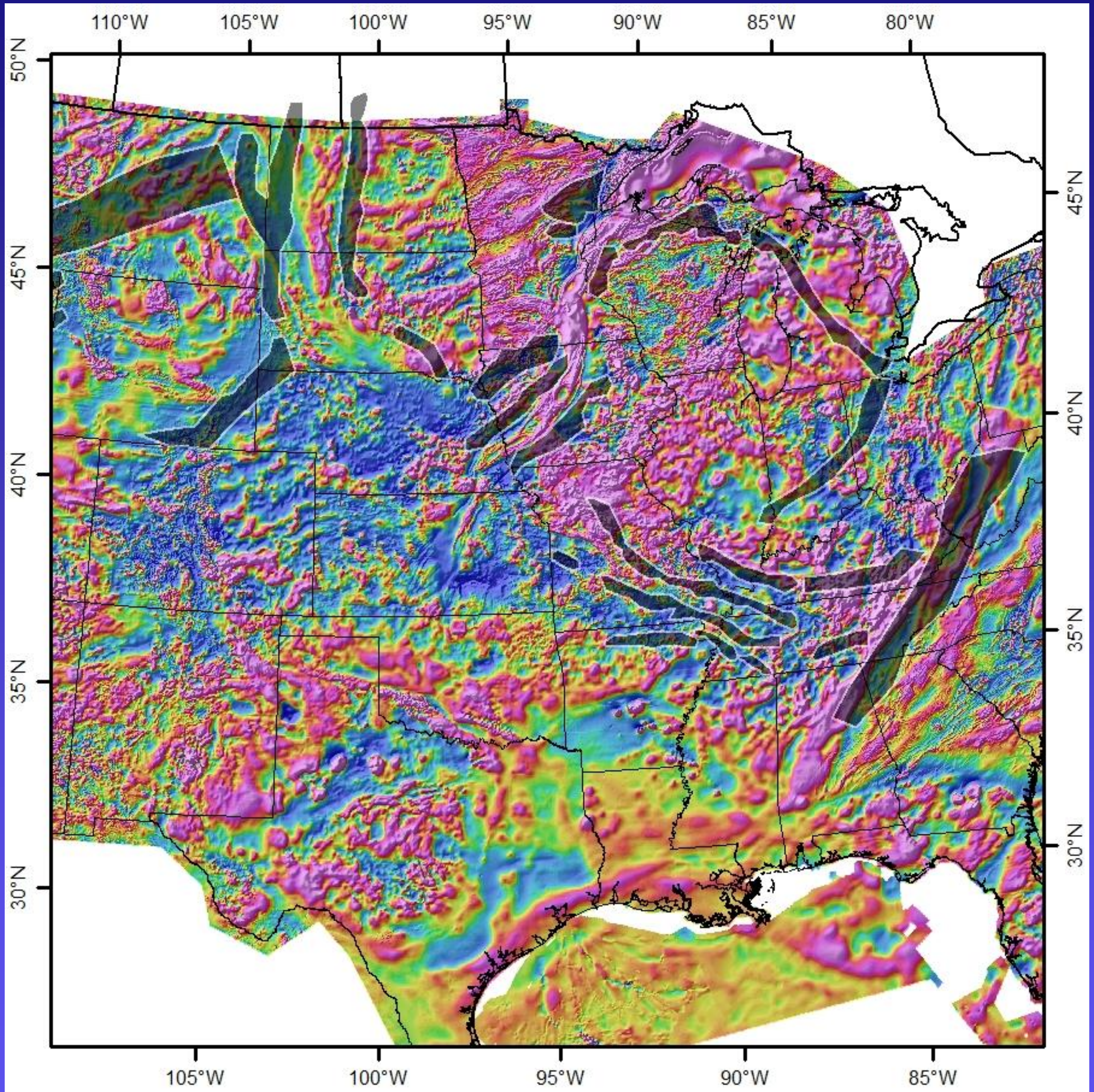
Huston et al. (2016)

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

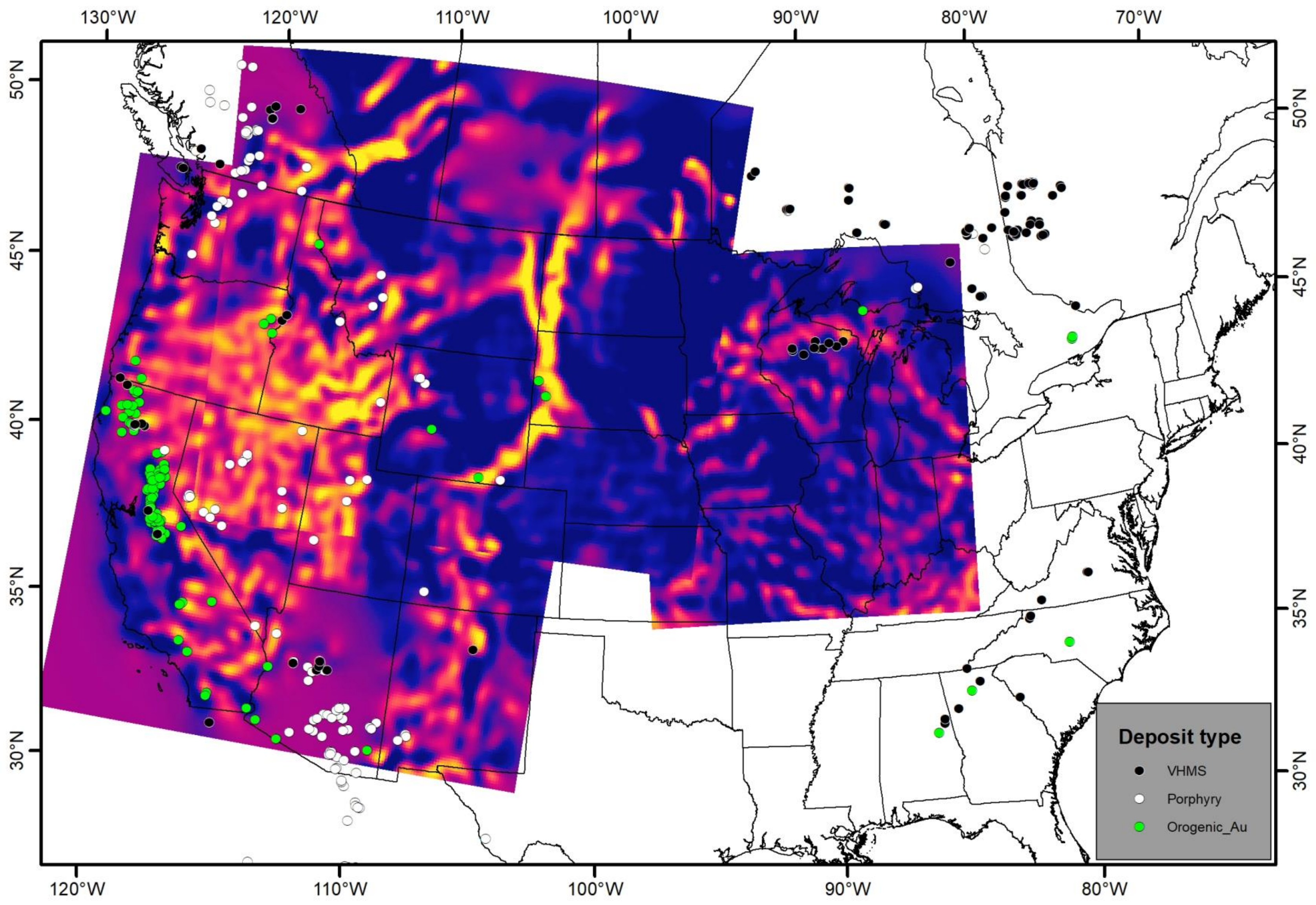
Prospectivity analysis

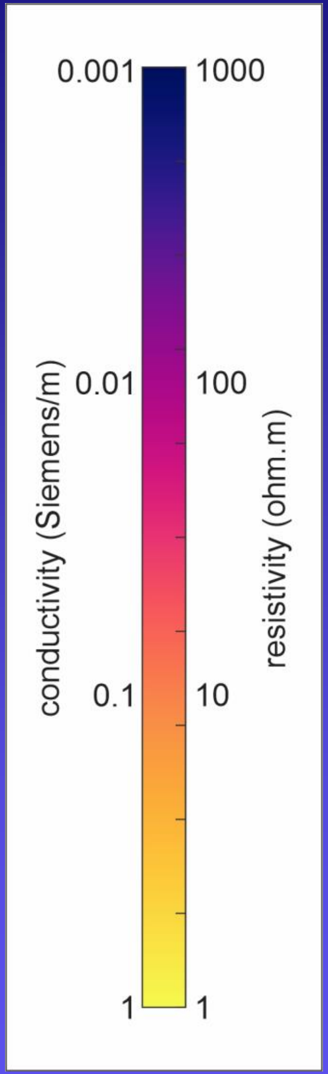


Skirrow et al. (2019)



Resistivity at 30 km + deposit locations





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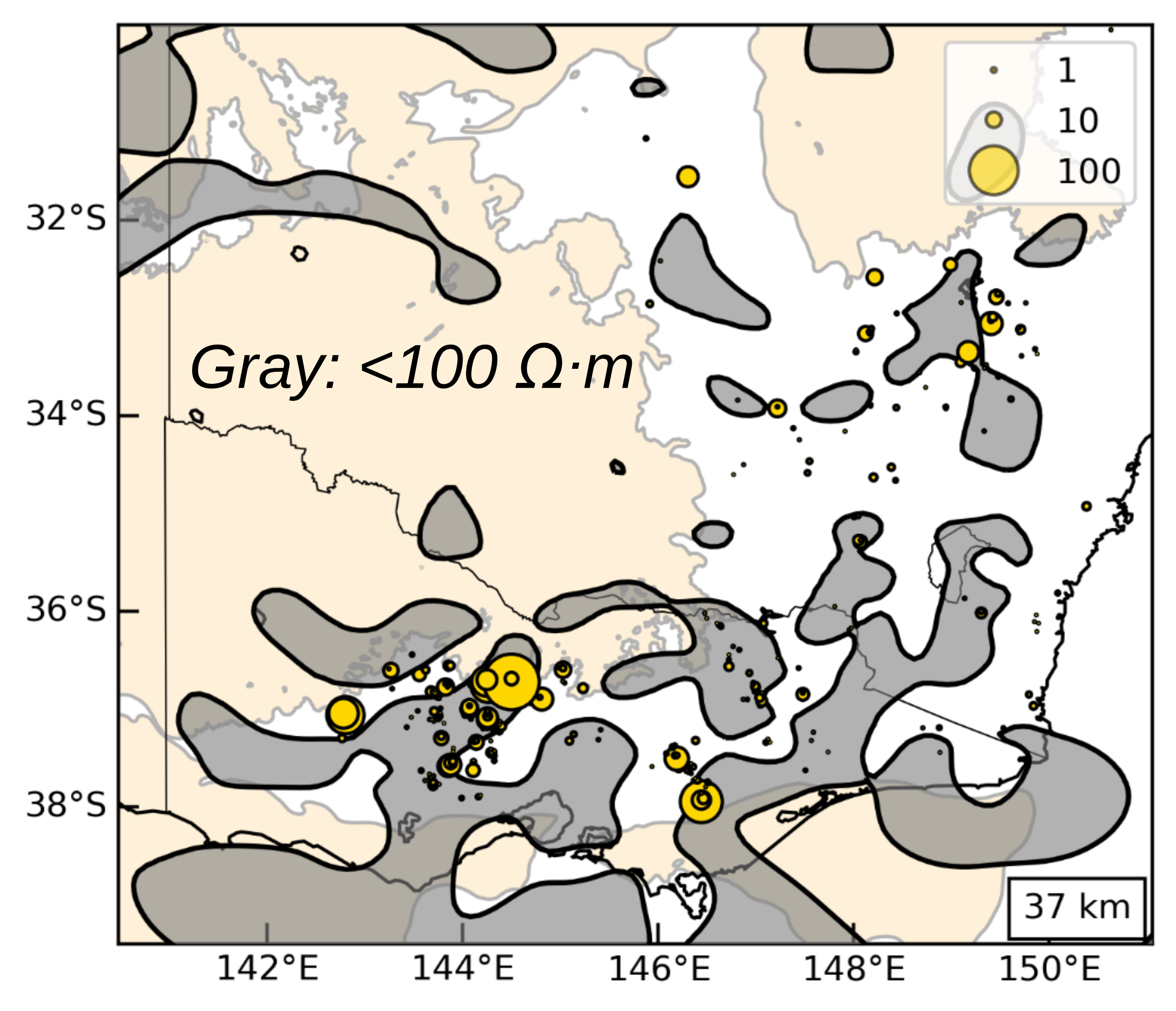
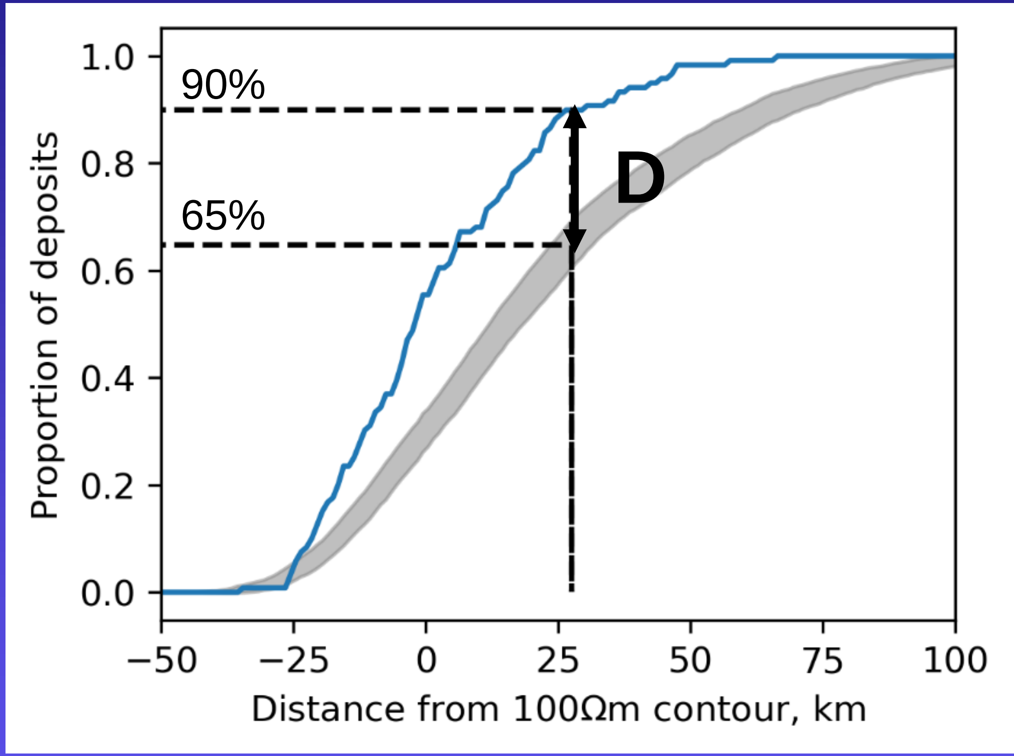
Kirkby et al., in prep.

Spatial relationship between deposits & conductors

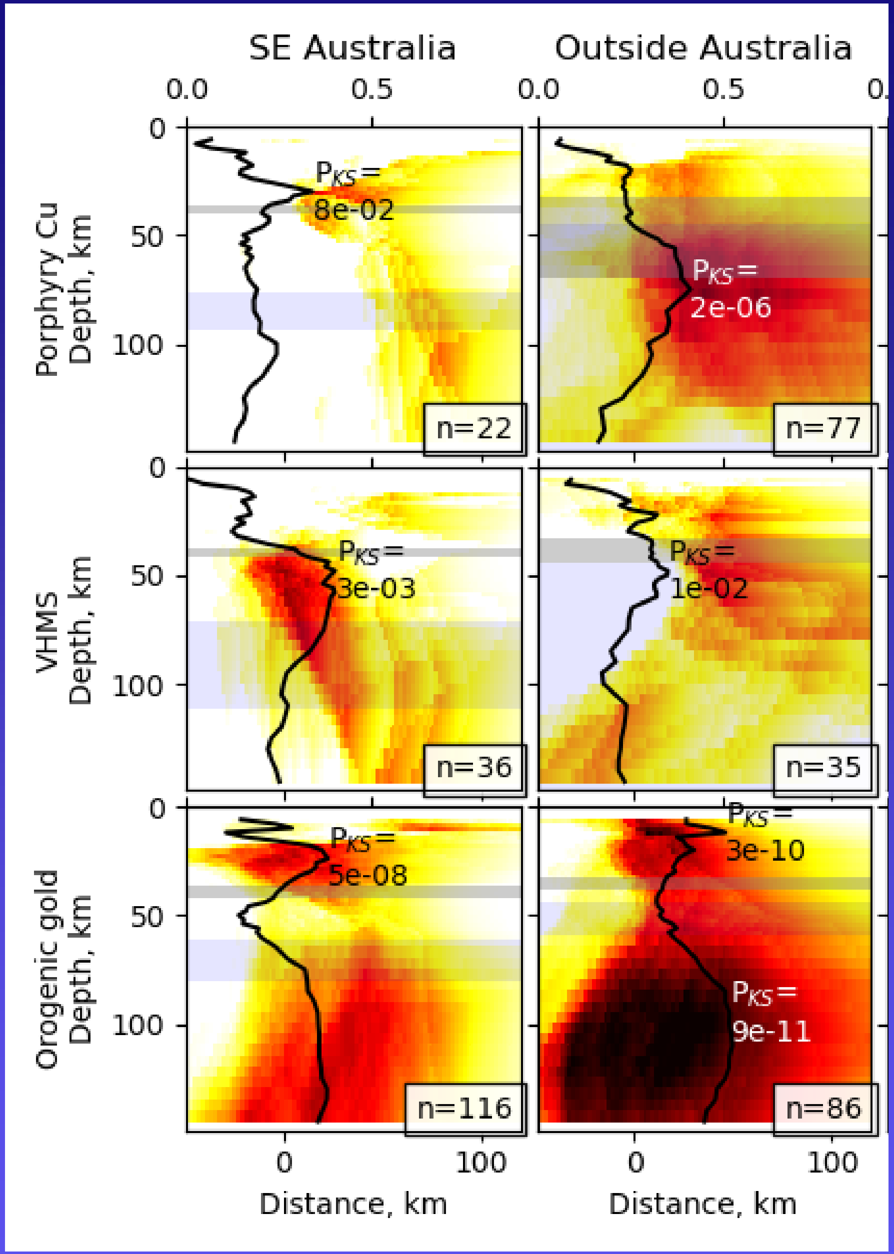




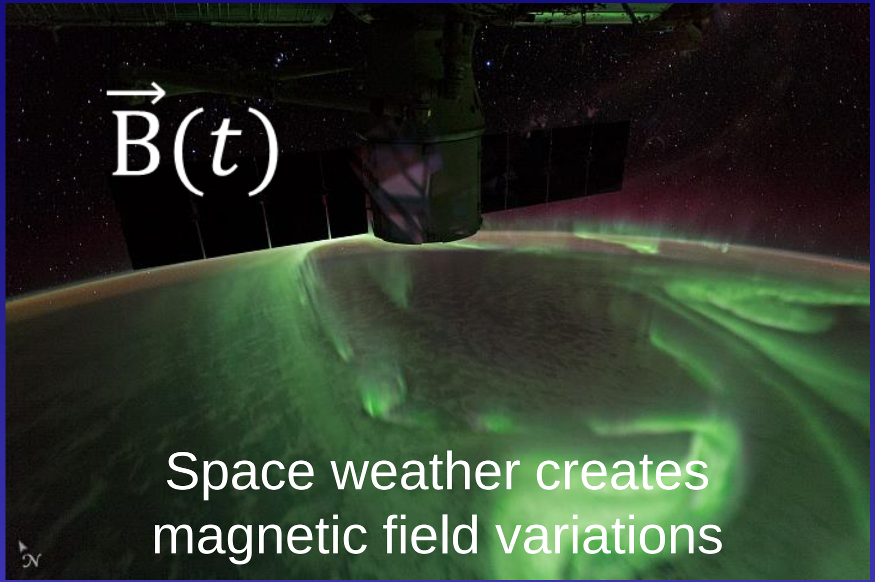
Kirkby et al., in prep.

Correlation as heat maps

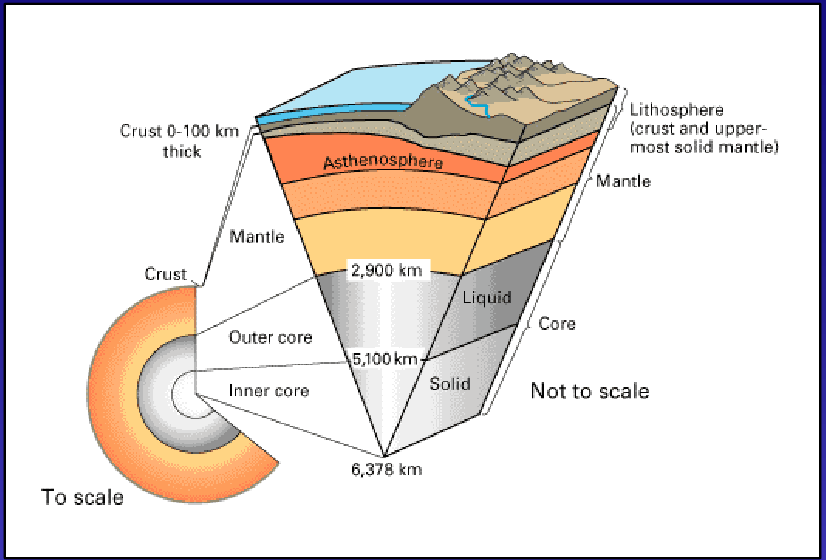
- **Probability that deposits and conductors are spatially related as a function of depth**
- **Different spatial/depth relationships for different deposit types**
- **Reflect different genetic models and positions within convergent margins**



Space Weather



$\overleftrightarrow{Z}$



changing magnetic field induces geoelectric fields in the Earth

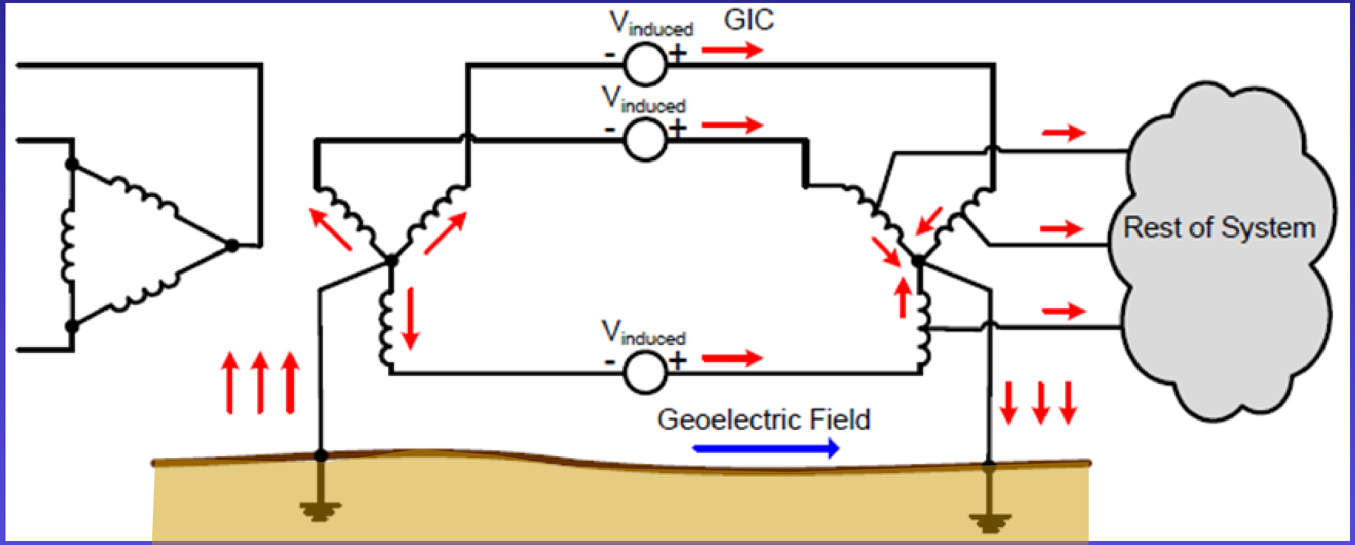
$$\vec{E}(t) = \overleftrightarrow{Z} * \vec{B}(t)$$

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

USGS

Geomagnetically Induced Currents (GICs)

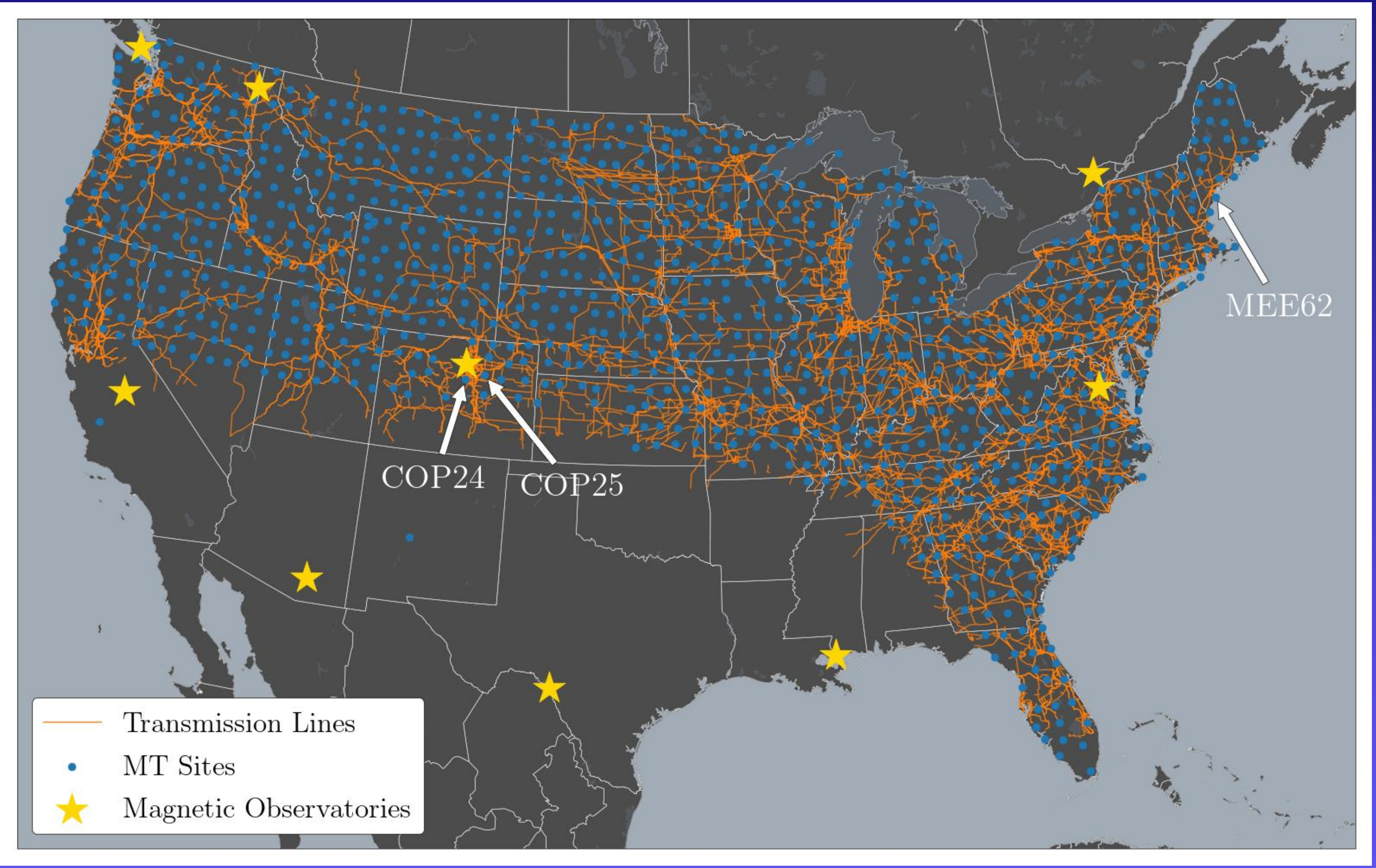
- Quasi-DC currents that flow in the power grid during a geomagnetic storm
- GICs enter the power grid through transformer groundings at substations
- Can trigger cascading failure and widespread black outs



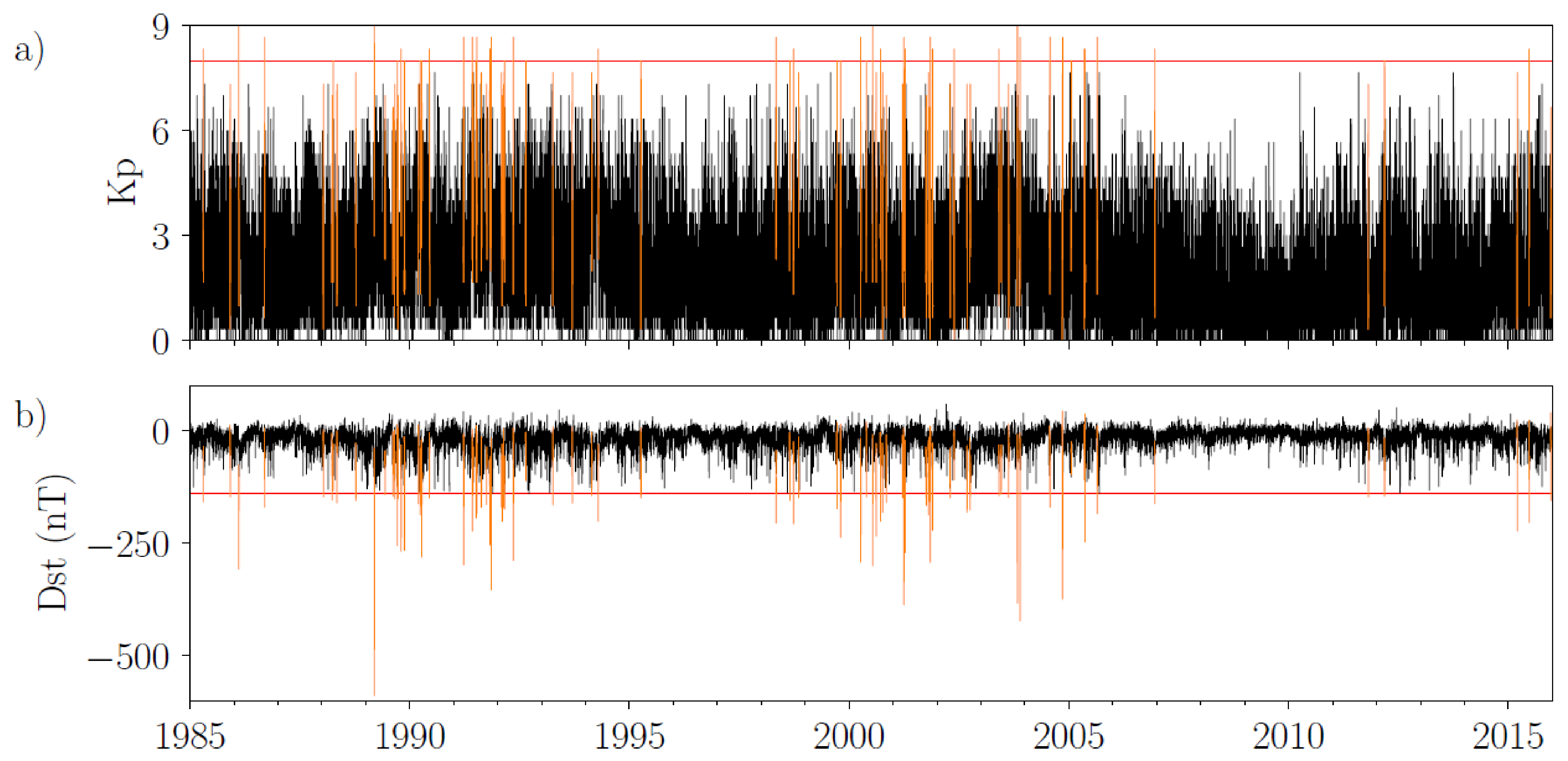
Haytham Saeed (2015)

USGS

MT Array data + mag observatories + transmission lines



Geomagnetic storm identification from magnetic indices



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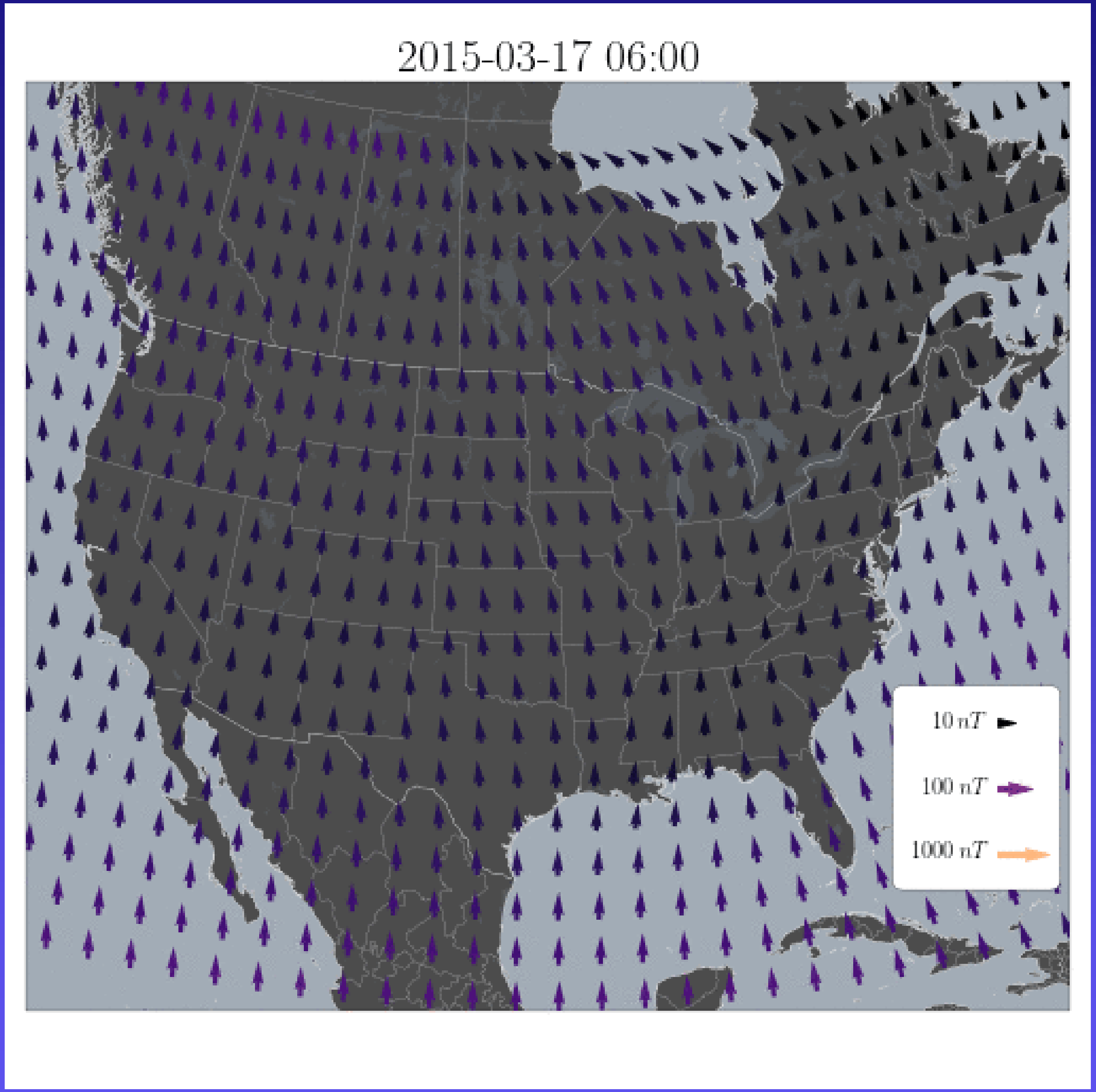
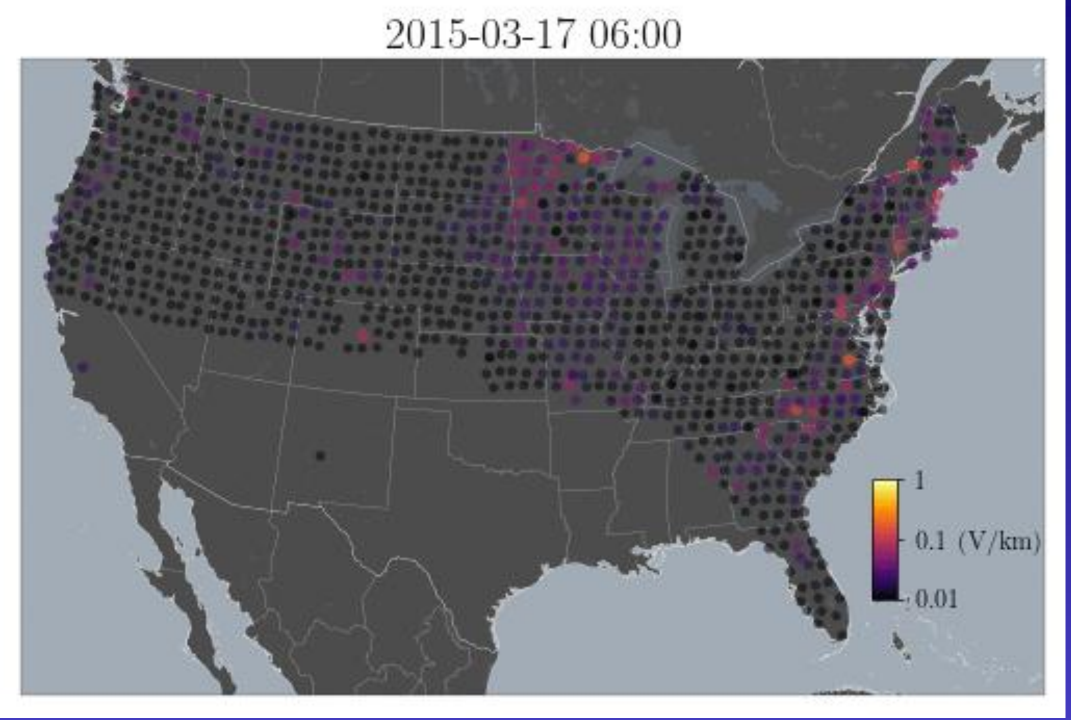
Lucas et al.(2020)

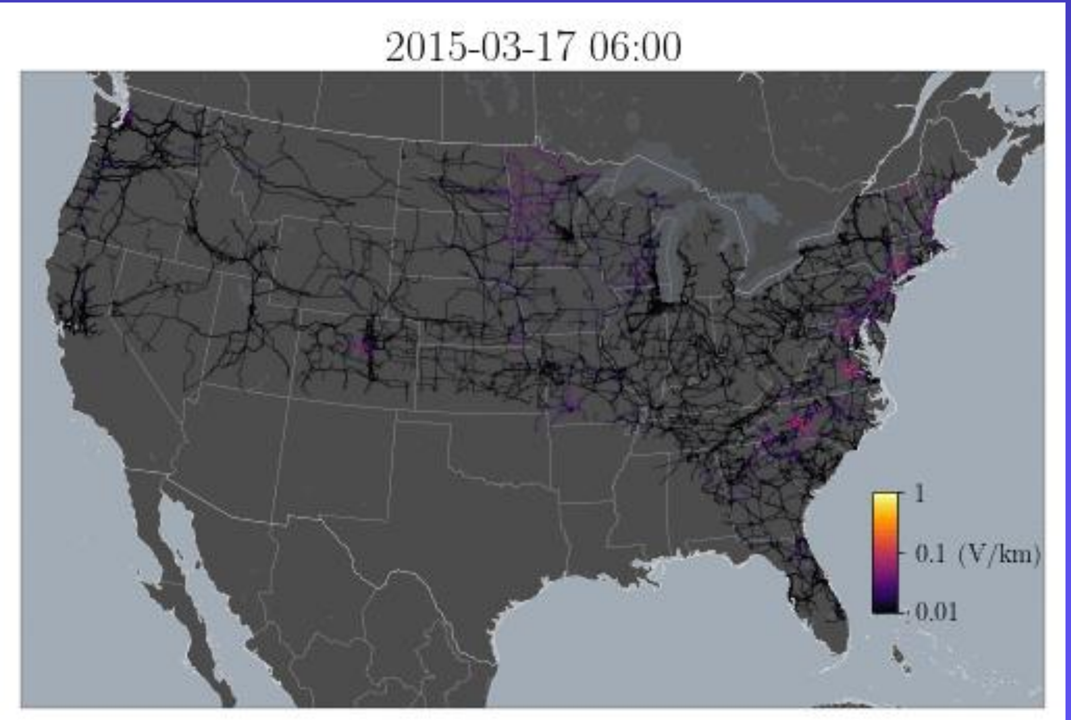
Magnetic field



Electric field



Normalized line voltage



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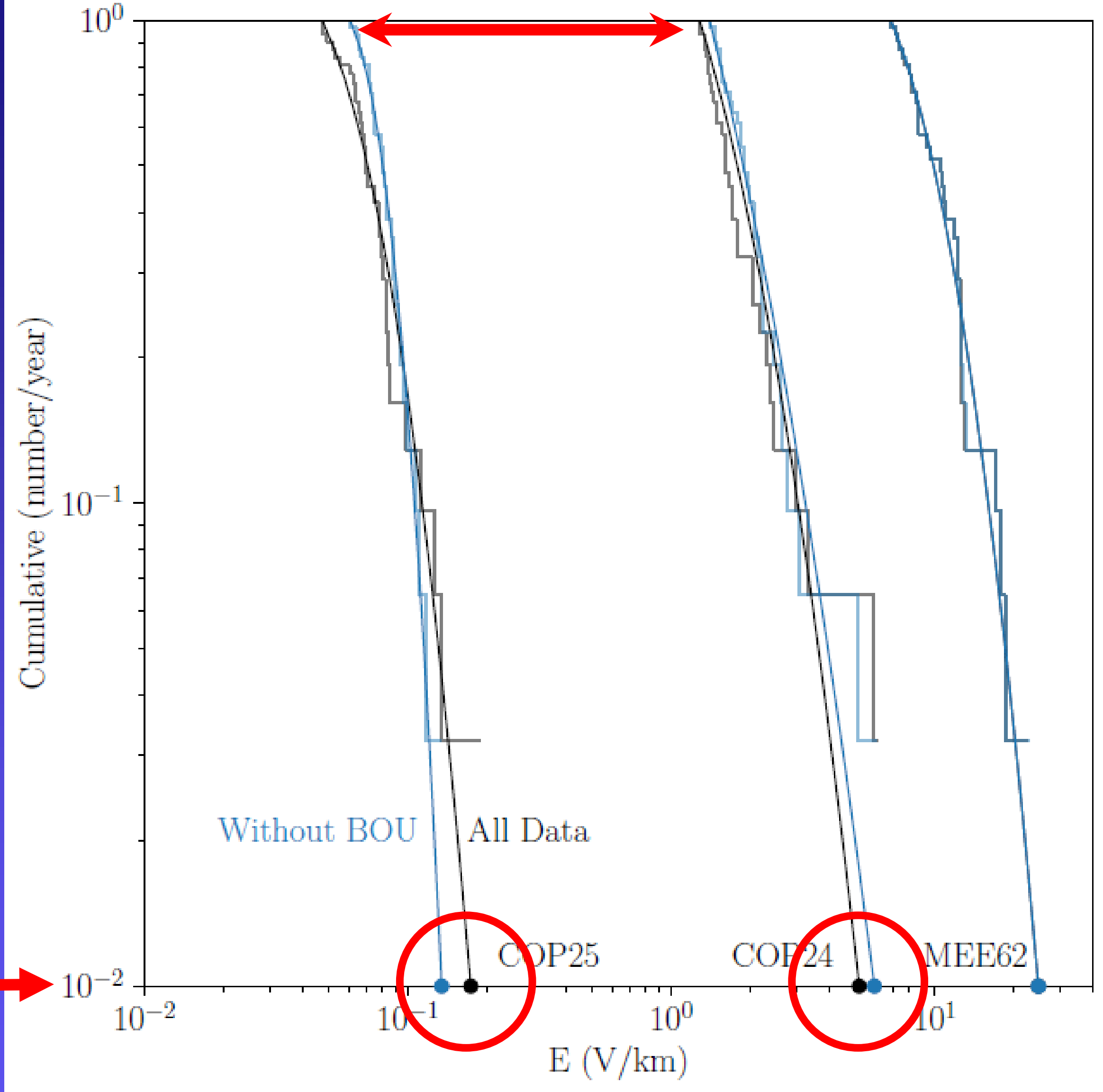
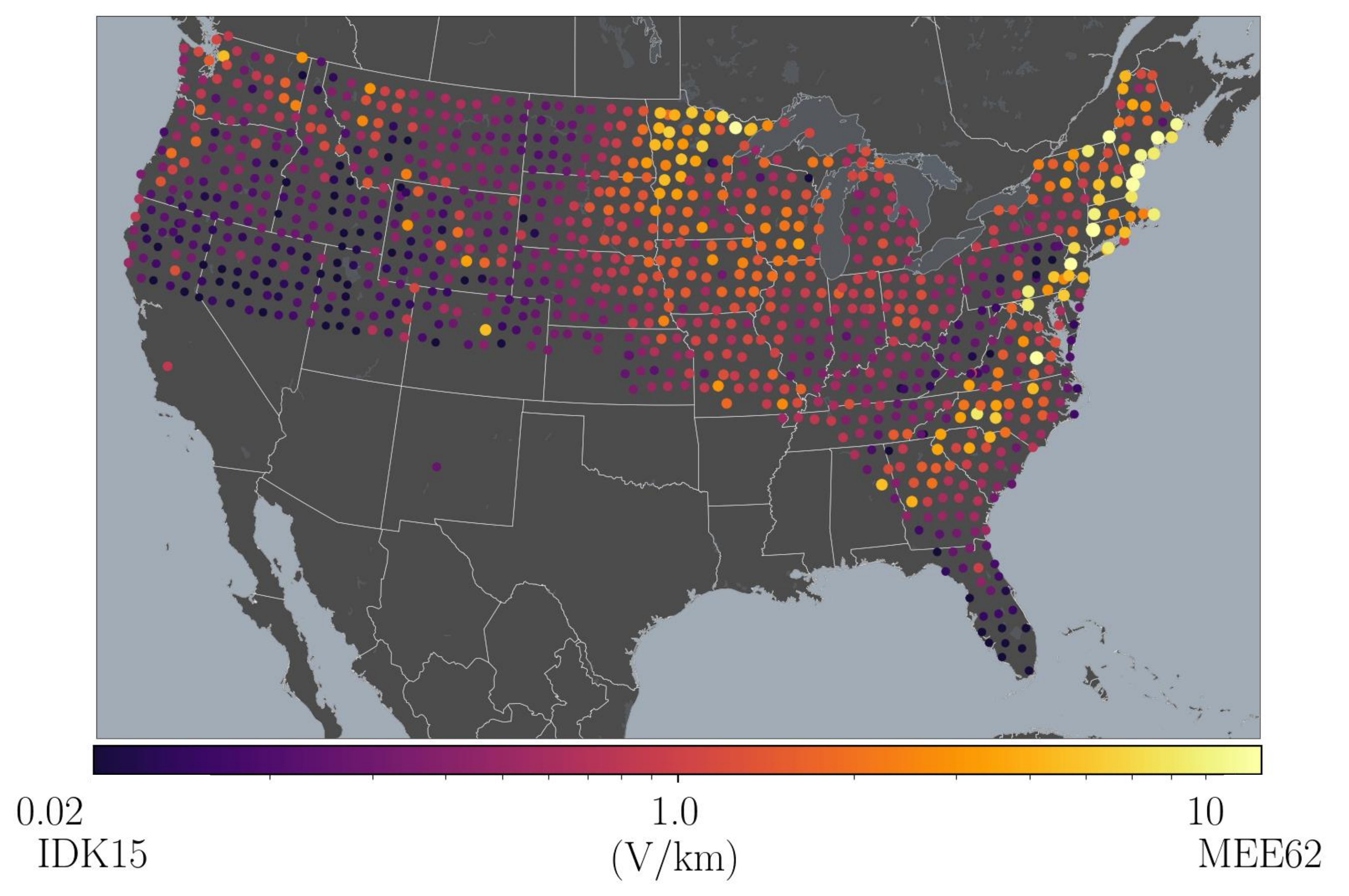
Statistics – peak geoelectric field for all storms

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



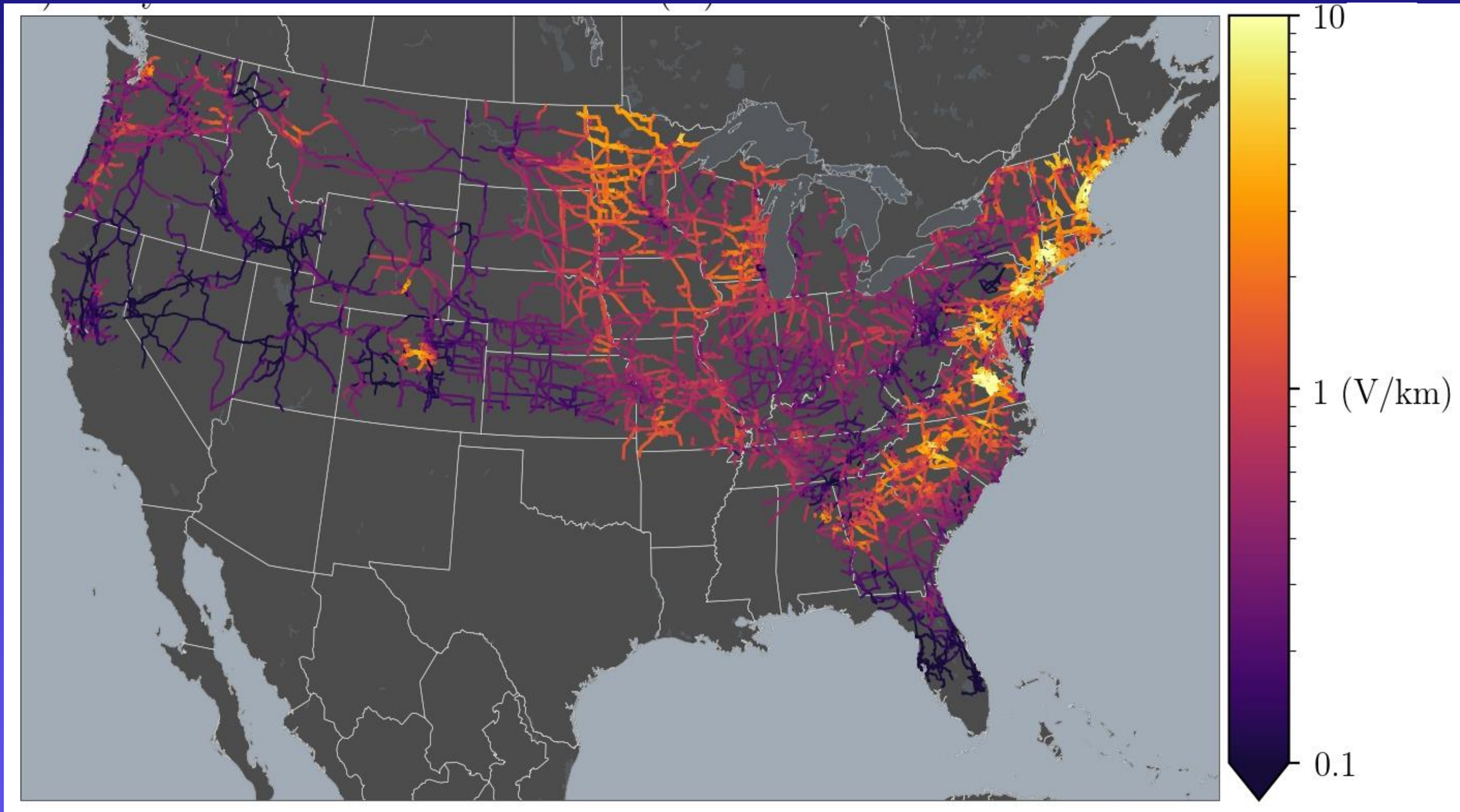
100-yr geoelectric field exceedance map

- **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
- IRIS: Bob Woodward, Andy Frassetto, Shane Ingate, Rob Wooley, Chad Trabant, Rich Karstens, Mick Van Fossen
- USGS: Anna Kelbert, Jade Crosbie, Ben Murphy
- Green Geophysics: Louise Pellerin
- Chaytus Engineering: Brady Fry
- GYS (GeoSystem), Phil Wannamaker, Zonge Engineering
- The many dedicated field personnel who sustained this monumental effort