Mapping the March 1989 Superstorm

Geoelectromagnetic hazards and impacts on the United States power grid

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A movie about CMEs was shown here.

The March 1989 magnetic superstorm:

Max –Dst = 589 nT (Kyoto) 565 nT (Oulu).

Brought aurorae and geomagnetic disturbance to midlatitudes.

Storms of similar intensity occur every 4 solar cycles (Love, 2021).

One of the most impactful storms in recorded history.

Interfered with radio communication, navigational systems, geophysical surveys. Disrupted satellite operations and damaged satellites. (Allen et al., 1989; Cliffswallow et al., 1993; Boteler, 2019).

The storm is well known for causing an electricity blackout in Québec, Canada (Bolduc, 2002).

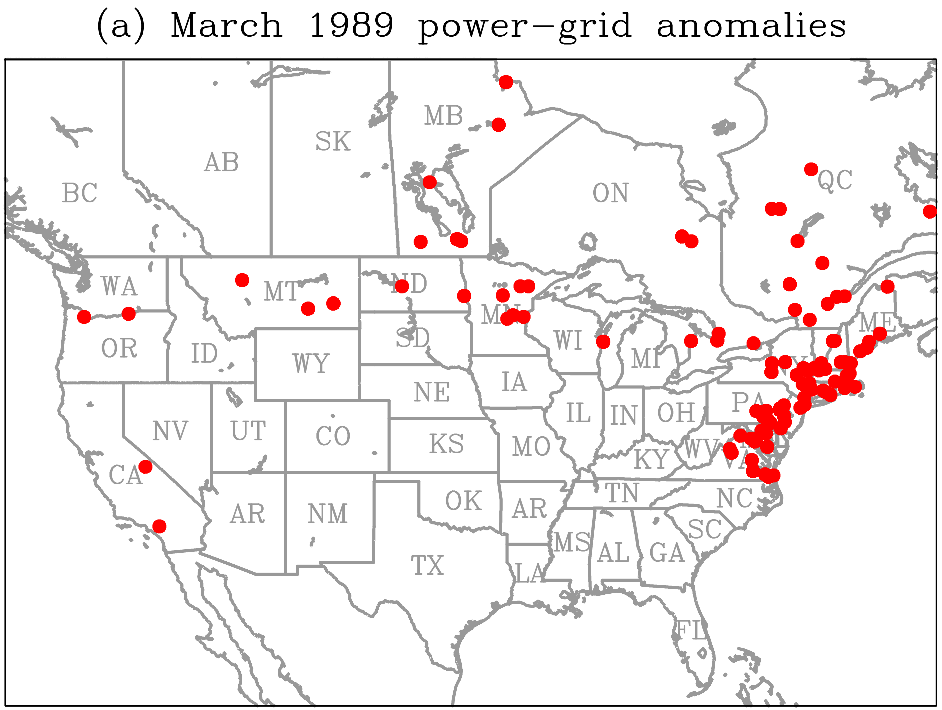
The storm also brought significant interference to contiguous United States power-grid systems, including damaging a high-voltage transformer in Salem, New Jersey (NERC, 1990).

Analyses of historical storms inform projects for mitigating the deleterious impacts of future storms.

Some studies anticipate that a future storm as intense as that of May 1921 or September 1859 could carry significant economic consequence (Baker et al., National Academy of Sciences, 2008).

Power-grid anomalies for March 1989 storm:

- Reported in publications.
- Mostly with begin times. Some with end times.
- Mostly named facilities (183 located).
- Severity of anomalies not detailed, but includes
  - Quebec blackout and damage to transformer at a nuclear power plant in New Jersey.
- Examples: “Alarm”, “oscillograph”, “capacitor”, “generator”, “voltage”, “MVAR”.

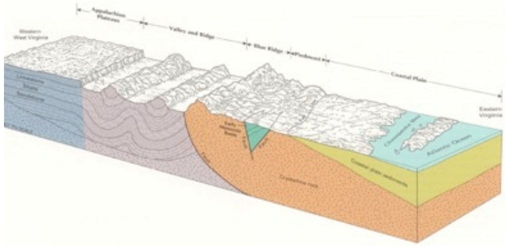


Input signal
time series

Convolution
through a filter

Output signal
time series

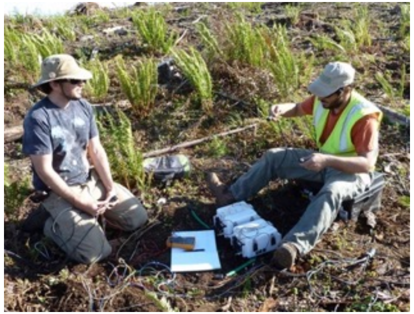
Geomagnetic
variation



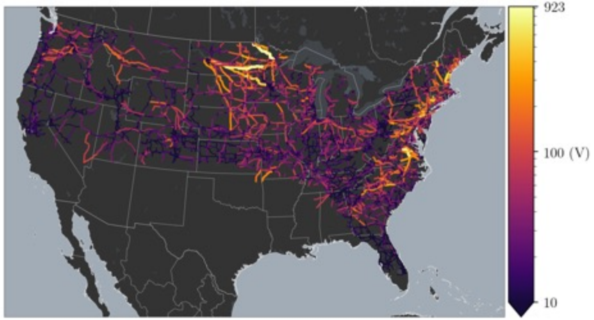
Geoelectric
field

Geomagnetic variation
recoded at observatory

Impedance measured during
magnetotelluric survey

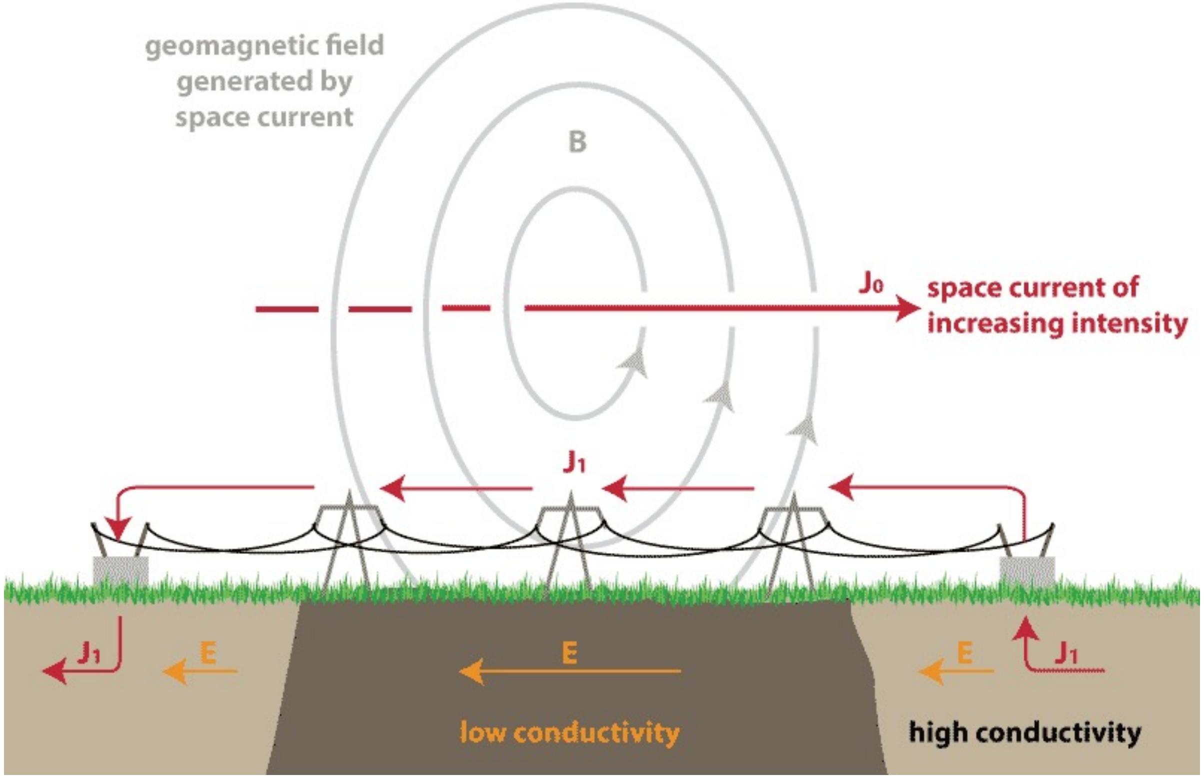


Geoelectric hazards
mapped onto power grids



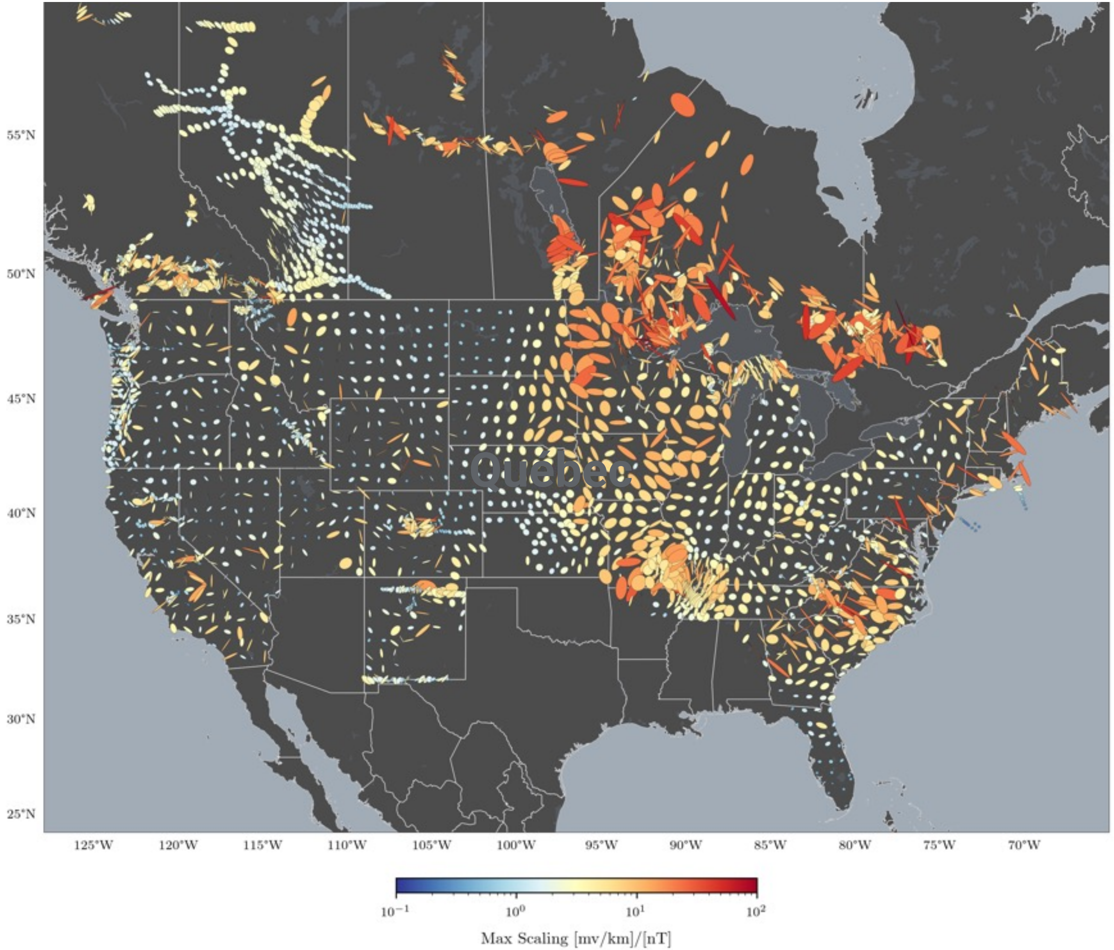
Love, J. J., Rigler, E. J., Pulkkinen, A., Balch, C. C., 2014.
Magnetic storms and induction hazards, Eos, Trans. AGU, 95(48), 445-446, doi10.1002/2014EO480001.

The electrical conductivity structure of the solid Earth affects magnetic-storm generation of electric fields.



Love, J. J., Kelbert, A., Murphy, B. S., Rigler, E. J. & Lewis, K. A., 2020. Geomagnetism Program research plan, 2020–2024, USGS Circular 1469, 19 p., doi:10.3133/cir1469.

Geography of impedance amplitude and polarization at 120 seconds.



USGS science for a changing world

NSF

earth scope

NASA

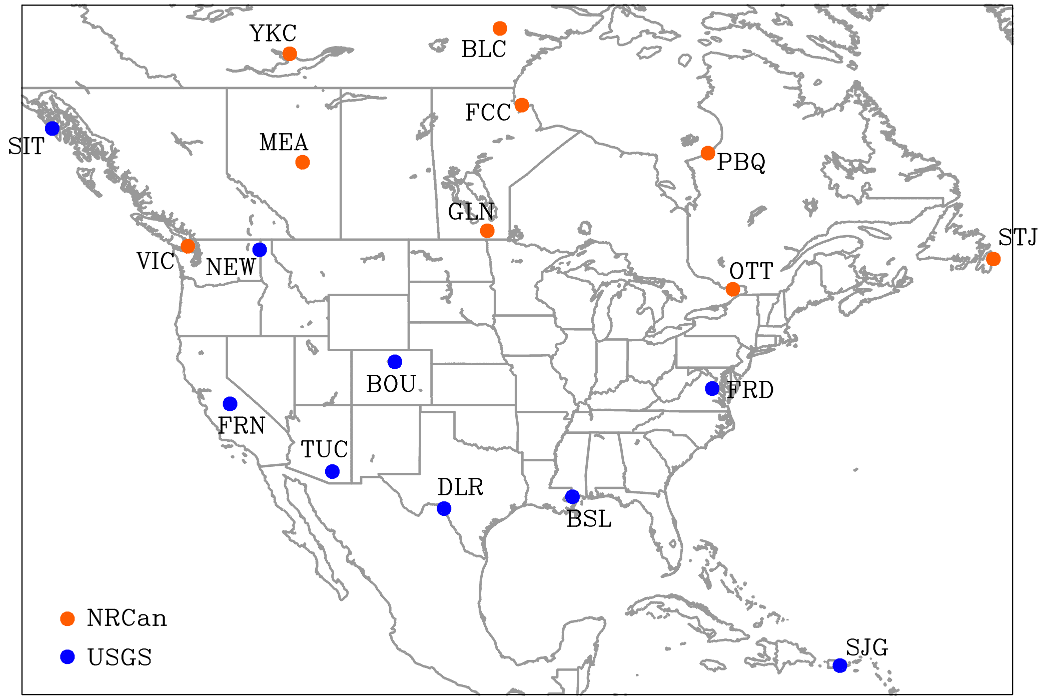
OSU Oregon State University

Canada's National LITHOPROBE Geoscience Project

University of Alberta

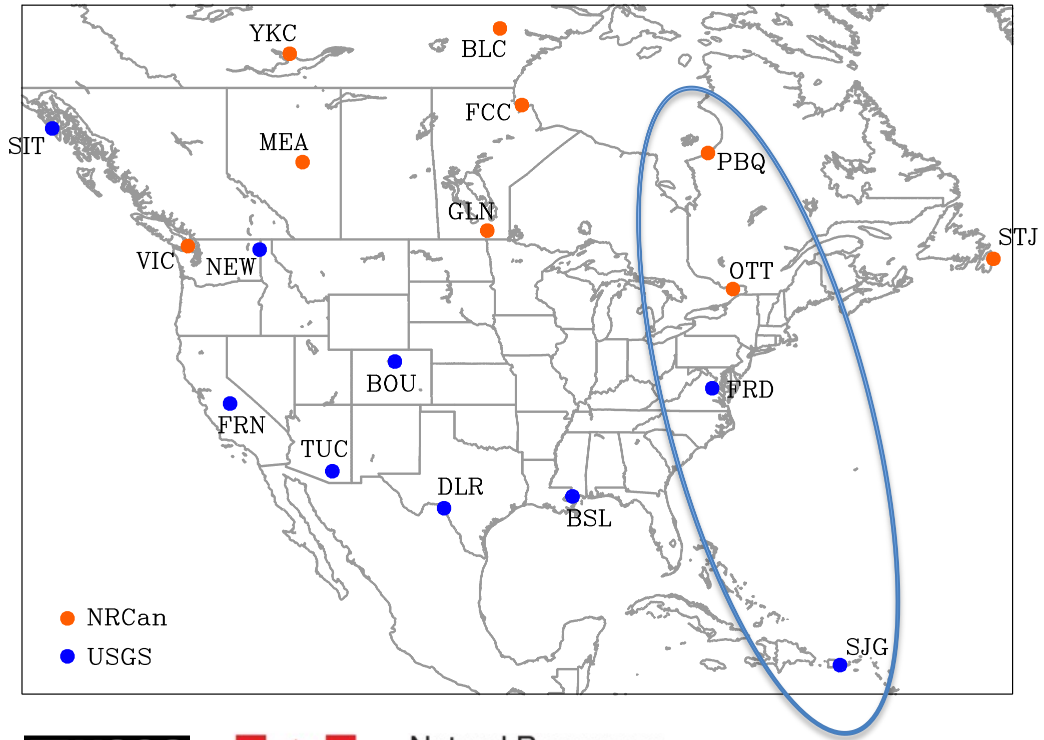
Kelbert, A., G. D. Egbert, and A. Schultz, IRIS DMC data services products: EMTF, The magnetotelluric transfer functions, doi:10.17611/DP/EMTF.1, 2011.

Magnetic observatories spanning the study region, in operation in 1989, providing 1-minute resolution data.



Natural Resources Canada

Magnetic observatories spanning the study region, in operation in 1989, providing 1-minute resolution data.



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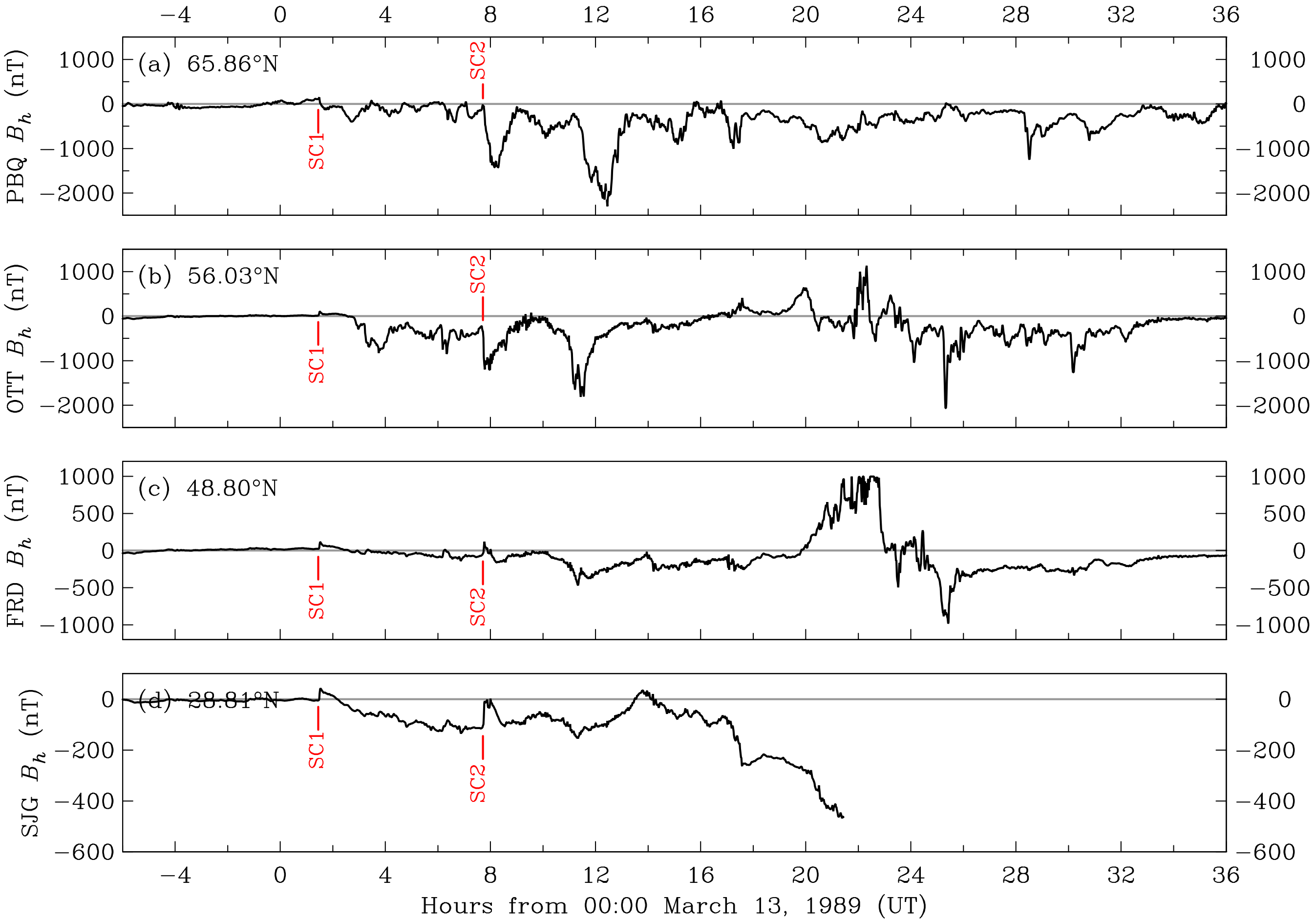
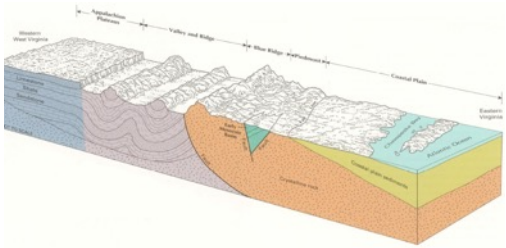
Natural Resources Canada



(a) 65.86°N
PBQ B_h (nT)
(b) 56.03°N
OTT B_h (nT)
(c) 48.80°N
FRD B_h (nT)
(d) 28.81°N
SJG B_h (nT)
SC1
SC2
Hours from 00:00 March 13, 1989 (UT)

Input signal time series → Convolution through a filter → Output signal time series

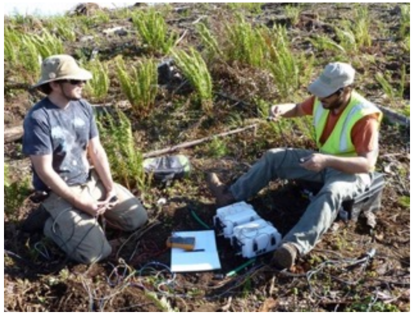
Geomagnetic variation →



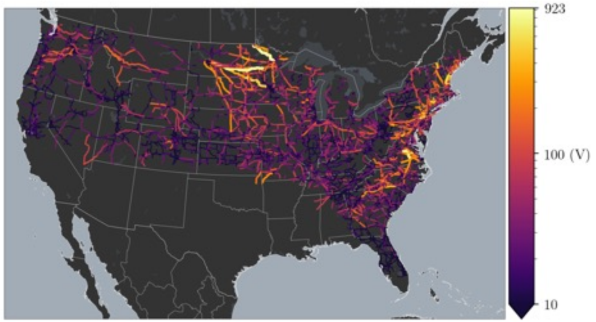
→ Geoelectric field

Geomagnetic variation recoded at observatory

Impedance measured during magnetotelluric survey



Geoelectric hazards mapped onto power grids

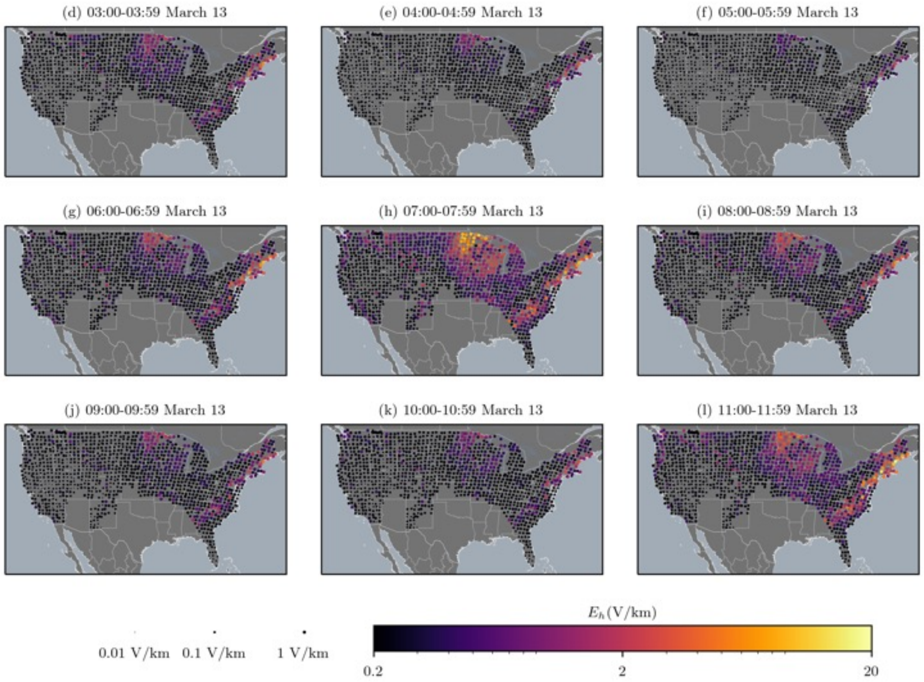


USGS science for a changing world
LASP Laboratory for Atmospheric and Space Physics University of Colorado Boulder
NOAA
NASA

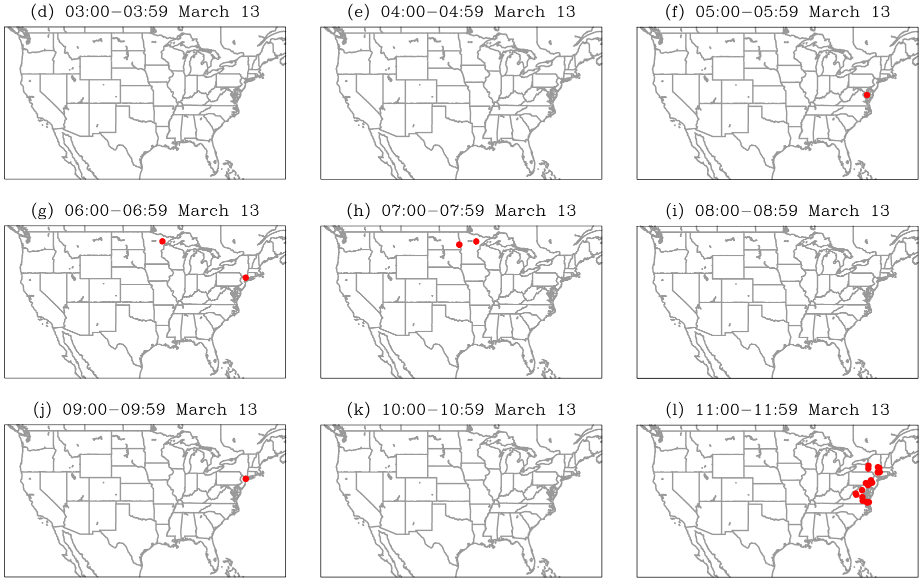
Love, J. J., Rigler, E. J., Pulkkinen, A., Balch, C. C., 2014.
Magnetic storms and induction hazards, Eos, Trans. AGU, 95(48), 445-446, doi10.1002/2014EO480001.

Nine hours of time, the storm's second sudden commencement and immediately after.

Peak 1-minute induced geoelectric field amplitude per hour.



Power-grid anomalies.



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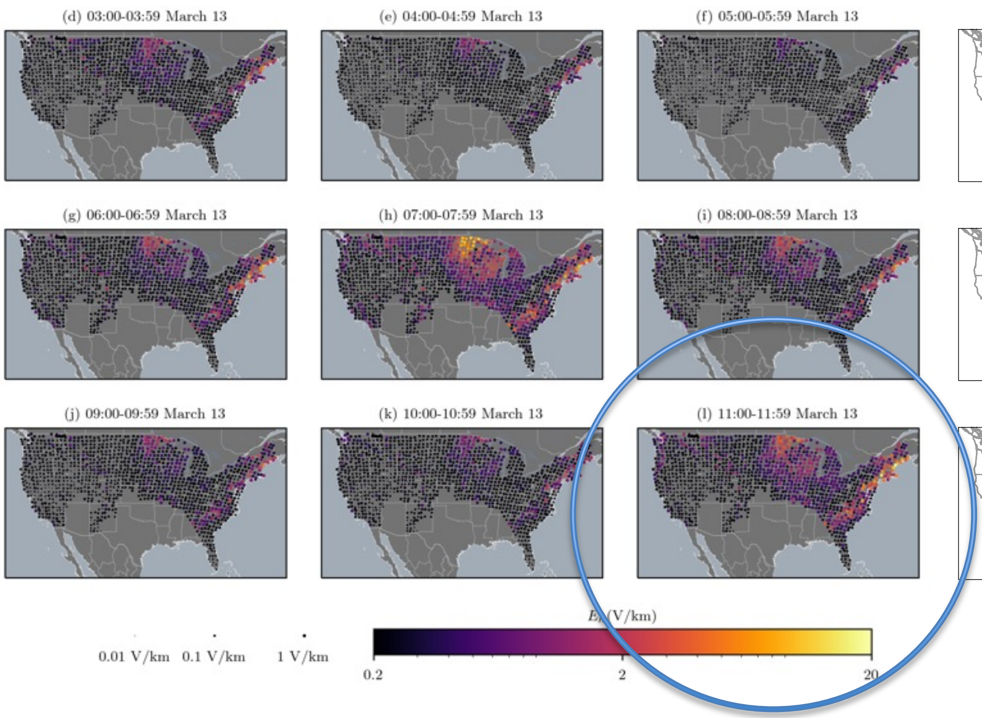

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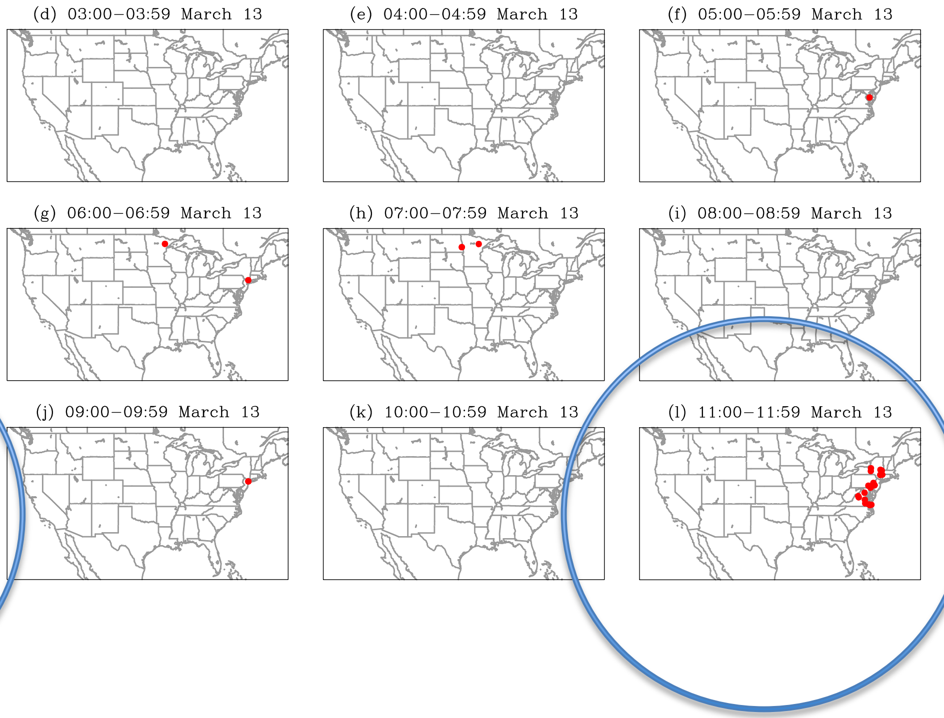
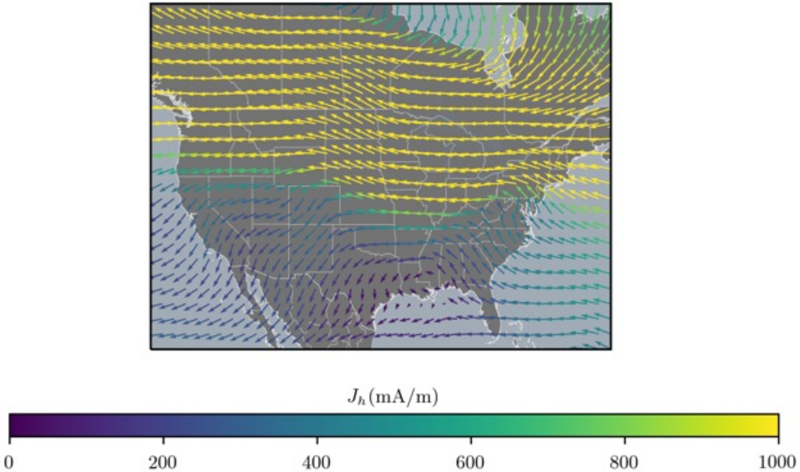
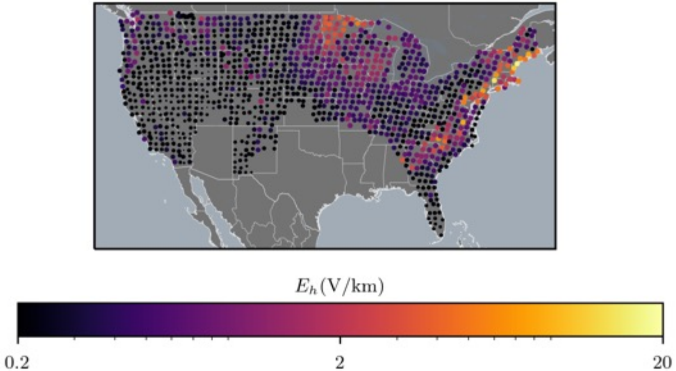


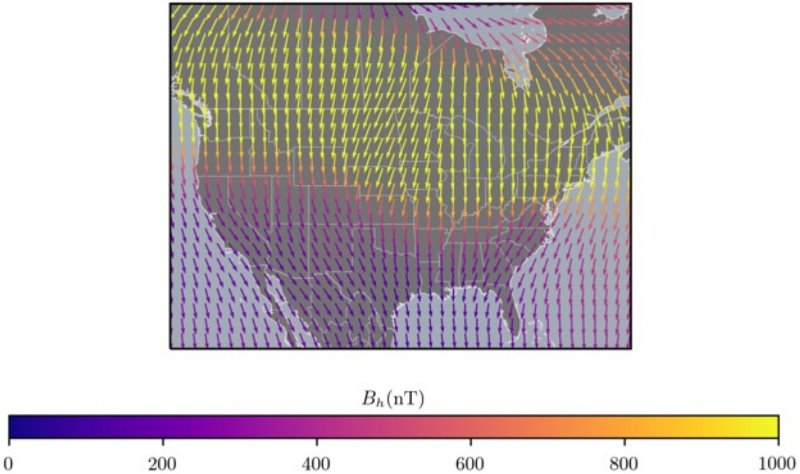
(a) 11:30 March 13



(l) 11:00-11:59 March 13



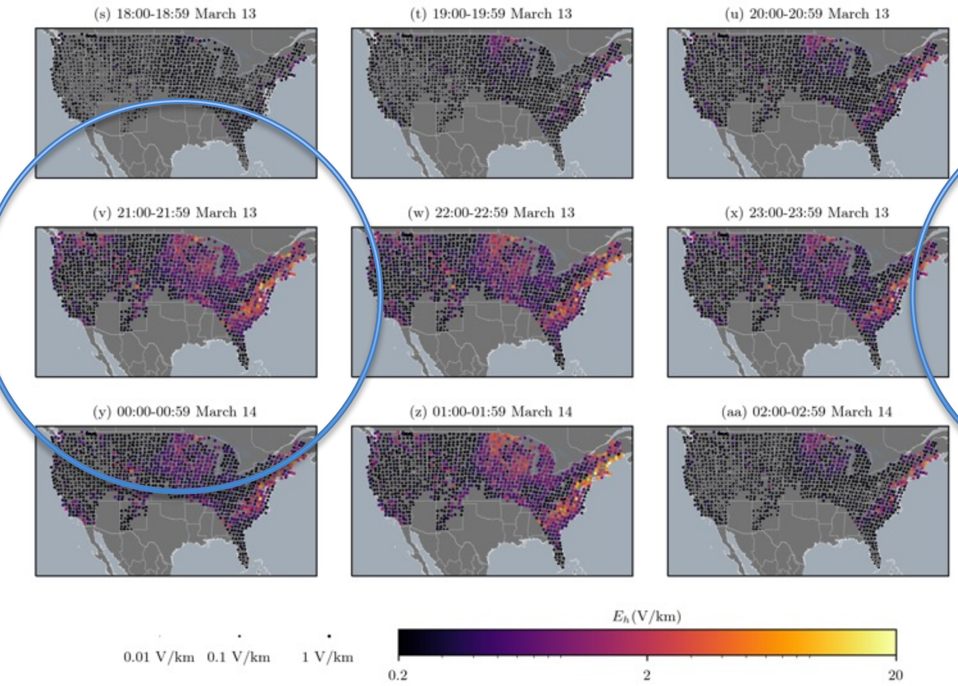
(d) 11:30 March 13



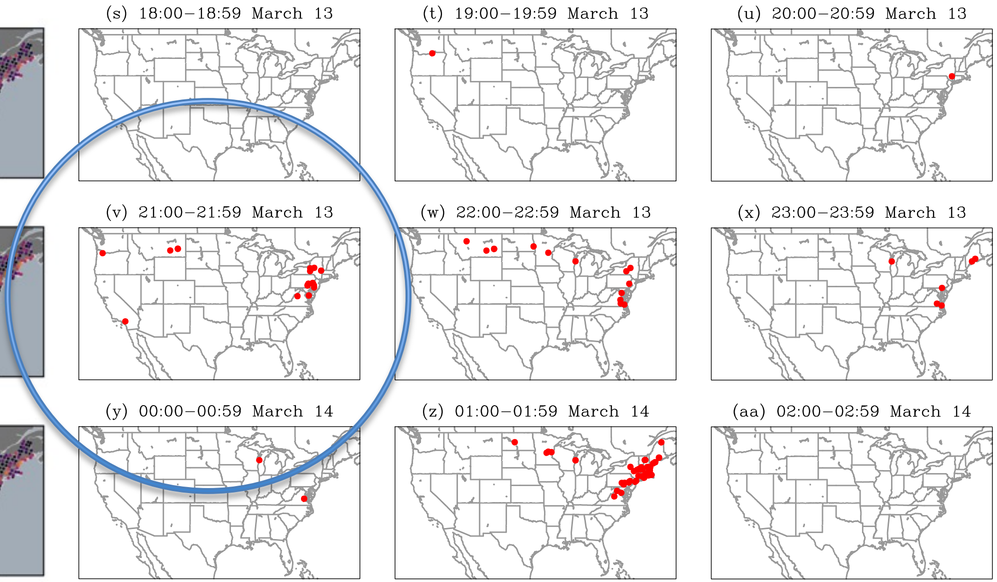
(l) 11:00–11:59 March 13

Nine hours of storm main-phase including maximum –Dst.

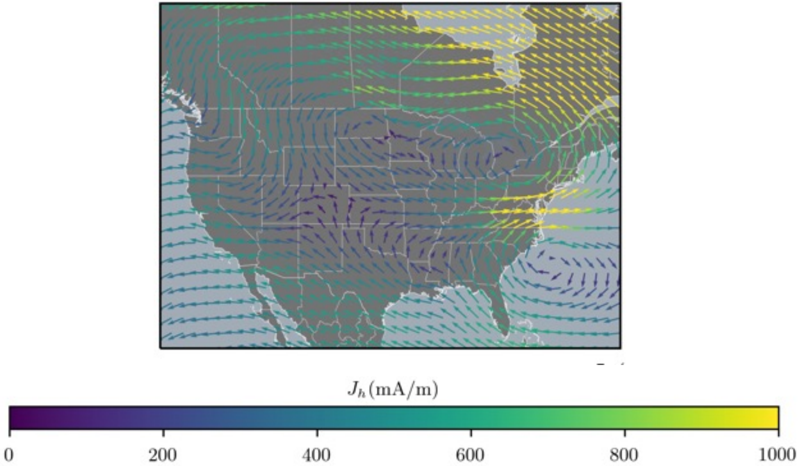
Peak 1-minute induced geoelectric field amplitude per hour.



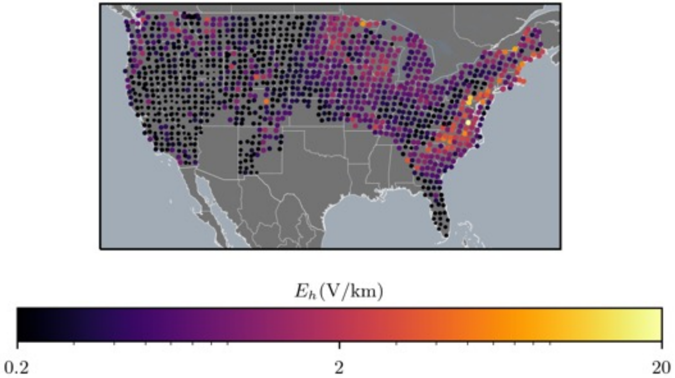
Power-grid anomalies.



(b) 21:30 March 13



(v) 21:00-21:59 March 13



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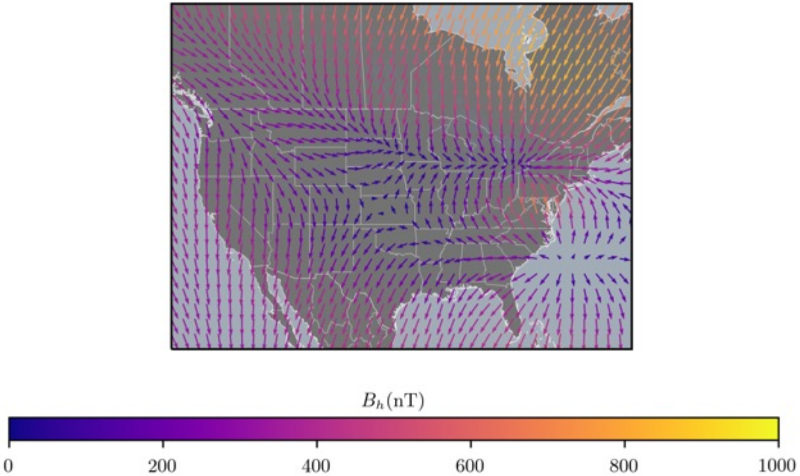

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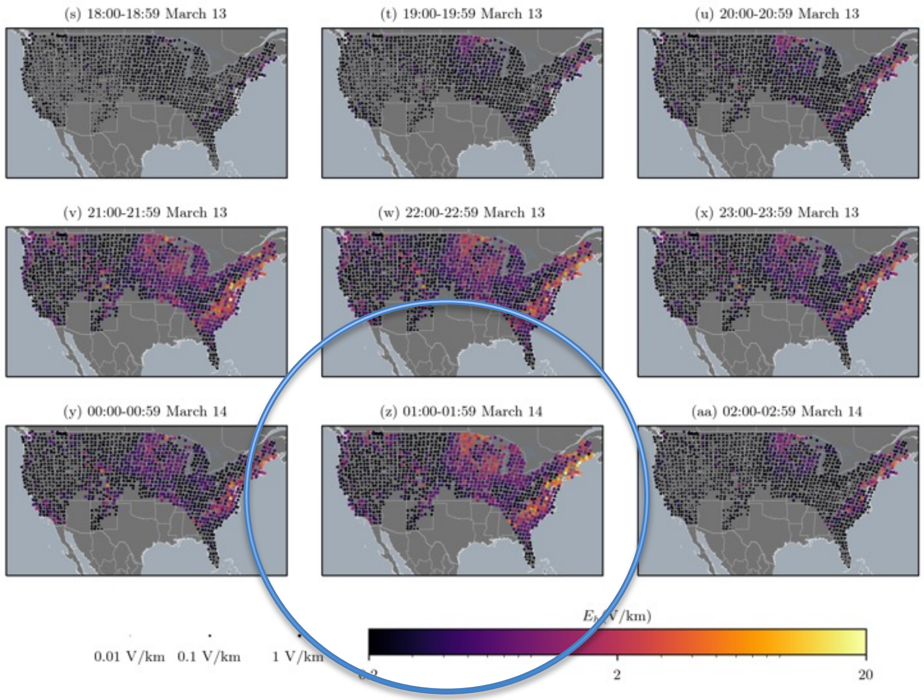
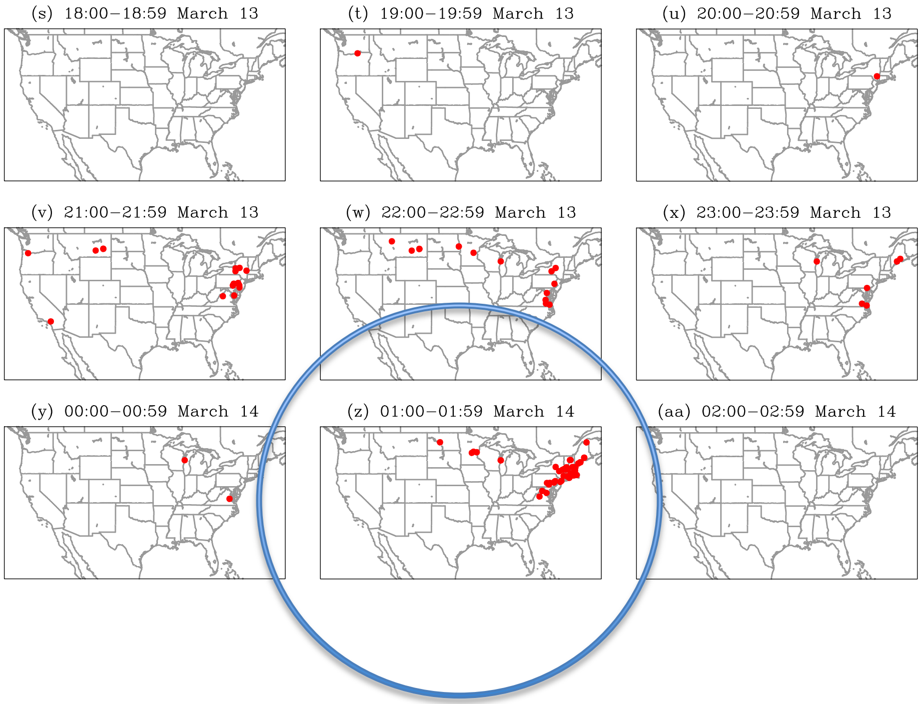
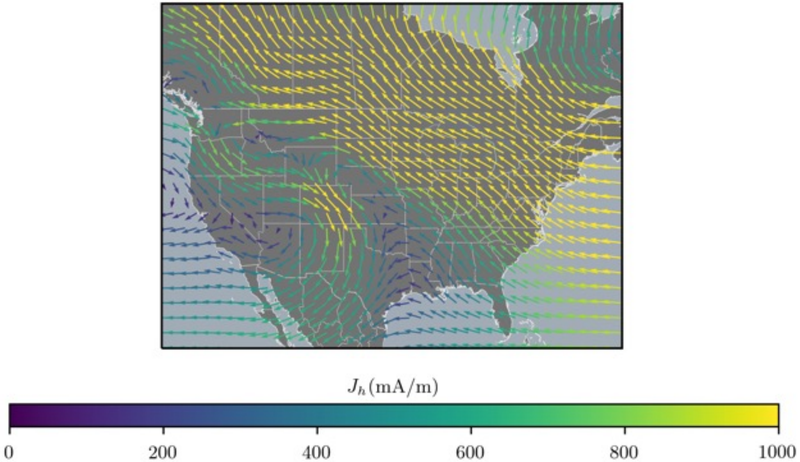


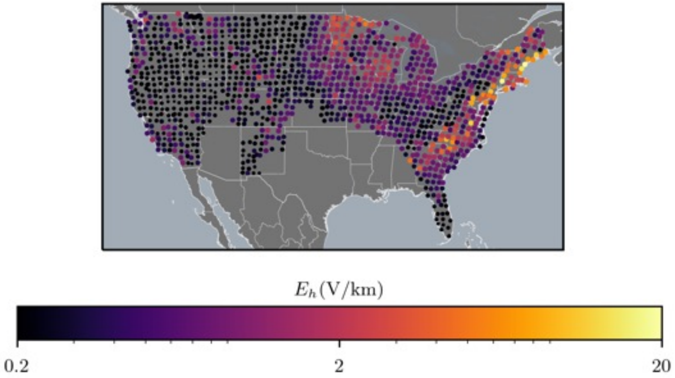
Power-grid anomalies.



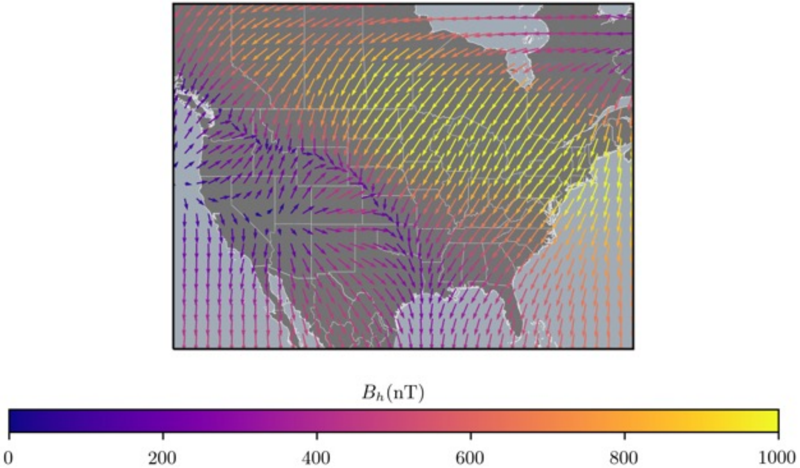
(c) 01:30 March 14



(z) 01:00-01:59 March 14



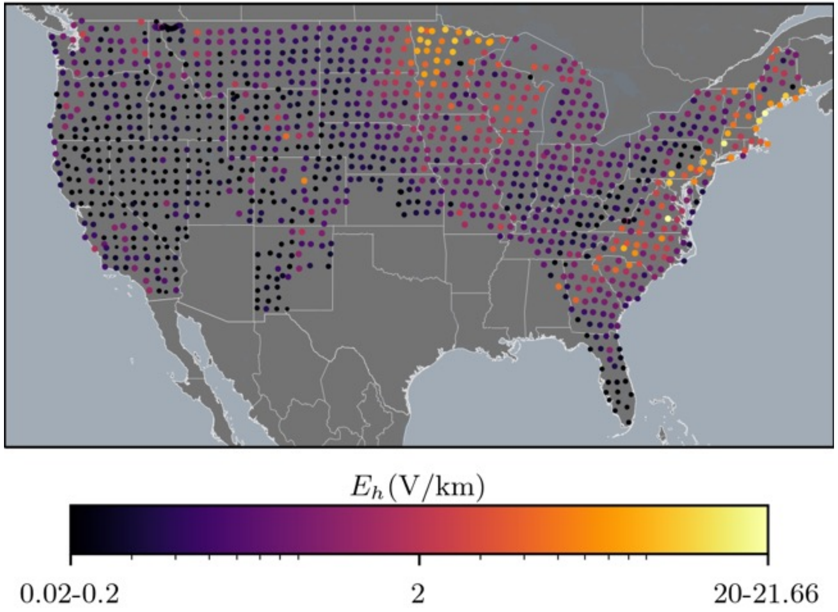
(f) 01:30 March 14



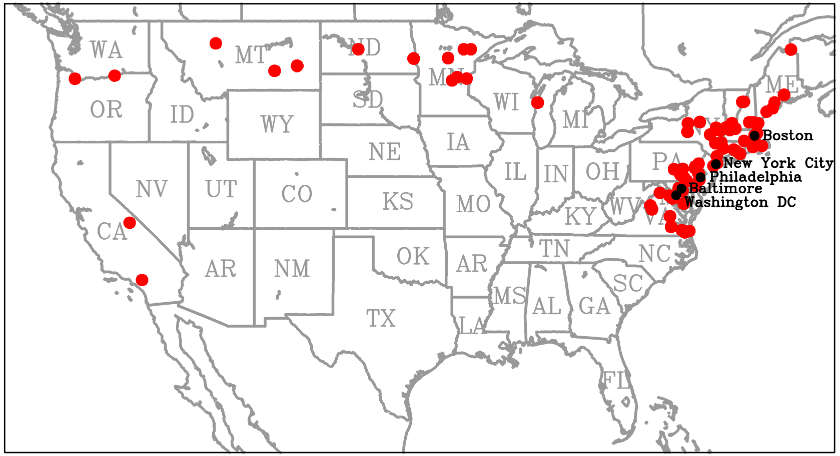
(z) 01:00–01:59 March 14

Integrate the results over time.

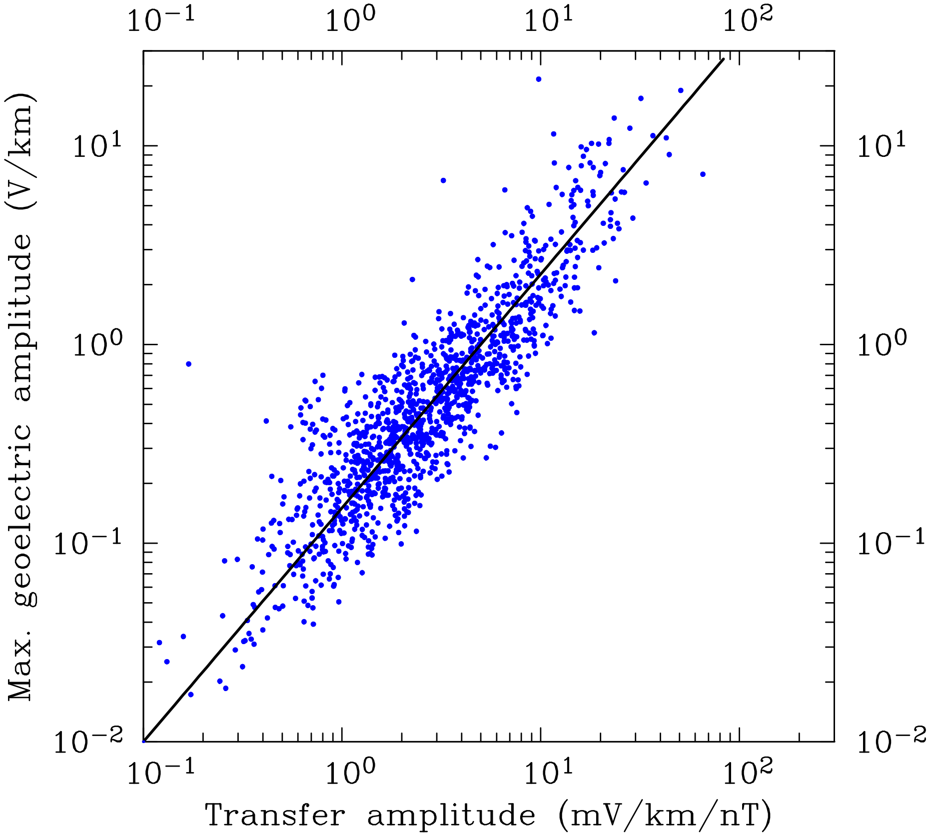
(a) Storm-maximum geoelectric amplitudes



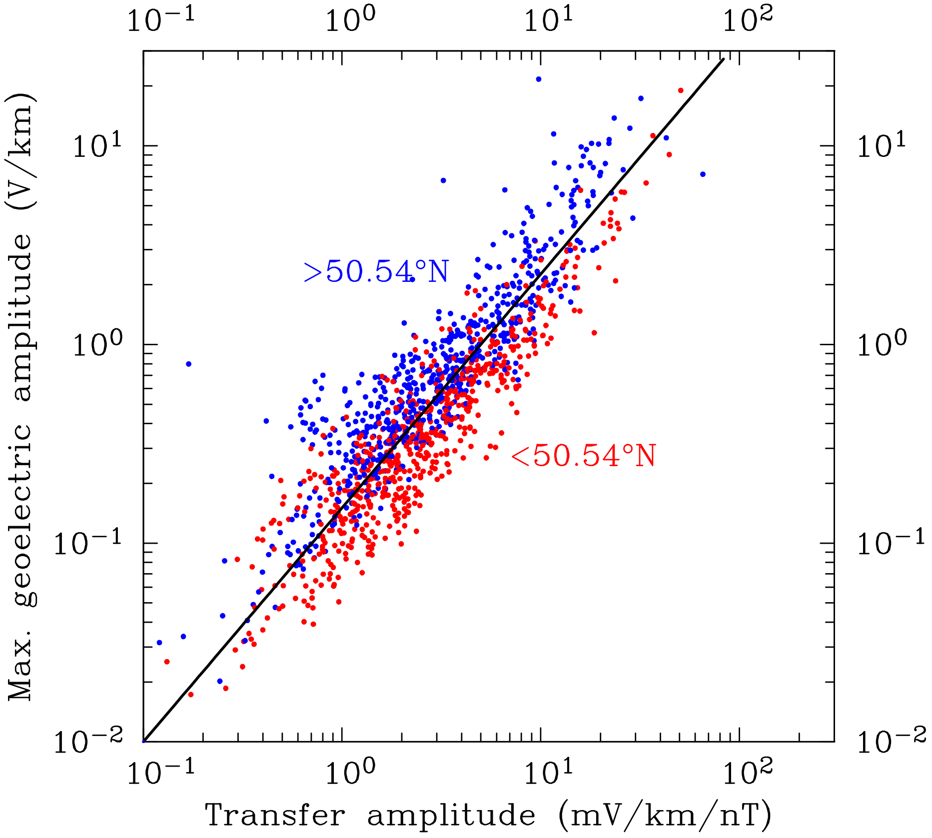
(b) March 1989 power−grid anomalies



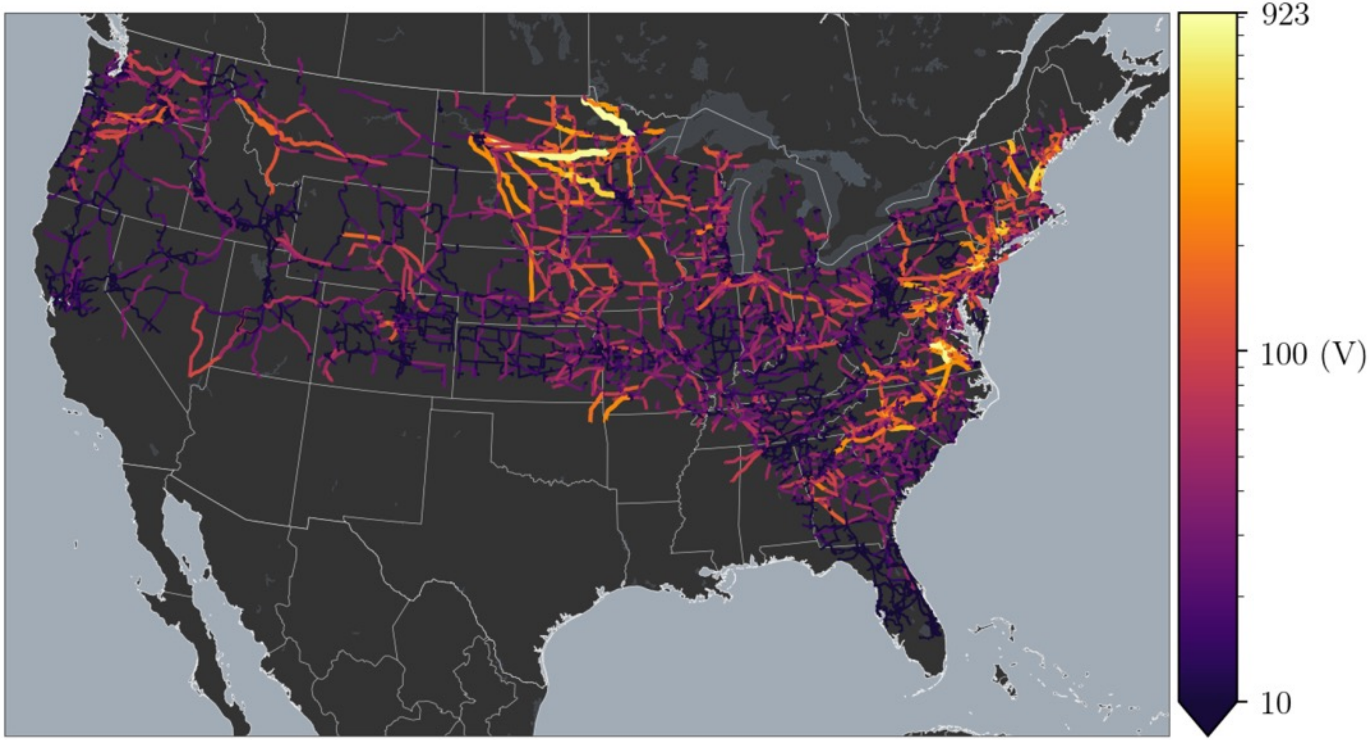
Geoelectric hazards across CONUS are primarily organized by the geography of surface impedance.



But, due to auroral electrojet sources, a weaker organization across geomagnetic latitudes is detectable.



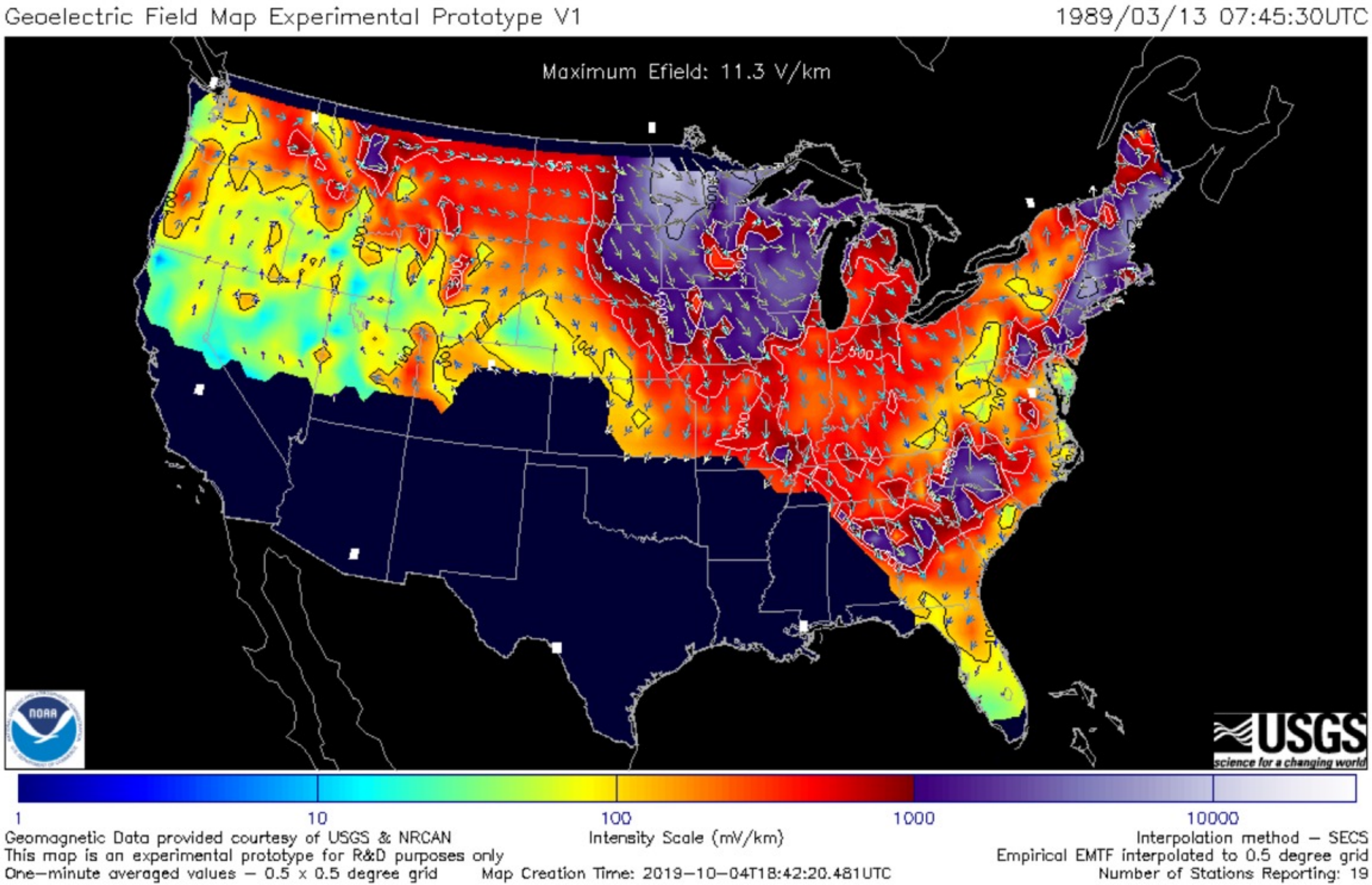
100-year voltages on national power grid.
Where geoelectric hazards are high and where they are low.



Lucas, G. M., Love, J. J., Kelbert, A., Bedrosian, P. A., and Rigler, E. J., 2020, A 100-year geoelectric hazard analysis for the U.S. high-voltage power grid, Space Weather, 18(2), e2019SW002329, doi:10.1002/2019SW002329.

spaceweather.com

Real-time geoelectric hazard mapping project.



Conclusions

- Mapping geoelectromagnetic fields across CONUS during the March 1989 magnetic storm presents challenges related to the sparsity of observatories, the quality of data collected in 1989, and the incompleteness of surveys.
- During the March 1989 magnetic storm, power-grid interference was concentrated where surface impedance is high, and when and where geoelectric amplitudes were high. This observation serves as partial validation of our geoelectric mapping project.
- Grid systems can be affected by during different storm phases, at different local times, and by a variety of ionospheric currents.
- Geoelectric hazards across CONUS are primarily organized by surface impedance. But, due to auroral electrojet sources, a weaker organization across geomagnetic latitudes is detectable.
- This work demonstrates the need for a denser network of geomagnetic monitoring stations across North America, the need for complete magnetotelluric surveying across Canada, and the importance of completing the national magnetotelluric survey of the contiguous United States.
- Much work remains to be done to integrate studies of natural geoelectric hazards with studies of power-grid vulnerability so that proper mitigation can be performed, all so as to improve grid resilience.
- There are possible opportunities for using the geoelectric hazard maps to quantify magnetic-storm risk.