Hazard Analysis of Geomagnetically Induced Voltages Throughout the US Power Grid

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Abstract

Storm-time geomagnetic disturbances induce significant geoelectric fields within the Earth that can adversely affect the operation of electric power grids. The recently completed magnetotelluric survey supported by the NSF EarthScope program (2006-2018) has produced a large public archive of impedance tensors across much of the continental United States (US). In this work, the EarthScope tensors are convolved with long time series of geomagnetic field variation recorded at USGS observatories to obtain estimated time series of historical geoelectric fields. Integrating these geoelectric fields across power transmission lines results in time series of geomagnetically induced voltages on each power line. These voltages are analyzed statistically to construct hazard maps of the maximum voltages that could be realized in transmission lines across the US for an extreme, once in one hundred-year, geomagnetic storm. In combination with grounding resistance data and network topology, these voltage estimates can be utilized by power companies to estimate extreme geomagnetically-induced currents within their networks. These voltage estimates can provide information on which power lines and substations are most vulnerable to geomagnetic storms and can guide power companies in assessments of where to install additional protections within their grid.

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Overview

Storm-time geomagnetic disturbances induce significant geoelectric fields within the Earth that can adversely affect the operation of electric power grids.

http://www.spaceweather.gc.ca

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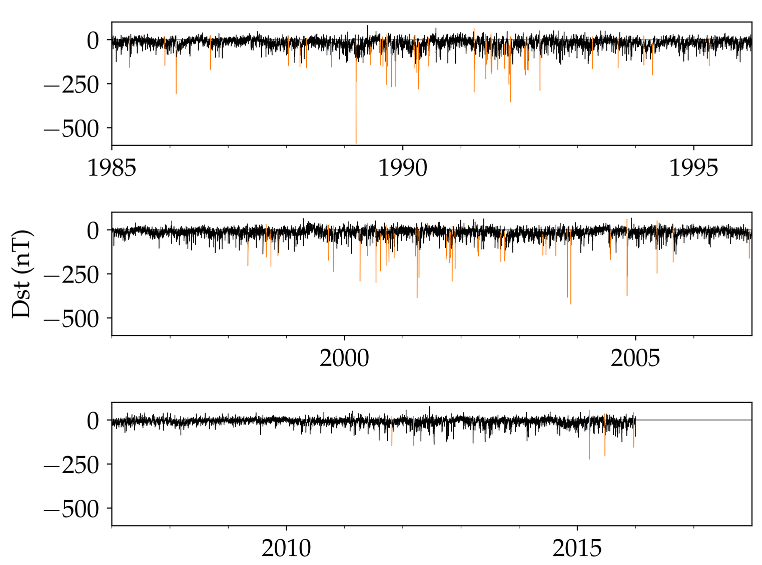
We present a data-driven hazard analysis of voltages that are estimated to happen on-average once-per-century.

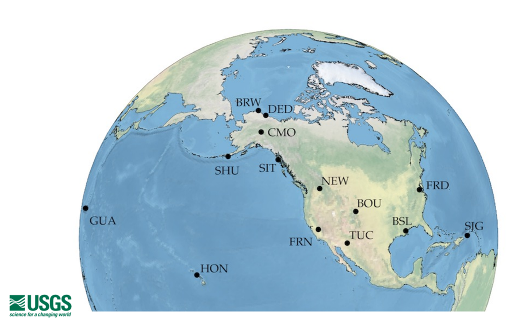
Identifying Storms

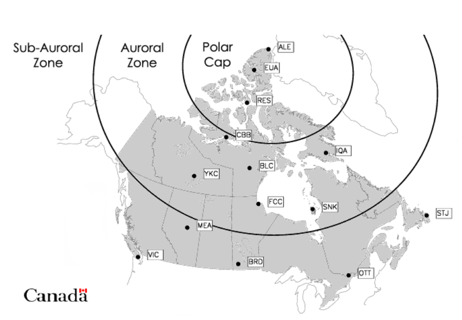
Storms are selected through an iterative process. The minimum Dst in the dataset is selected, and then 1.5 days on each side of this minimum is specified as a storm-time. This is repeated until there are no Dst values less than -140 nT. This process identifies 78 storms from 1985-2015.



Individual Storm Calculations

For each geomagnetic storm identified above, we gather all of the recorded time-series of magnetic observatory measurements from the USGS and NRCan.

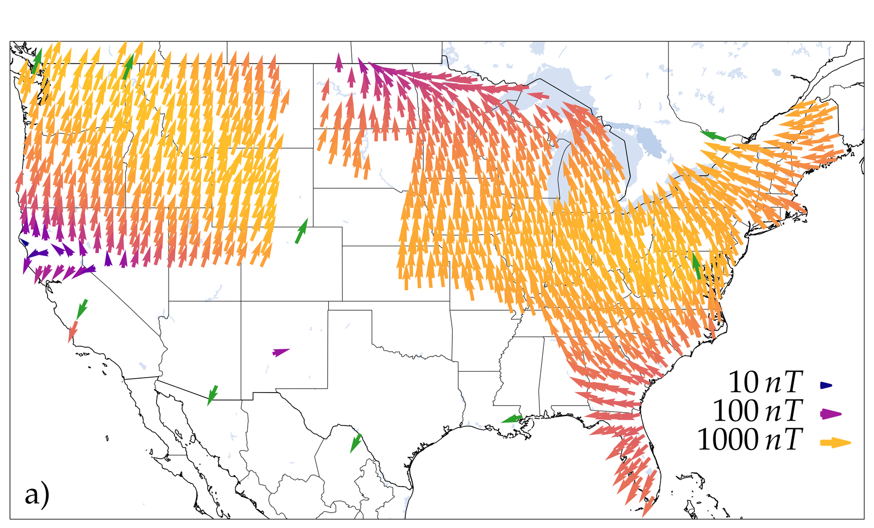




Magnetic Field

We then interpolate these magnetic measurements with SECS basis functions across the US to generate estimated magnetic field time-series at each magnetotelluric (MT) site from the NSF EarthScope Project.

$$\bar{B}_{site} = f(\bar{B}_{obs1}, \bar{B}_{obs2}, \ldots)$$

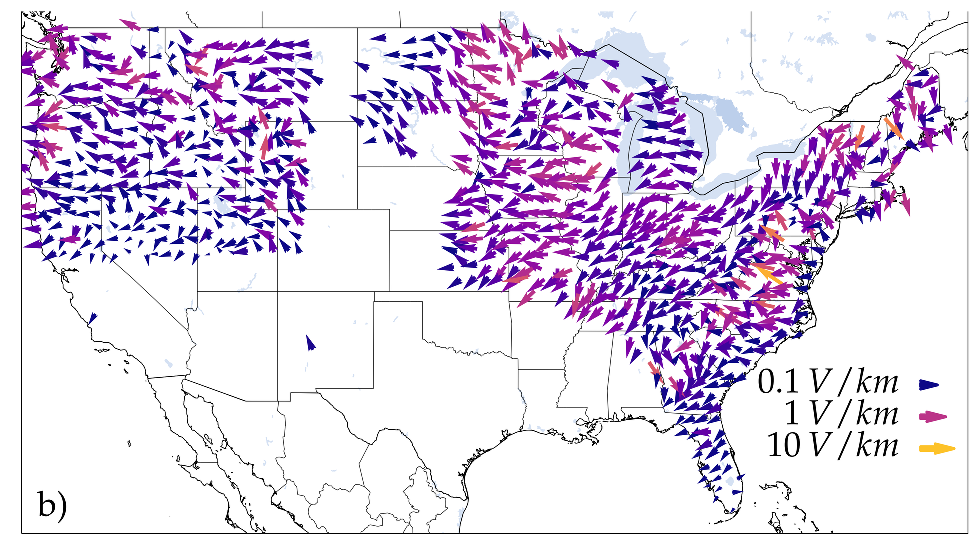


01:00 UTC on March 14, 1989

Electric Field

An electric field time series is produced at each site through a convolution of the local site impedance (related to Earth conductivity structure) with the local magnetic field. Impedance tensors are obtained from the NSF EarthScope Project: http://ds.iris.edu/spud/emtf

$$\bar{E}_{site} = \bar{\bar{Z}}_{site} * \bar{B}_{site}$$



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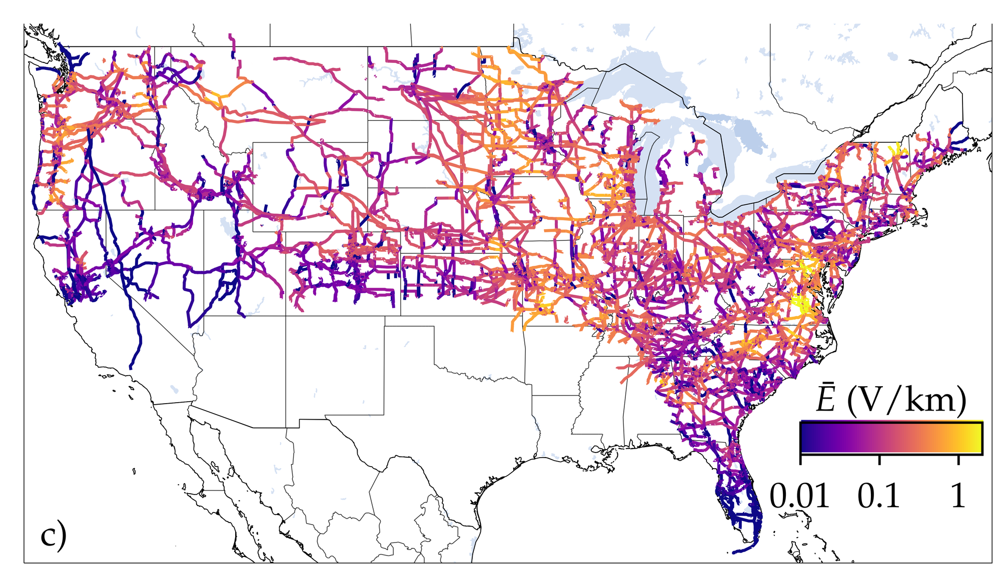
Transmission Line Voltages

The voltage induced in the transmission lines is calculated by integrating the electric fields along the transmission lines

$$V = \int_L \bar{E} \cdot d\bar{l}$$

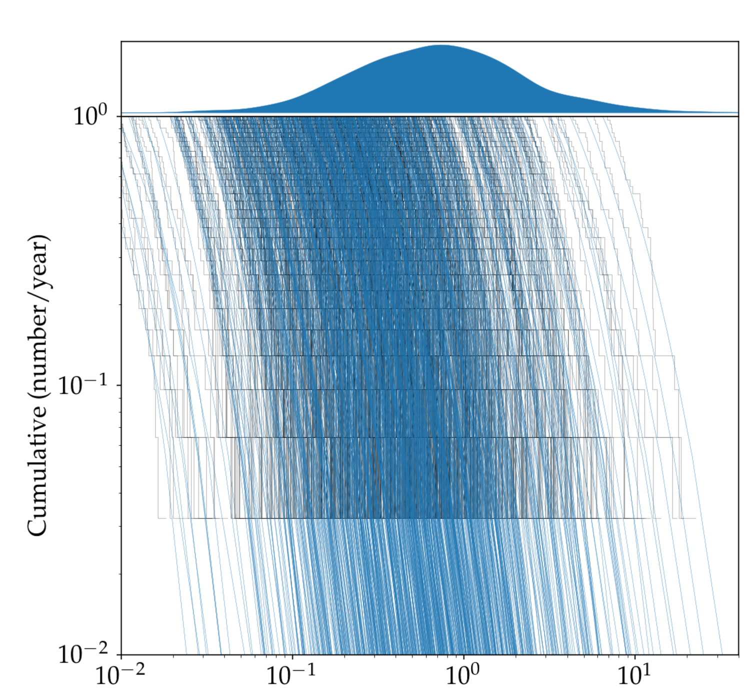


01:00 UTC on March 14, 1989

Plotted is $\bar{E}$ = V/L, to scale the voltages, which produces a better visualization to account for the large disparity in line lengths throughout the US

Statistical Analysis

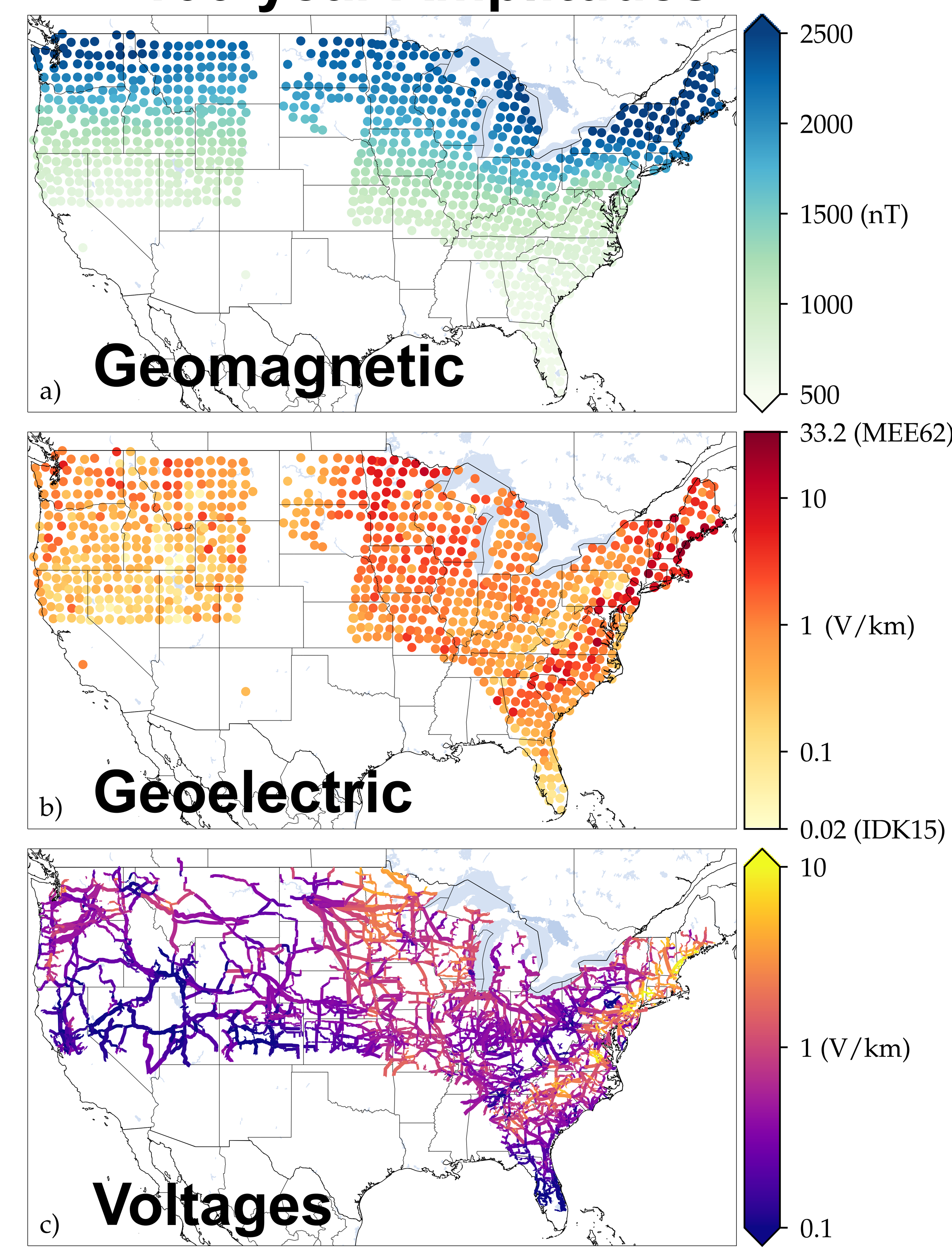
For each storm, the peak amplitude of each quantity is identified at all MT sites. This produces a list of storm maximums at each site that can be viewed as a cumulative distribution. We then fit a lognormal curve to the cumulative from each site to predict the maximum that would be expected on-average once-per-century.



Hazard Analysis

The once-per-century amplitudes viewed across the US, enables stake-holders to identify areas that are more or less prone to geomagnetic storm effects

100-year Amplitudes



a) The magnetic field amplitudes vary by about one order of magnitude, aligned primarily with the N-S geomagnetic poles.
b) The geoelectric hazard spans more than 3 orders of magnitude and is strongly driven by geologic features, although the magnetic trend is still in the data.
c) Large voltages in transmission lines correspond to regions of high geoelectric hazard while also incorporating directionality of the lines into the equation.

Summary

A data-driven statistical approach was used to calculate once-per-century geomagnetic, geoelectric, and transmission line hazards across the US. This data can be used to update benchmarks and standards within the Space Weather and Electric Utility communities.

Get in touch: Greg Lucas, glucas@usgs.gov
All of the data and code are available under open-source licenses for everyone to use. I'm always looking for other collaborations, so please reach out if this interests you!