Understanding, Modelling, and Quantifying the Space Weather Effects of Geomagnetically Induced Currents (GICs) on the Electric Power Grid

UNIVERSITY OF ALBERTA

Ian R. Mann[1]*, Darcy Cordell[1,2], Hannah Parry[1], Stavros Dimitrakoudis[3], Andy Kale[1], David Milling[1]

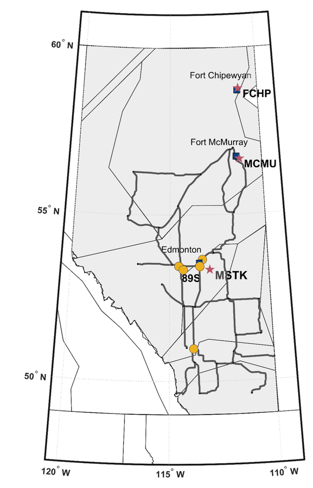
(1) Department of Physics, University of Alberta, Edmonton, CAN (2) Athabasca University, Athabasca, CAN, (3) National and Kapodistrian University of Athens, GRE *imann@ualberta.ca

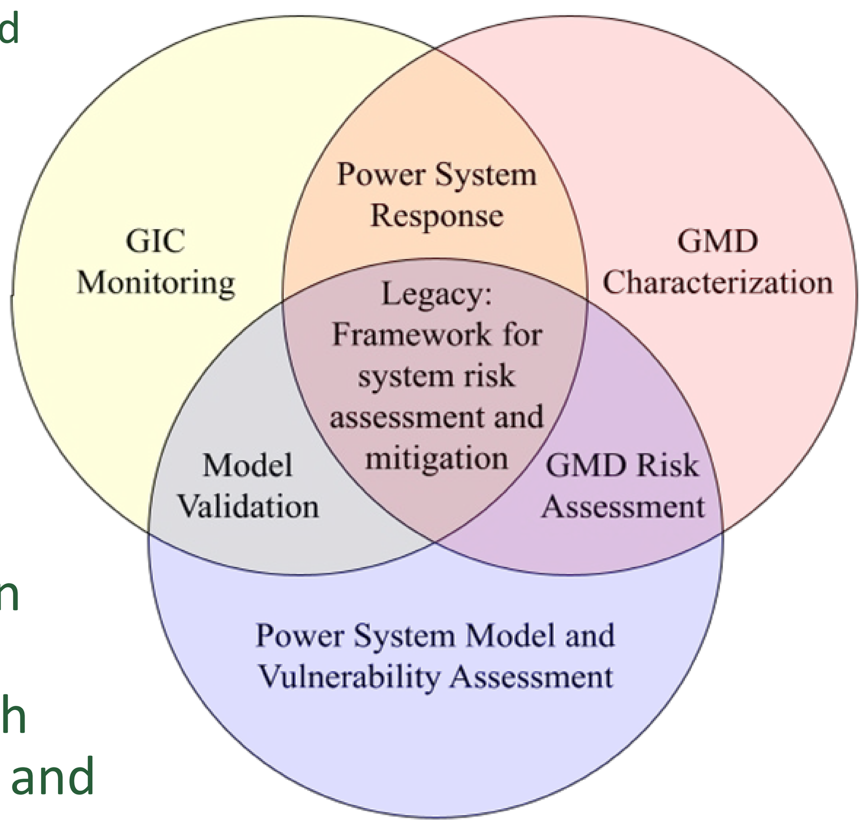
Abstract

Geomagnetic disturbances (GMD) are excited in the geospace system by a range of solar wind and related internal drivers, and whose occurrence rates change on timescales from minutes and hours, to days, months, and years, and through the solar cycle, and indeed from solar cycle to solar cycle. Here we use data from the Canadian Array for Real-time Investigations of Magnetic Activity (CARISMA; www.carisma.ca) spanning more than 35 years of operations to review a variety of solar wind drivers of GMD, and examine the characteristics of the resulting GMD on the ground. In addition, we use a province-scale model of the Alberta electric power grid in Canada to examine the geomagnetically induced currents (GICs) which result from these GMD. We focus on large geomagnetic storms during solar cycle 25, and highlight the characteristics of a number of drivers of the large GMD which also result in large GICs. We further place these characteristics from solar cycle 25 in the context of the historical measurements from CARISMA and whose dataset spans a number of solar cycles. Specifically, we derive the statistics of 1-in-100 year storm magnitudes of not only magnetic but also electric fields using magneto-telluric determined ground impedance tensors. Finally, we provide some perspectives on the interplay between the magnitudes and spatiotemporal variations of the GMD and electric fields on the GICs which result in the electric power grid, including the effects arising from the non-uniform topologies of the networks of conducing infrastructure which comprise real-world electric power grids.

GIC Risk Assessment with Power Industry

Alberta Power Grid





GMD Data

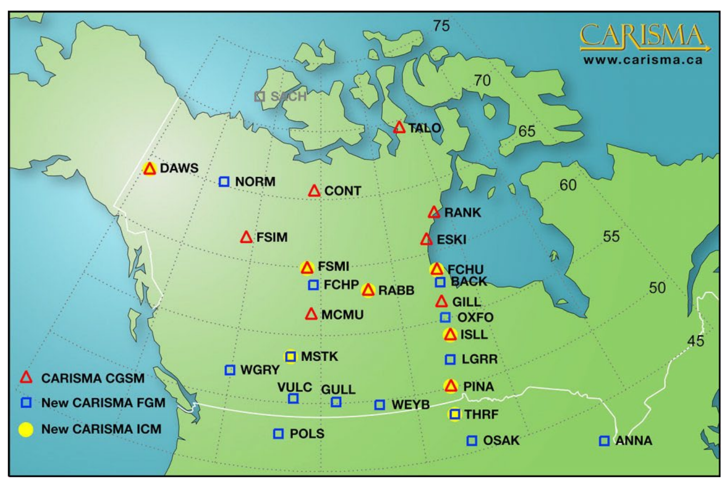
[www.carisma.ca]

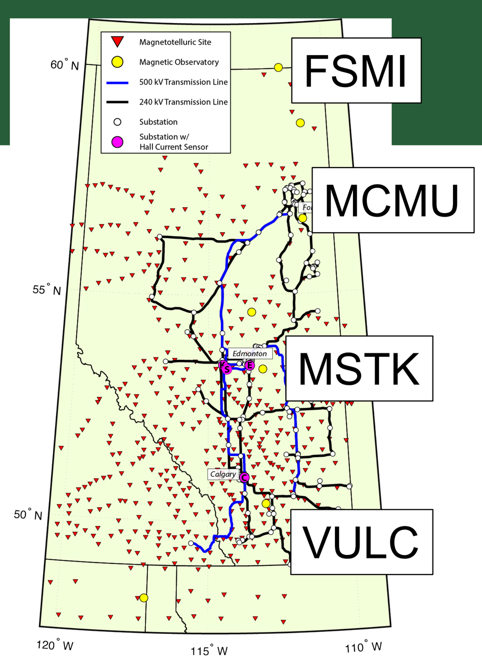
Alberta, Canada.

3-year Canadian NSERC Funded Partnership with Power Industry and Government Regulator

UNIVERSITY OF ALBERTA · ALTALINK · ATCO Electric · aeso

GMD with CARISMA Array; Ground Impedance from MT Surveys in Alberta



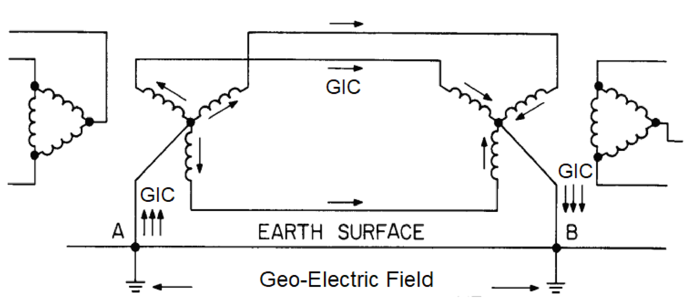


(left) CARISMA magnetometer array stations; (right) Map showing magnetotelluric (MT) and selected magnetometer stations, power network, and transformer neutral-ground Hall sensors in Alberta.

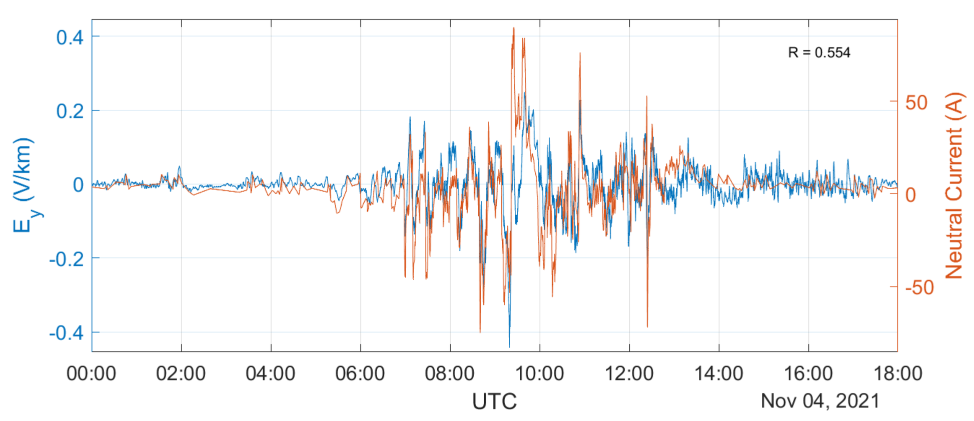
Derived Electric Fields from GMD and Z

The magnetotelluric method is used to estimate the geo-electric field from the impedance tensor, Z, which contains information about Earth's conductivity structure, and the measured magnetic field, B, inferred from CARISMA magnetometer stations.

$$\mathbf{E}(\omega) = \frac{1}{\mu_0}\mathbf{Z}(\omega)\mathbf{B}(\omega)$$

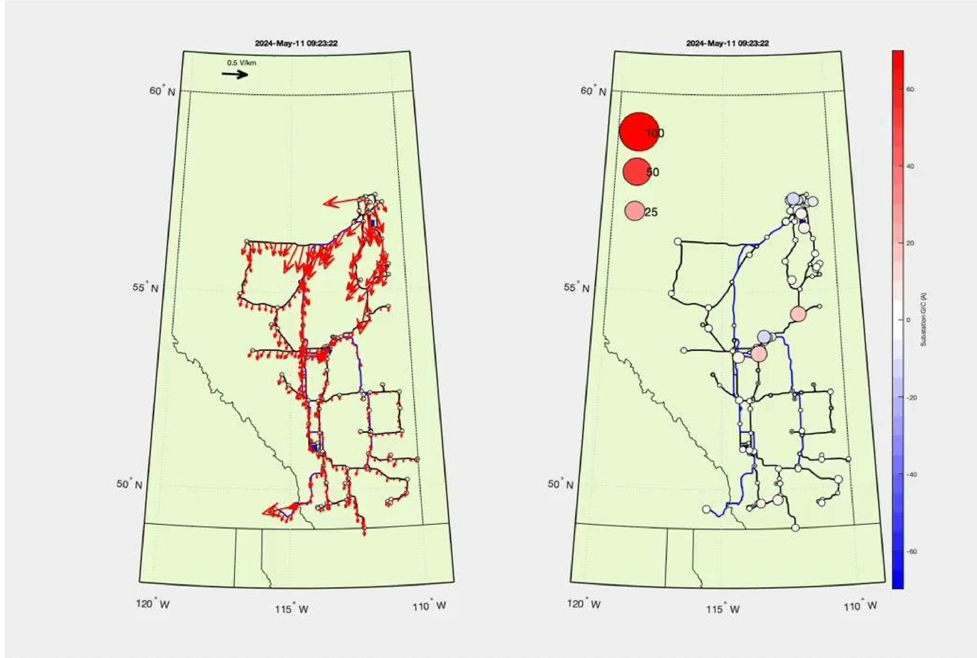


Schematic of GIC flow through high-voltage transmission line, up and down through the grounding points at the transformer neutrals [from Kappenman, 2010].



Local electric field derived using MT impedance and local GMD from MTSK station in the CARISMA array (blue). Measured transformer neutral to ground (TNG) GIC from Hall sensor (blue) (Parry et al., 2024).

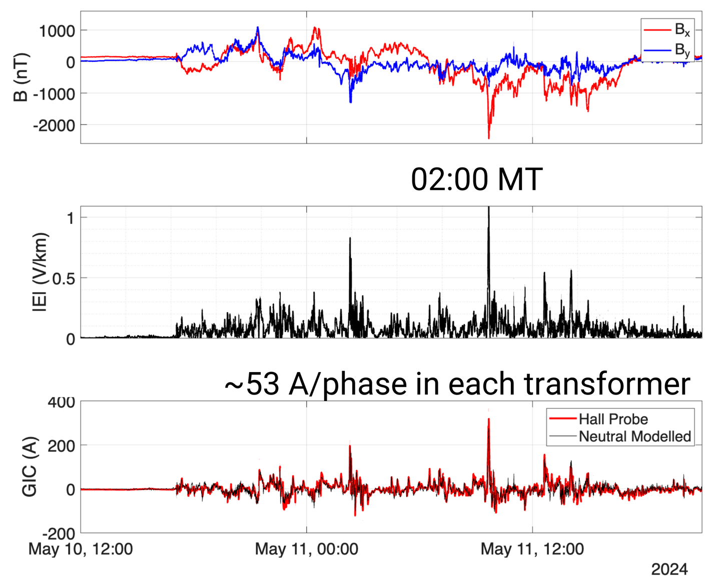
Modelling GIC on Alberta Power Grid

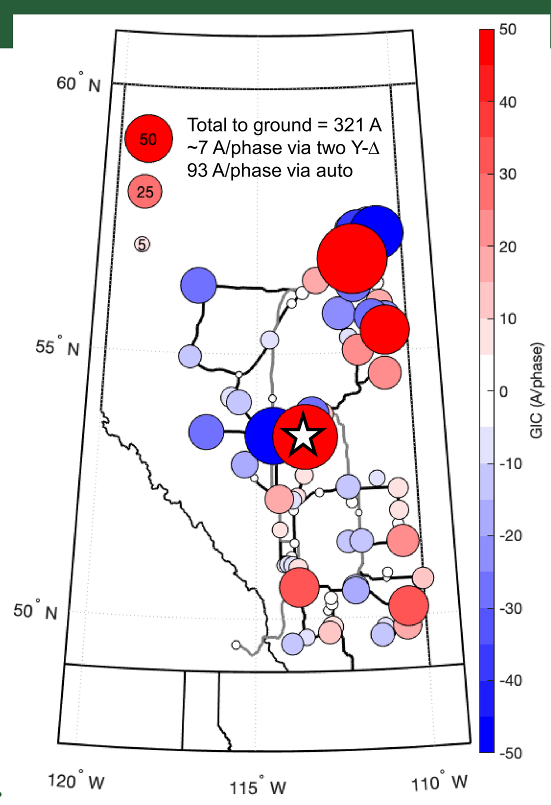


Combining E, determined from interpolated dB and MT impedance, and power network model characteristics allows a model to be used to assess GIC flows in the Alberta grid. Validated using Hall sensor TNG GIC sensor data.

[Cordell et. al, 2021; 2024; 2025; Parry et al. 2024]

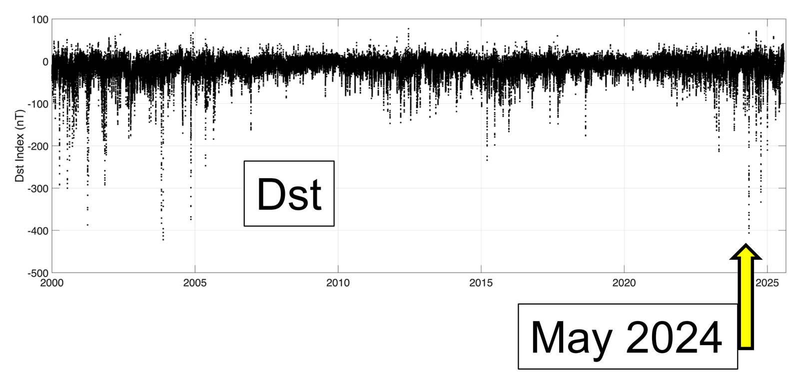
May 10-12, 2024 Superstorm

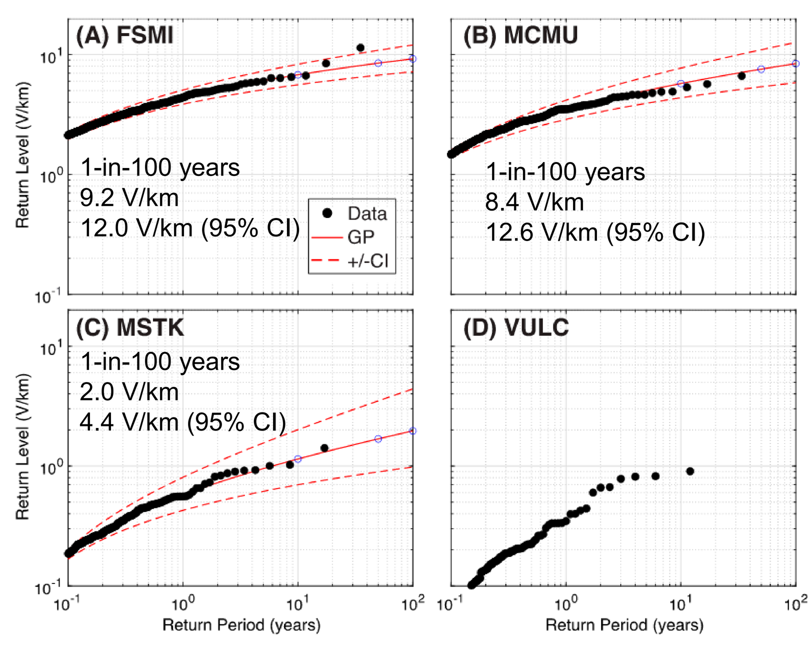




Large GIC close to Fort McMurray (North-East Alberta), a region of large Z, and at transformers near Edmonton.

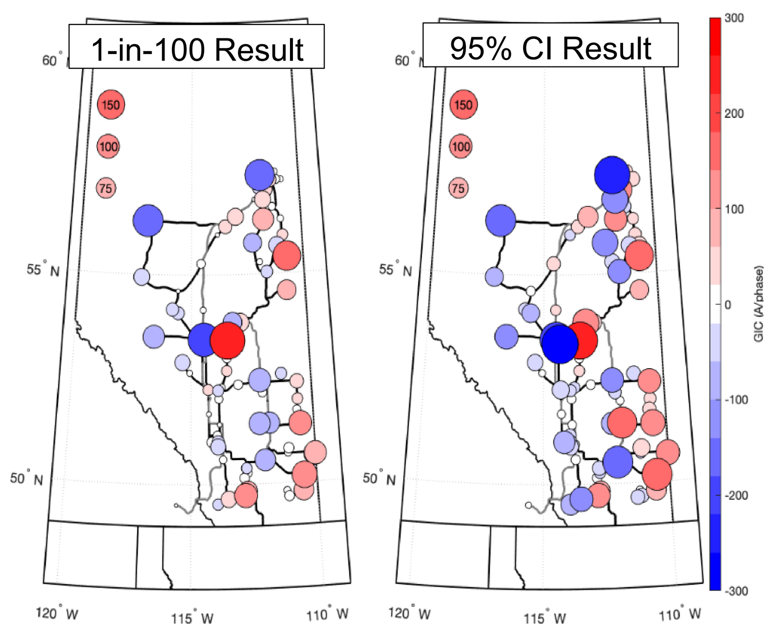
Extreme Electric Field Statistics





Pareto distribution analysis of 1-in-100 year E-field for FSMI, MCMU, MSTK and VULC (Cordell et al., Space Weather, doi.org/10.1029/2024SW004305, 2025).

Extreme Model GIC Statistics



GIC model statistics for network driven by station-by-station extreme electric fields.

- 1-in-100 geoelectric fields
  - 9 substations >75 A/phase to ground
  - 4 transformers >75 A/phase
- 95% upper CI:
  - 32 substations >75 A/phase to ground
  - 24 transformers >75 A/phase

1-in-100 yr geoelectric fields in Alberta could drive >75 A/phase GIC

Acknowledgements

Thank you to Colin Clark and AltaLink for providing neutral current data and transmission line information for the GIC modelling.

Thanks to the CARISMA team for data. CARISMA is operated by the University of Alberta, funded by the Canadian Space Agency.

Thanks to Prof. Martyn Unsworth, U. Alberta, and his team for MT survey data.