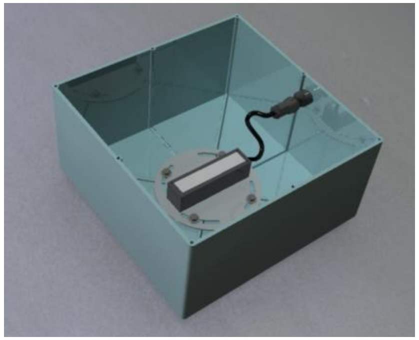
GIC modeling: From the solar wind to power system impacts

JL Gannon

Computational Physics, Inc.

NSF Hazards GMD Project

- NSF award 1520864, focus is on better understanding of GMD impacts on the power grid
- Interdisciplinary
- Academic, Industry and Government partners
- Strongly desire utility participation!
  - One activity is the deployment of four magnetic and electric field monitors with one second resolution
  - At Odessa TX, Univ. Illinois, two other TBD locations in US



Thank you: NSF, EarthScope, USGS, Carisma, McMac

cpi COMPUTATIONAL PHYSICS, INC.

NSF Project Team

PI: Tom Overbye, UIUC

University of Illinois, Urbana-Champaign: Farzad Kamalabadi, Jonathan Makela, Hao Zhu, Mark Butala, Komal Shetye

Computational Physics, Inc. : Jennifer Gannon

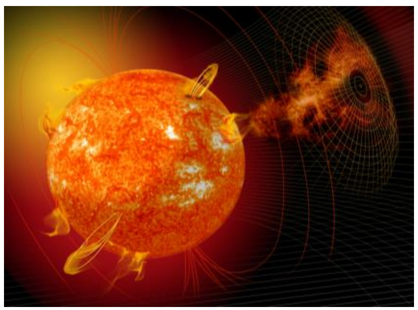
Virginia Polytechnic University : Zhonghua Xu

Colorado School of Mines : Andrei Swidinsky, Stephen Cuttler

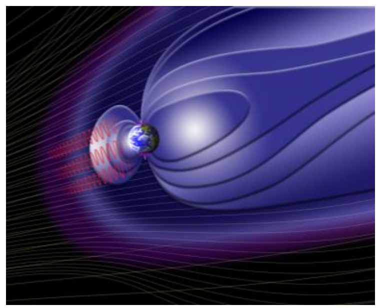
Advisors/Consultants : Chris Balch (NOAA-SWPC), David Boteler (NRCAN), Peter Fernberg, Michael Henderson (GICMagnetics)

GIC Impacts

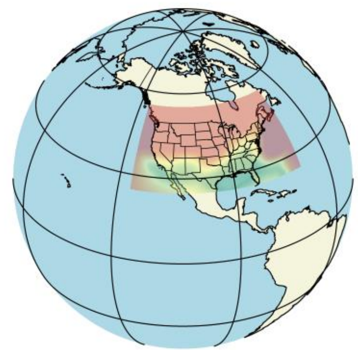
Solar Wind Drivers



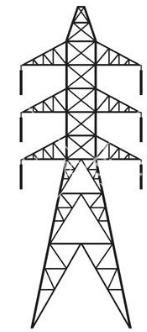
Currents in the Magnetosphere-Ionosphere System



Geomagnetic Fields and Induced Electric Fields at Ground-Level



GICs induced in long conductors



This project incorporates cross-disciplinary studies spanning the solar wind drivers through direct system impacts.

Four project components: Geophysical Analysis, Instrumentation, Predictive Studies, and System Modeling

Predictive Modeling

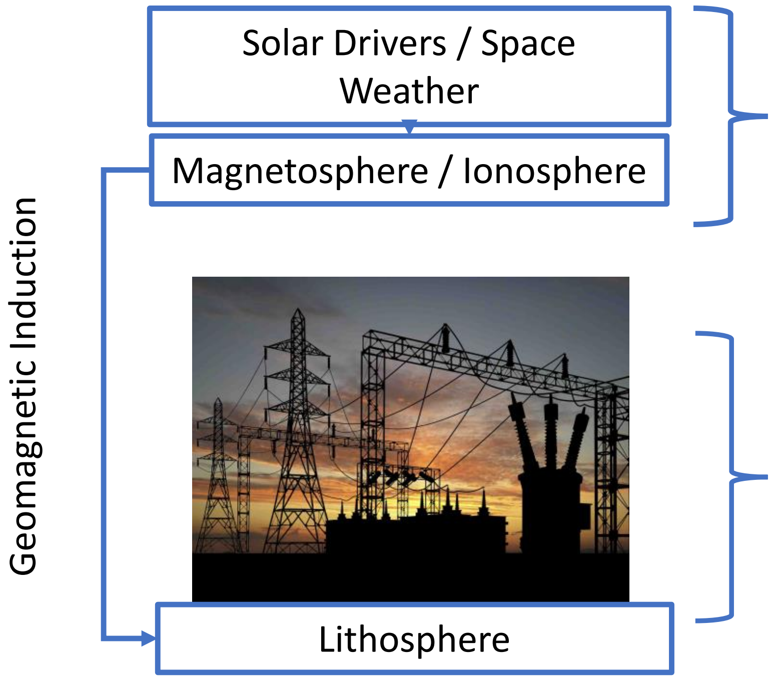
Two parallel projects: Virginia Tech and UIUC

1. Virginia Tech – Correlation studies between the solar wind and ground based magnetic field.
2. UIUC – Machine learning and advanced statistical techniques.

These independent projects complement and inform each other.

Predictive Modeling - UIUC

Physical Parameters Controlling Induced Geoelectric Currents Are Routinely Measured



Magnetic field, solar wind composition and velocity from:

- SOHO, STEREO, SDO (Sun)
- ACE and DISCOVR (L1)
- DMSP, others (In-Situ)

Relevant measurements on the ground include:

- Magnetometer (magnetic field)
- Geoelectrical field monitor (electric field)
- Geomagnetically induced current monitor (current)
- Lithospheric conductivity (electric conductivity)

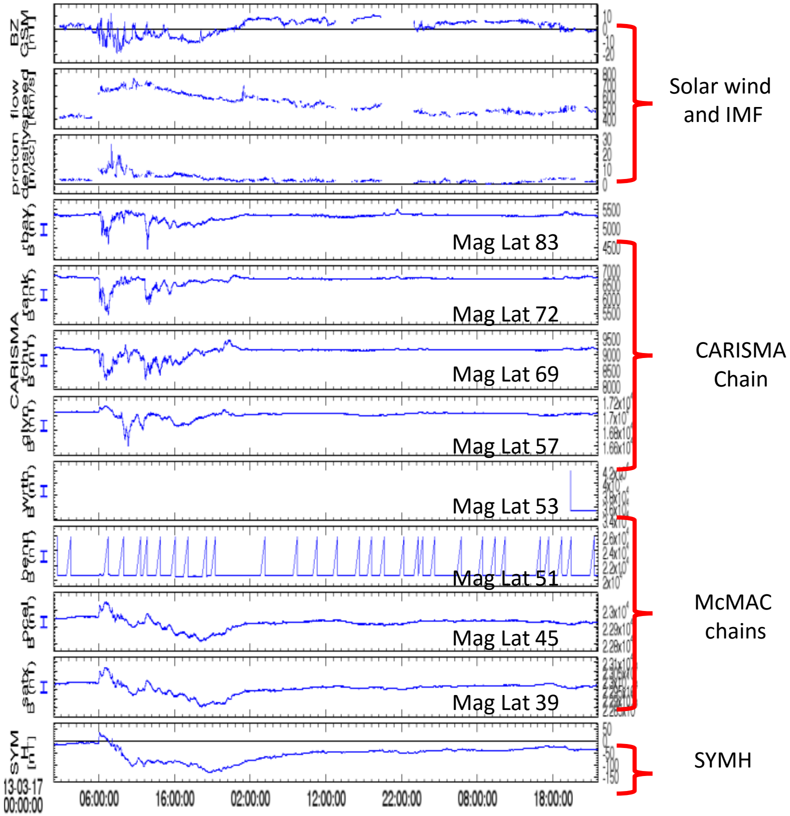
Predictive Modeling - UIUC

- Statistical Prediction Fills Measurement Record Gaps

- Currently available data is sparse
  - Sparse spatial coverage of magnetic field sensors
  - Intense solar storms are rare

- Forecast geomagnetic storm impact by modulating geo-effective input to current conditions:
  - Interplanetary magnetic field Bz
  - Earth axial tilt (season)
  - Position within 11-year solar cycle
  - Storm intensity and other conditions

Predictive Modeling – Virginia Tech



Investigating the magnetic field variation responding to the large geomagnetic storms, for example the St. Patrick day storm on 2013-03-17.

Correlations between solar wind features and specific GIC-relevant spectral components of B on the ground.

What is the scale length of magnetic field fluctuations vs. frequency and latitude?

Instrumentation – Space Hazard Monitor

Magnetic field and electric field sensors.

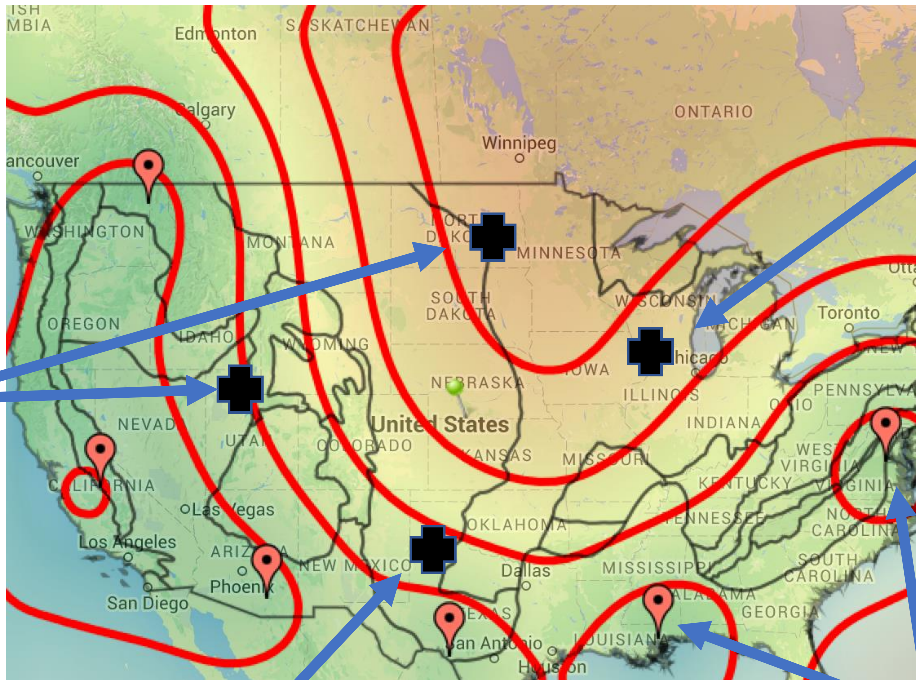
Design emphasis on real-time stability and reliability (< 1 second data latency), with specific application to power grid hazard monitoring.

Off-grid power and Communications

Integrates with CPI's AVERT GIC Hazard and equipment monitoring tools

COMPUTATIONAL PHYSICS, INC.

Instrumentation: SHM Site Installations



SHM 2: UIUC

SHM 3,4: TBD locations

SHM 1: Odessa, TX

USGS observatories

Four installation sites under NSF grant, with public access to real-time data.

Additional commercial installations at utility locations (TBD).

Looking for utility (or other) partners for site 3 and 4, with emphasis on filling operational gaps. Contact Jenn Gannon (gannon@cpi.com) for more info.

COMPUTATIONAL PHYSICS, INC.

Instrumentation – First Installation

.

First installation near Odessa, TX on May 7-8, 2016.
1. Magnetic and electric field instruments
2. Installation will be on-site at utility partner location; ~100m from transformer assets.
3. Also performing secondary validation measurements at a very magnetically quiet site ~25 miles away; This will provide validation of measurements from primary installation, as well as magnetotelluric (MT) information for conductivity models.

For access to this data, please contact Jennifer Gannon (gannon@cpi.com)

Potential issues:
1. We expect noise in the magnetic field time series due to proximity to transformers. HydroQuebec has successfully placed magnetometers this close to substations, but it is not for detailed or scientific level analysis. It is unknown how accurate the electric field measurements will be this close to a substation.
2. There may be difficulties in the long-term deployment of electrodes in very dry locations. For proper functioning and electrode contact with the soil, moisture is required. We will be testing methods of maintaining proper conditions.

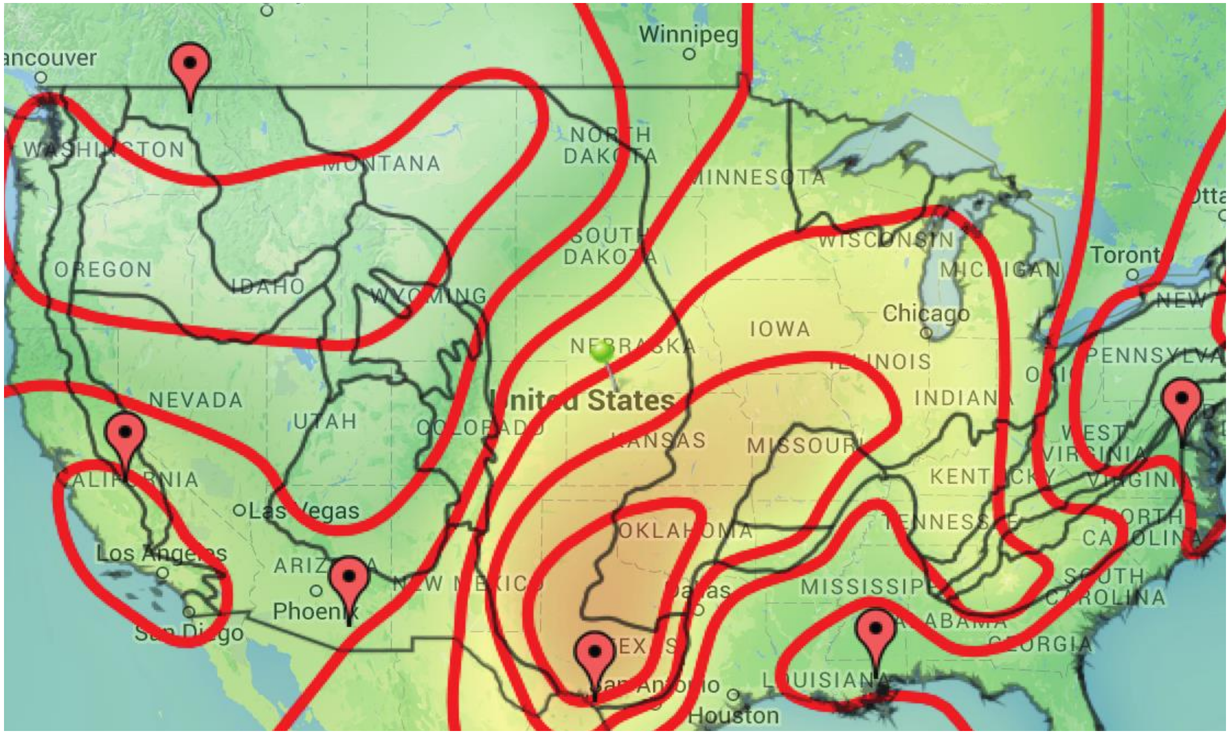
Geophysical Analysis

Calculation of electric fields from:

Magnetic field observations

Magnetic field models

Conductivity models

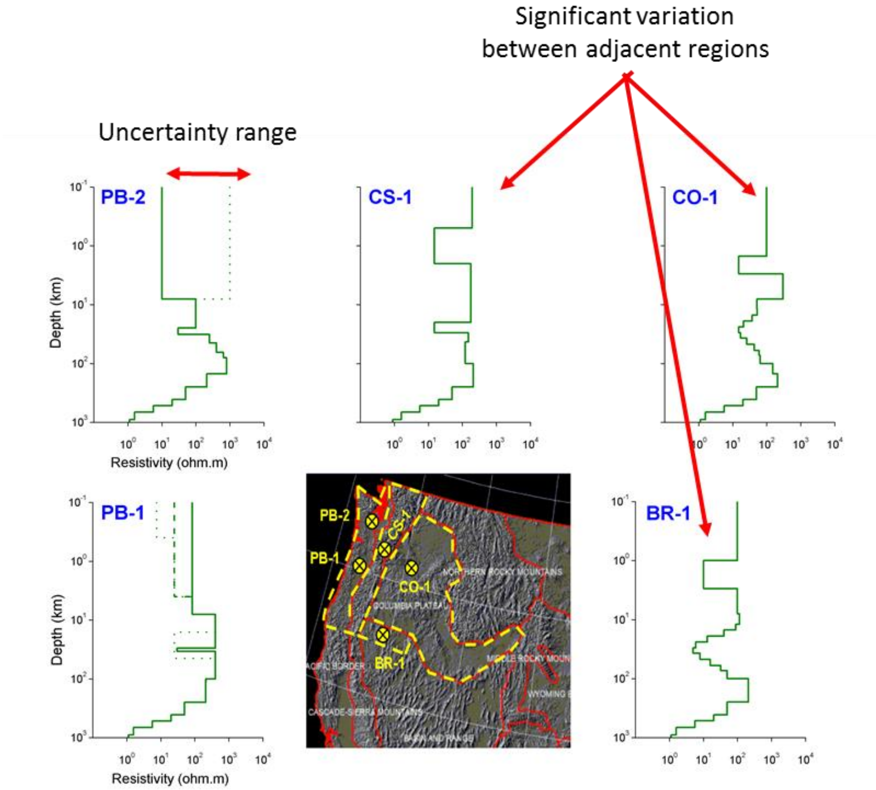


Real-time GIC hazard indicators @ http://gmd.cpi.com

COMPUTATIONAL PHYSICS, INC.

Geophysical Analysis: Validation of Methods and Models

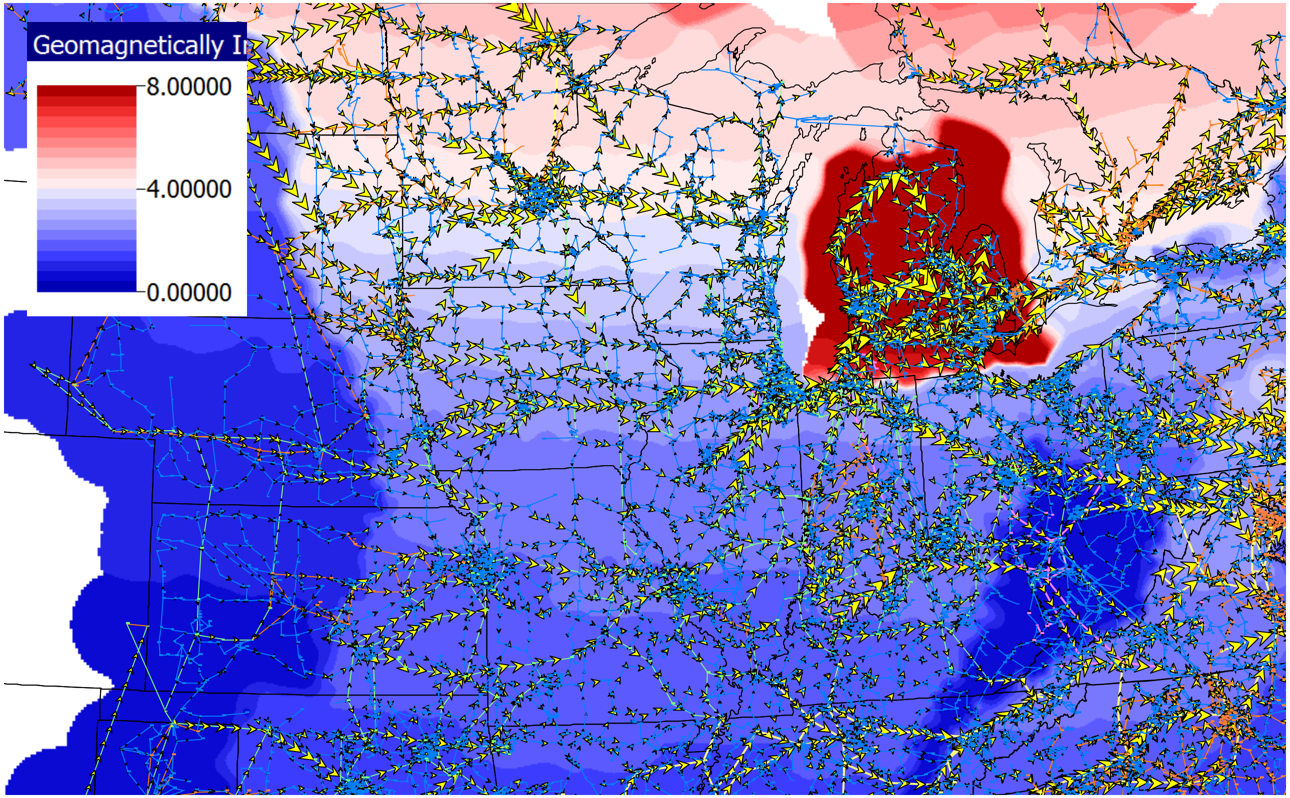
- ***How much does 3D conductivity contribute?*** Comparisons of electric field calculations using 1D, 2D and 3D conductivity models from increasingly complex geology, using historical magnetic storm data.
- ***Are the estimation methods for E equivalent?*** Comparisons of electric field calculation algorithms and methods (time domain, frequency domain, wavelet).
- ***Do estimates match reality?*** Validation using available and newly measured magnetic and electric field data.



From Fernberg et al., EPRI, 2012

COMPUTATIONAL PHYSICS, INC.

System Models: Non-Uniform Electric Field Results

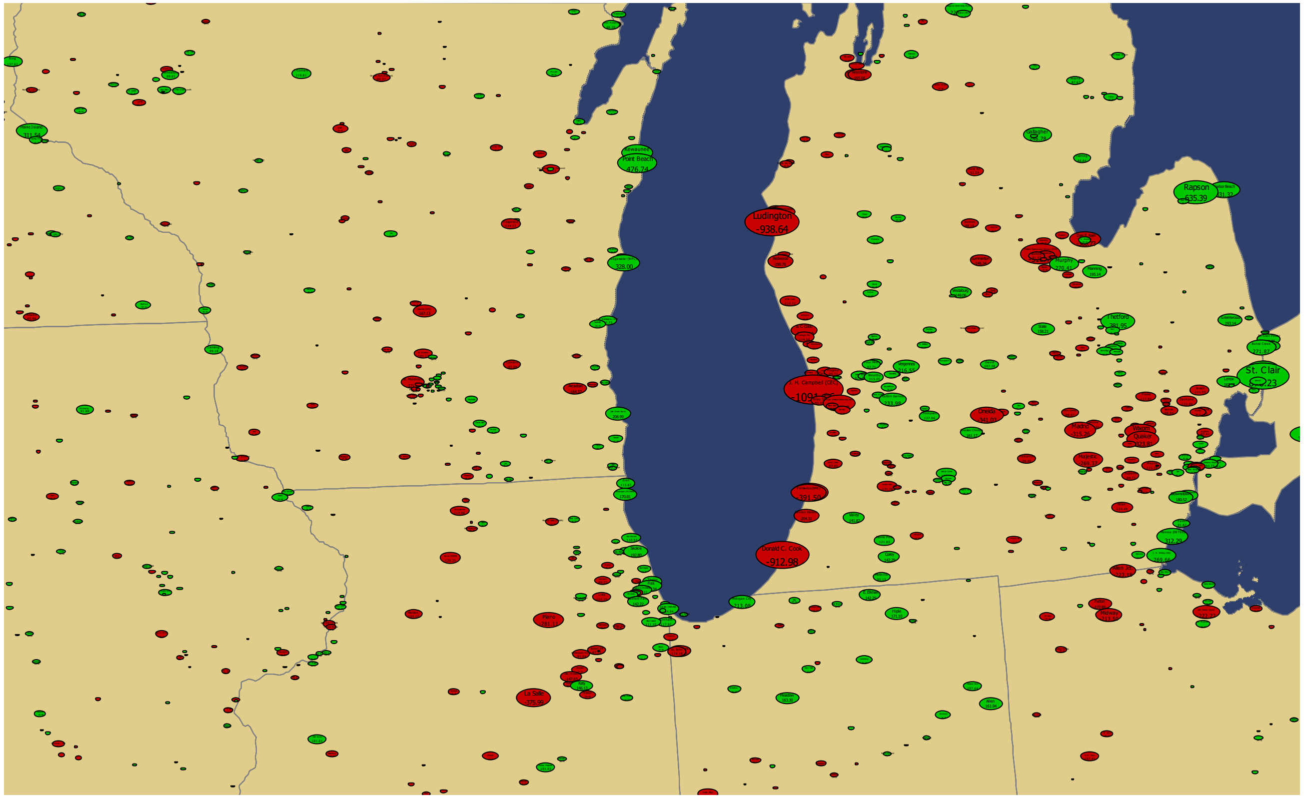


Contour shows the assumed electric field; yellow arrows show the GICs

Results are for illustration only and not represent an actual GMD event

COMPUTATIONAL PHYSICS, INC.

System Models: Geographic Data Views can Automatically Visualize Results

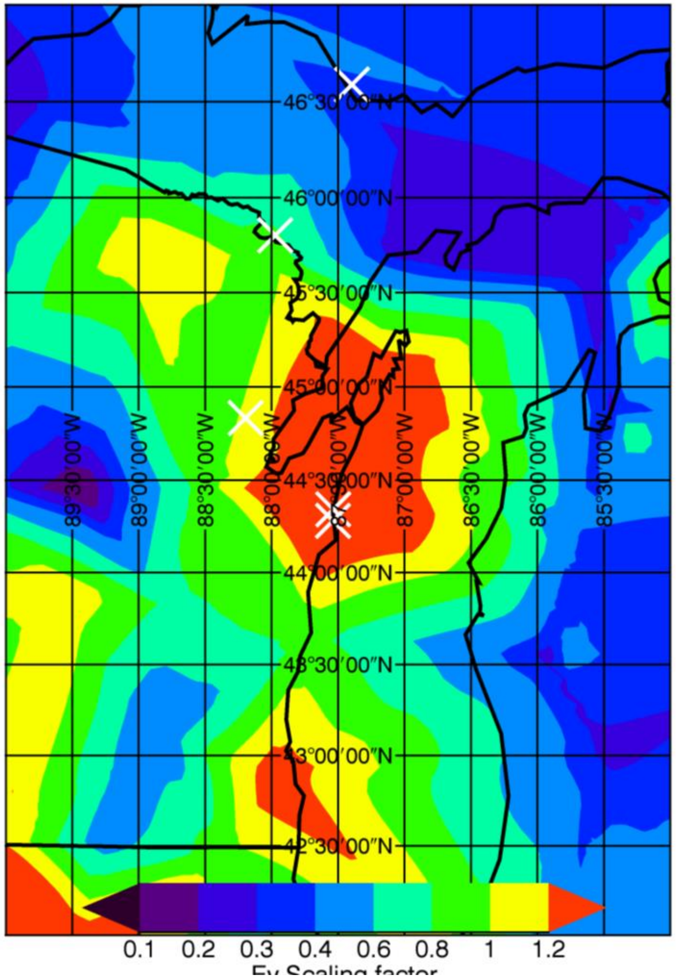


Results are for illustration only and do not represent an actual GMD event

Ovals show the substation neutral GICs, with size proportional to value and color direction (red into sub, green into ground)

COMPUTATIONAL PHYSICS, INC.

System Models: Wisconsin example



Calculation of electric field using modeled magnetic fields and 3D Earthscope impedance tensor transfer functions.

GIC data shows anomalous readings at one station.

Combining electric field simulations with system models to assess impacts.

COMPUTATIONAL PHYSICS, INC.

Common difficulties in GIC analysis

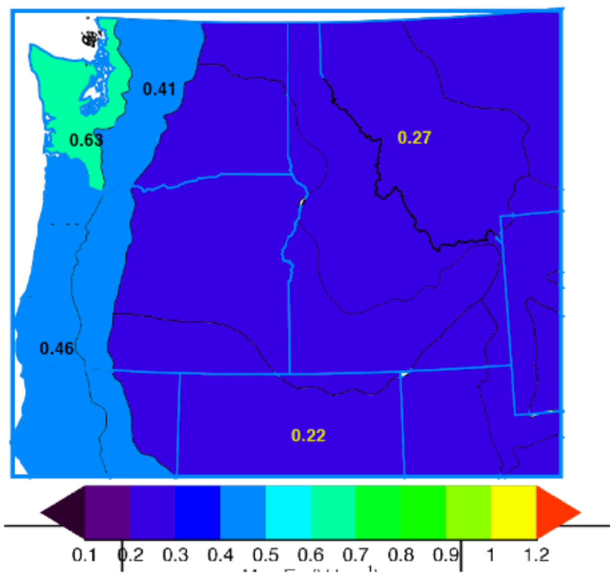
- Public data availability for hazard analysis
- Access to validation data
- Access to system models or test cases
- What does this really mean for the utilities and what can they do with the information?

Through this project, the following will be publicly available:

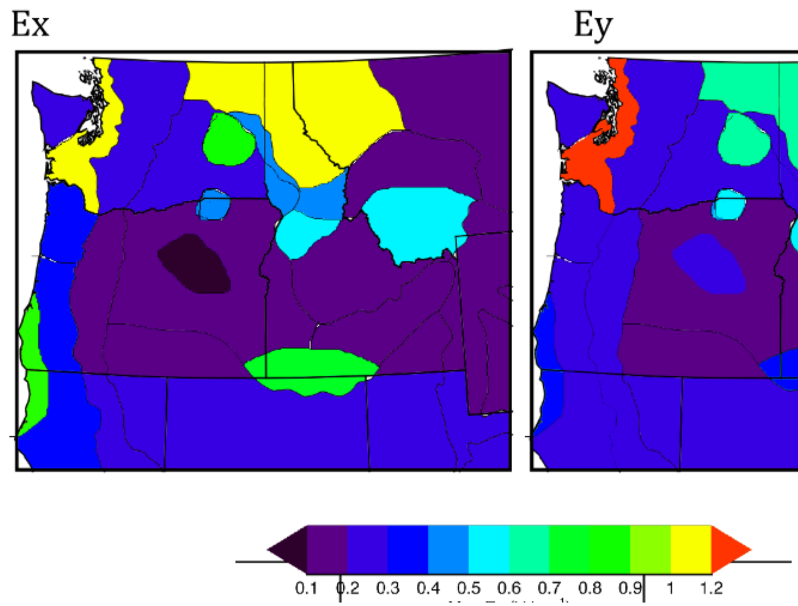
- Geophysical data from four SHM stations
- Results from validation efforts
- Better understanding of direct impacts for system operators

Thank you.

Geophysical Analysis



Conductivity scaling factors using NERC guidelines

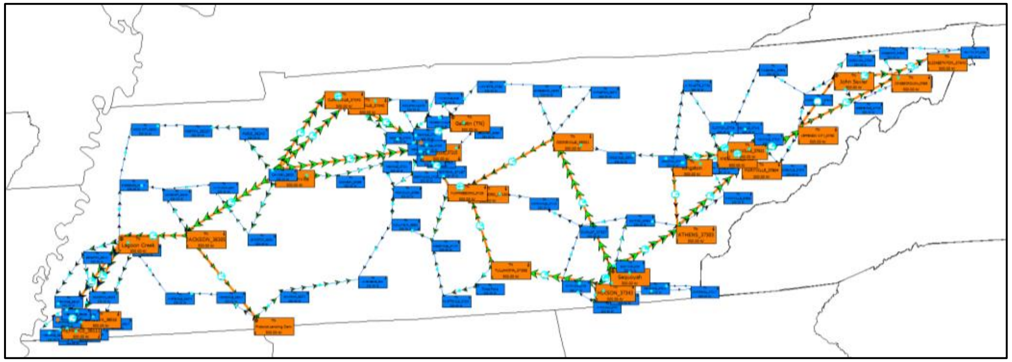


Conductivity scaling factors derived from Earthscope data

COMPUTATIONAL PHYSICS, INC.

System Models: GMD Synthetic Cases

- GMD software comparison is limited by the availability of public cases
- This is being address by a new ARPA-E project in which the goal is to create large-scale, geographic synthetic cases that can be freely distributed
- Below image shows a prototype 150 bus case



Cases with up to 100,000 buses will be created

COMPUTATIONAL PHYSICS, INC.