NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Geomagnetic Disturbance Mitigation

Guidance, Reliability Standards and Research

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RELIABILITY | ACCOUNTABILITY




About NERC: Mission

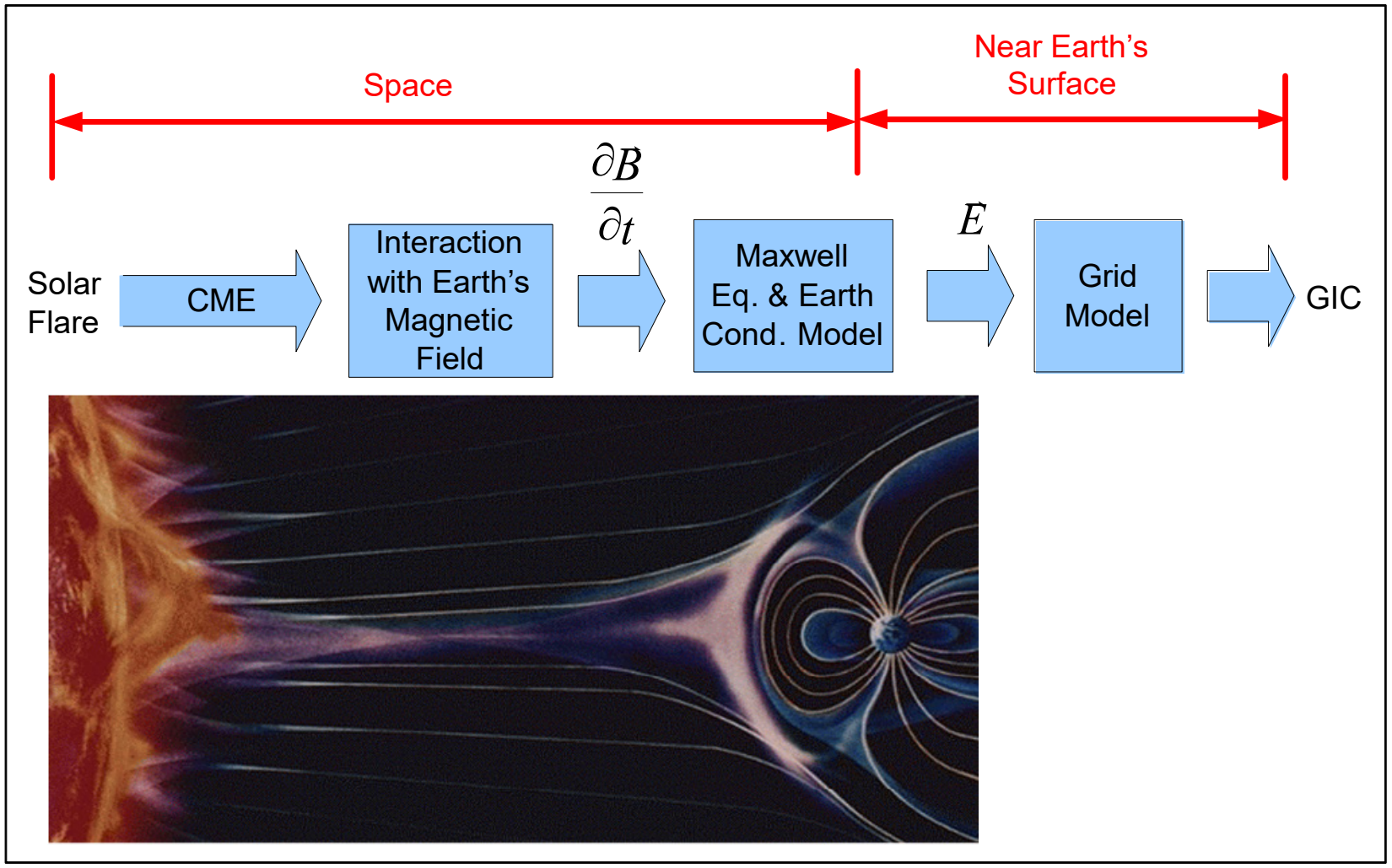
To ensure the reliability of the North American bulk power system

- Develop and enforce reliability standards
- Assess current and future reliability
- Analyze system events and recommend improved practices
- Encourage active participation by all stakeholders
- Accountable as ERO to regulators in the United States (FERC) and Canada (NEB and provincial governments)

Vision for Mitigating GMD Impacts

- The ERO Enterprise reduces risks to the Bulk Power System from severe GMD events through evolving efforts:
  - Reliability Standards
  - Partnerships to pursue leading-edge research and tool development
  - Development of data collection programs
- NERC works with diverse stakeholders throughout North America to carry out its vision
- Carry out the charge
  - The Department of Energy-NERC report on *High-Impact, Low- Frequency (HILF) Event Risk* (2010) analyzed rare risk scenarios
    - Cyber Attack
    - Coordinated Physical Attack
    - Geomagnetic Disturbances (GMD)

Geomagnetic Disturbances



System and Transformer Impacts

- System
  - Transformer saturation
  - Overloading capacitors
  - Incorrect protection system operation
  - Static compensators, DC links, other electronics (e.g., Inverters)
- Transformer
  - Overheating
  - Reactive power consumption
  - Voltage distortion

The amount of heating that develops in the windings and structural parts of a transformer depends on:

- Magnitude, frequency, and duration of GICs
- Geology
- Design

The loss of life from GIC to a transformer is dependent on:

- Transformer condition
- Past Performance
- Operational Loading

Transformer Impacts

- When power systems experience significant GIC:
  - Transformers experience half-cycle saturation
  - Protection and control devices may experience elevated harmonic distortion and increase the risk of current-transformer saturation
- GIC leads to incorrect or undesired operation of protection and control devices
  - Unintentionally isolating equipment at times when it provides critical support to the system
- SVCs and capacitor banks are also vulnerable to harmonics if the protection device operates on peak

Guidance

NERC Conclusions from 2012 Task Force Report

Major Conclusion No. 1	• *Most likely result from a severe GMD event in North America will elevated risk voltage instability or collapse*
Major Conclusion No. 2	• *System operators and planners need analytic tools and information sharing to understand impacts and develop mitigation strategies*
Major Conclusion No. 3	• *Some transformers may be damaged or experience reduced life, depending on design and current health*

Task Force Developed a Series of Guidance Documents for Planners

Application Guide for Calculating GIC in the Bulk-Power System

- Describes theory and details to perform GIC calculations or explain the basis of commercial products

GMD Planning Application Guide

- Describes recommended approach for performing GMD system and equipment impact studies

Transformer Modeling Guide

- Provides a generic magnetic model for planners to use in the absence of a manufacturer validated model
- Testing and model validation of limited assets began in June 2013

Guide for Assessing GIC Mitigation Measures

- Provides a recommended approach for evaluating system effects of hardware mitigation measures

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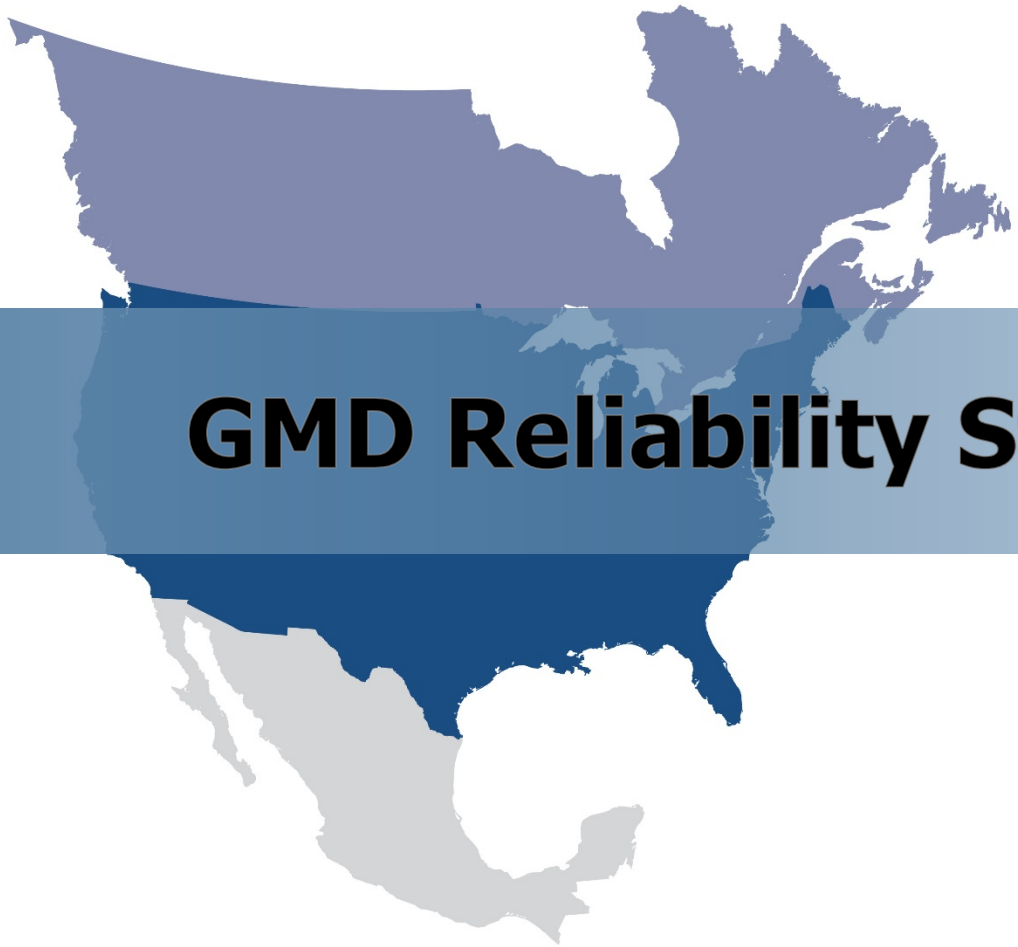
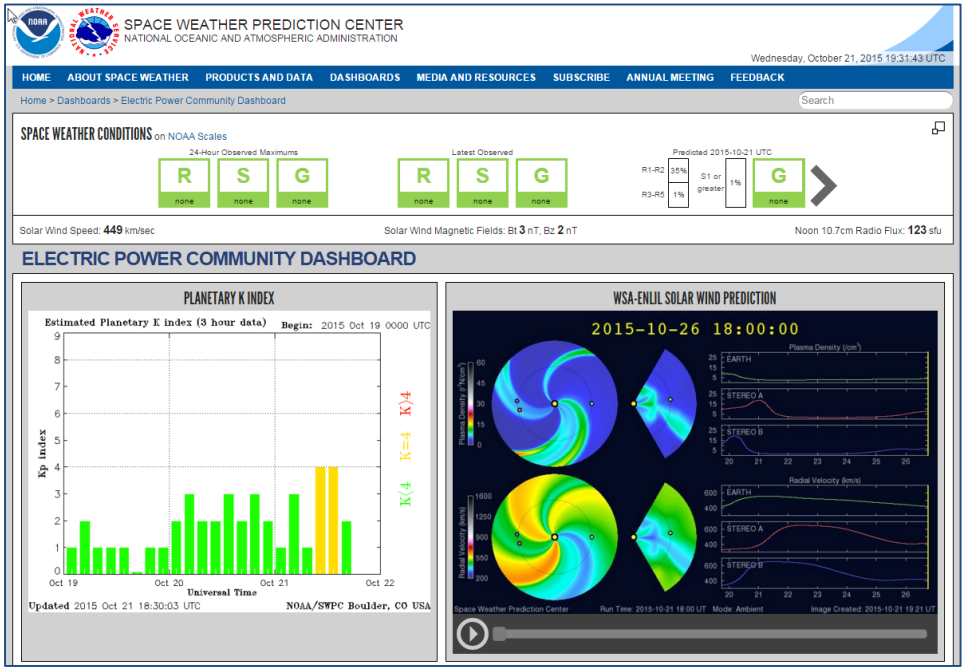


GMD Reliability Standards

EOP-010-1: Operating Procedures

- Requires grid operators to have procedures for mitigating GMD impacts
  - Increased situational awareness
  - System posturing
  - Reconfiguration

- Operators receive alerts from NOAA Space Weather Prediction Center and Space Weather Canada



www.swpc.noaa.gov

Identification		*Notification*				*Mitigation*
CME on the Sun	Magnetic Deviation Detected by ACE	NOAA and STDN Issue Warnings	**Eastern Inter.** MISO RC **Western Inter.** WECC RC	Balancing Authorities Notified	NERC GOP and TOP Functions Notified	Real-Time System Operations Actions Taken

Time

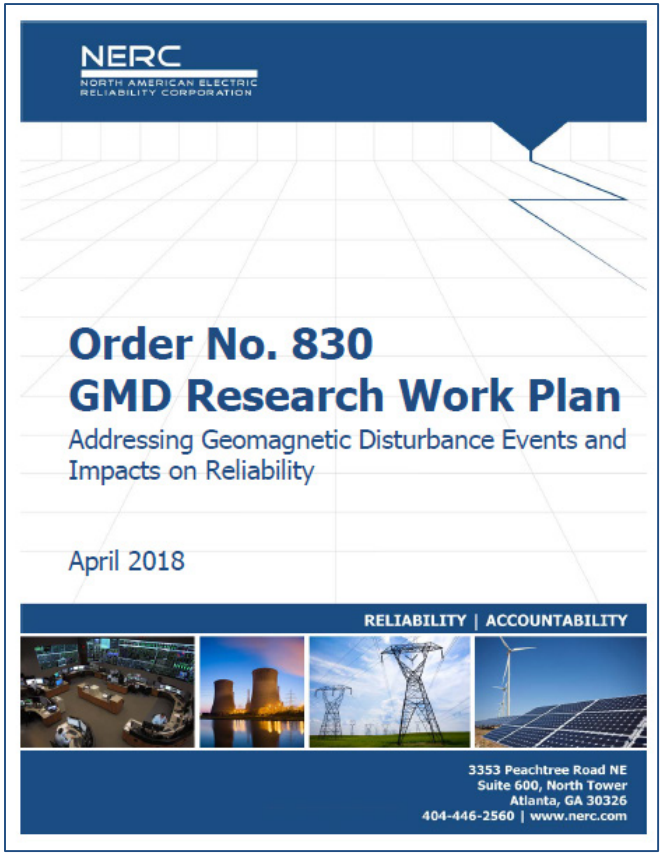
TPL-007: Transmission Planning

- Addresses risks of voltage collapse and equipment damage in the Bulk Electric System (BES) caused by GMD events
- Applicable Entities:
  - **Planning Coordinator (PC) and Transmission Planner (TP)**—perform geomagnetically-induced current (GIC) calculation and network analysis (i.e., Vulnerability Assessments) on Facilities
  - **Transmission Owner(TO)**—that own Facilities
  - **Generator Owner (GO)**—that own Facilities
- Facilities
  - Transformer(s) with a high-side, wye-grounded winding with terminal voltage greater than 200 kV
- Benchmark & Supplemental GMD event
- GMD Vulnerability & Transformer Thermal Assessment
- Corrective Action Plan (CAP)

GMD Research

NERC GMD Research Plan

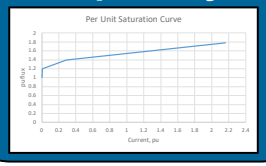
- Federal Energy Regulatory Commission (FERC) Order initiates further actions to address geomagnetic disturbances (GMD)
  - Additional research
  - Data collection
- Two-year research effort with Electric Power Research Institute (EPRI)
  - Funding support from utilities
  - Promotes further knowledge of severe GMD event impacts
- EPRI makes reports and tools available to the public at no charge



NERC GMD Research Plan Tasks

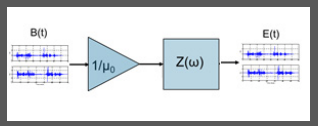
Improved Earth Conductivity Models

Improved Harmonic Analysis Capability

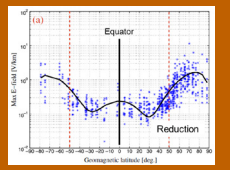


- EPRI Project is scheduled to address specific research objectives by Q1 2020
- Support TPL-007 standard
- EPRI publishes technical reports for each objective

Geoelectric Field Evaluation

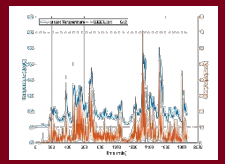


Latitude Scaling Factor



Harmonic Impacts

Transformer Thermal Impacts



Spatial Averaging

$$E_{peak} = 8 \times \alpha \times \beta \text{ (V/km)}$$

α= Geomagnetic Latitude Scaling Factors

β= Conductivity Scaling Factor

Recent Report: Earth Models

- **Task Objective:** Improve the accuracy of earth conductivity models used for GIC modeling
- **Issue:** Deep earth structure strongly affects GMD risk to the BPS
  - Historical Earth conductivity models referenced in TPL-007 need to be validated with new data

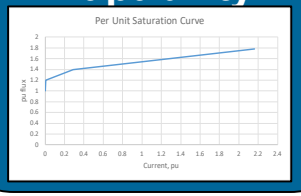
EPRI Report: Use of Magnetotelluric Data to Validate/Improve Earth Models

- **Outcomes:** Updated model regions could improve GMD studies
- **Next Steps:**
  - Evaluation of results is ongoing including GIC measurement comparisons using updated earth models
  - EPRI research team will calculate geoelectric field scaling factors for updated regions (related activity in EPRI Geoelectric Field Tool Evaluation Report)

Recent Tool: Harmonics Assessment

- **Task Objective:** Develop tools for system-wide GMD harmonics assessment
- **Issue:** GIC-related harmonics can impact transformers and equipment needed for voltage support during GMD events
  - GMD Vulnerability Assessments required by TPL-007 include harmonic impacts
  - Industry needs tools and guidelines for wide-area harmonic impact assessments

Improved Harmonic Analysis Capability



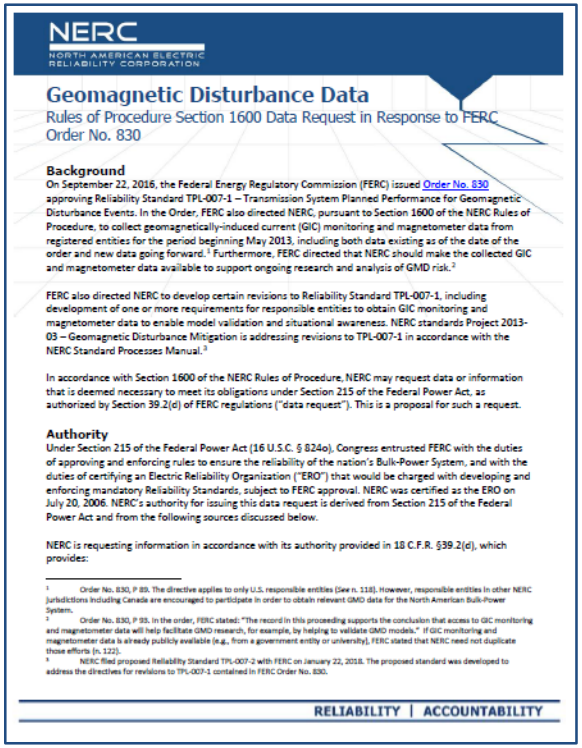
- EPRI released a Beta version of open source software (public)
- **Next Steps:**
  - Incorporate user feedback and enhancements
  - Use tool to examine effects on tertiary winding harmonic heating
  - EPRI expects to release final tool and documentation Q1 2020

Recent Report: Transformer Vibration

- **Task Objective:** Assess potential impacts of vibrations and other GMD-related harmonic issues on BPS equipment
- **Issue:** GMD-related harmonics can lead to increased vibrations in large power transformers
- **EPRI Report:** Transformer Vibration Analysis
- **Outcomes:** Factory and field tests to-date have indicated vibrations due to GIC have minimal impact on mechanical integrity
- **Next Steps:**
  - EPRI performing long-term field monitoring of large transformer tank vibrations

Data Collection and Availability

- Order No. 830 includes directives for collecting data to “improve our collective understanding” of GMD risk
  - Includes GIC and Magnetometer data
  - NERC is to make data available to the public
- NERC developed a Rules of Procedure Section 1600 data request with GMD Task Force (GMDTF) and technical committee input
- Approved by NERC Board in August 2018



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Geomagnetic Disturbance Data

Rules of Procedure Section 1600 Data Request in Response to FERC Order No. 830

Background

On September 22, 2016, the Federal Energy Regulatory Commission (FERC) issued Order No. 830 approving Reliability Standard TPL-007-1 – Transmission System Planned Performance for Geomagnetic Disturbance Events. In the Order, FERC also directed NERC, pursuant to Section 1600 of the NERC Rules of Procedure, to collect geomagnetically-induced current (GIC) monitoring and magnetometer data from registered entities for the period beginning May 2013, including both data existing as of the date of the order and new data going forward.[1] Furthermore, FERC directed that NERC should make the collected GIC and magnetometer data available to support ongoing research and analysis of GMD risk.[2]

FERC also directed NERC to develop certain revisions to Reliability Standard TPL-007-1, including development of one or more requirements for responsible entities to obtain GIC monitoring and magnetometer data to enable model validation and situational awareness. NERC standards Project 2013-03 – Geomagnetic Disturbance Mitigation is addressing revisions to TPL-007-1 in accordance with the NERC Standard Processes Manual.[3]

In accordance with Section 1600 of the NERC Rules of Procedure, NERC may request data or information that is deemed necessary to meet its obligations under Section 215 of the Federal Power Act, as authorized by Section 39.2(d) of FERC regulations (“data request”). This is a proposal for such a request.

Authority

Under Section 215 of the Federal Power Act (16 U.S.C. § 824o), Congress entrusted FERC with the duties of approving and enforcing rules to ensure the reliability of the nation’s Bulk-Power System, and with the duties of certifying an Electric Reliability Organization (“ERO”) that would be charged with developing and enforcing mandatory Reliability Standards, subject to FERC approval. NERC was certified as the ERO on July 20, 2006. NERC’s authority for issuing this data request is derived from Section 215 of the Federal Power Act and from the following sources discussed below.

NERC is requesting information in accordance with its authority provided in 18 C.F.R. §39.2(d), which provides:

[1] Order No. 830, P 89. The directive applies to only U.S. responsible entities (See n. 118). However, responsible entities in other NERC jurisdictions including Canada are encouraged to participate in order to obtain relevant GMD data for the North American Bulk-Power System.

[2] Order No. 830, P 93. In the order, FERC stated: “The record in this proceeding supports the conclusion that access to GIC monitoring and magnetometer data will help facilitate GMD research, for example, by helping to validate GMD models.” If GIC monitoring and magnetometer data is already publicly available (e.g., from a government entity or university), FERC stated that NERC need not duplicate those efforts (n. 122).

[3] NERC filed proposed Reliability Standard TPL-007-2 with FERC on January 22, 2018. The proposed standard was developed to address the directives for revisions to TPL-007-1 contained in FERC Order No. 830.

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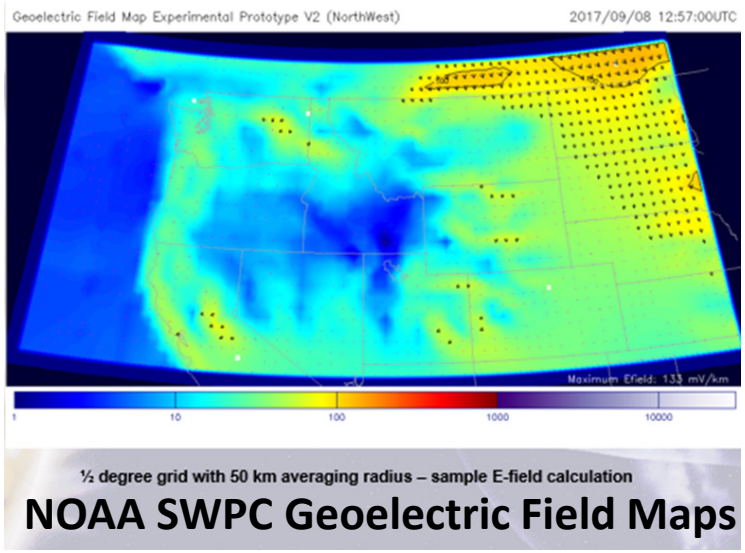
Approved by NERC Board in August 2018

Why collect GMD data

- Use data to improve e-field modeling
  - Earth models
  - Latitude scaling
- Use data to improve GIC system models and risk assessments
  - Determine **duration and intensity** of **GIC** pulses
  - **Evaluate transformers** susceptibility to half-cycle saturation
  - **Assess vulnerability** of operating assets and facilities
  - **Define** acceptable levels of **risk tolerance**
- Support research into GMD event characteristics



$$E_{peak} = 8 \times \alpha \times \beta \ (V/km)$$

GMD Data Collection Overview

- Data will be collected for GMD events that meet or exceed K_P-7
  - Historical events back to May 2013
  - Future events from implementation of data collection program
  - On average, 200 K_P-7 GMD events occur in 11-year solar cycle
- Transmission Owners and Generator Owners with GIC and/or magnetometer data are applicable entities
  - Non-U.S. entities are not obligated to participate but are encouraged
  - Reporting by an entity (e.g., EPRI) on behalf of applicable entities is acceptable
- NERC will make data available to researchers

Final Thoughts

- The BPS is well-protected and the industry is becoming increasingly confident that the risks are mitigated
- Continue to refine technical guidance and requirements as research and tools emerge
- Technologies continue to be advanced that can help mitigate risks

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Questions and Answers

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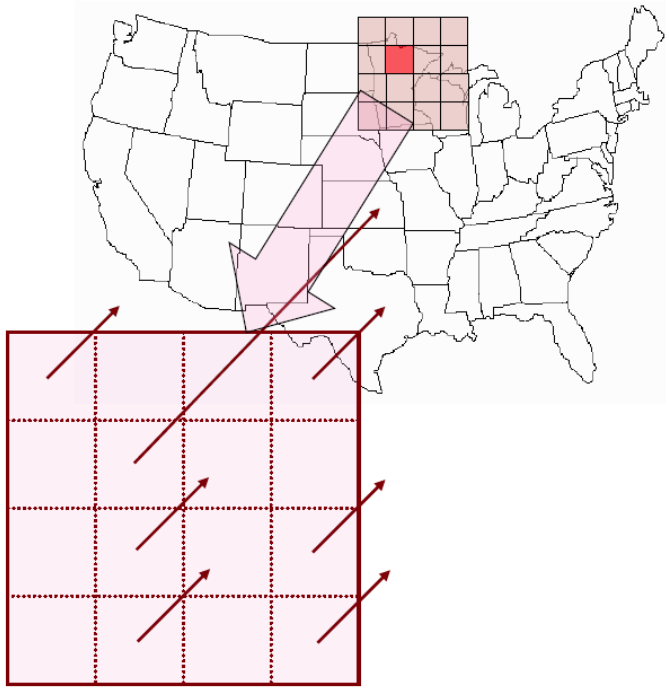
Reference Slides: Research Tasks

Task 1 -Analyze Spatial Averaging Used in Benchmark GMD Event

- Further evaluate the Benchmark GMD Event used in TPL-007-1
- Improve understanding of the physics and spatial scales of localized geoelectric field "hotspots"
  - Analysis of measurement data
  - Compare to simulated predictions
- Determine impacts of spatial averaging assumptions on bulk-power system reliability
  - GIC analysis
  - Power flow analysis
  - Transformer thermal assessments



Task 2 -Analyze Latitude Scaling

- Evaluate geomagnetic latitude scaling factors associated with severe GMD events
- Perform analysis to provide:
  - Additional technical support for existing latitude scaling factors, or
  - Propose new values as appropriate

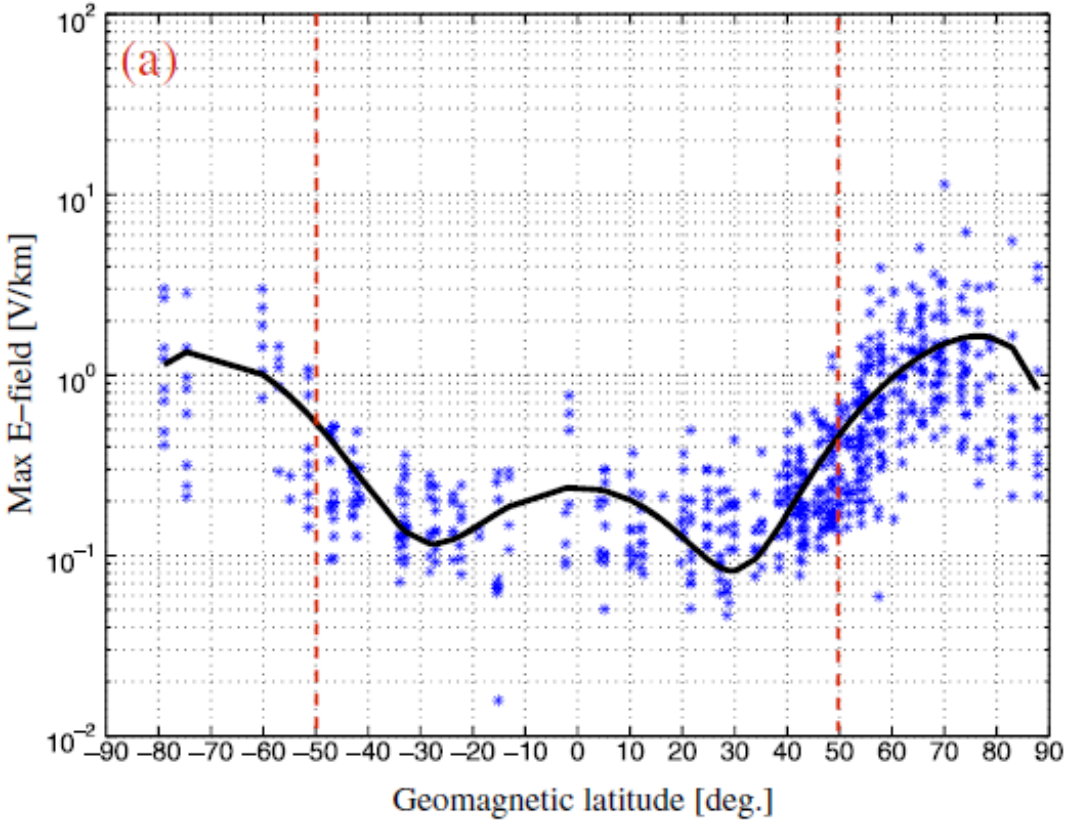
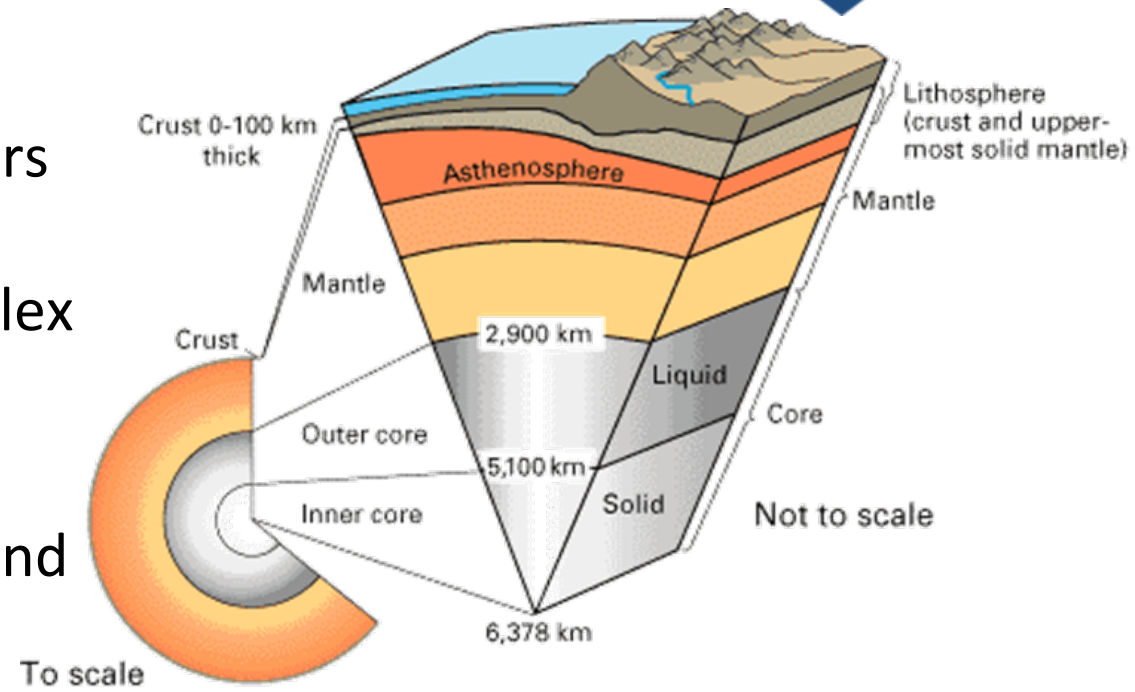


Image source: C Ngwira and A Pulkinnen et al. Space Weather (2013)

Task 3 – Improve Earth Models for GIC Studies

- Determine if the earth conductivity scaling factors in TPL-007-1 need to be revised using more complex modeling
- Develop techniques and guidelines for using GIC and magnetometer data to perform model validation
- Establish a working group on modeling non-uniform geoelectric fields



Task 4 and 5 –Transformer Thermal Impact

- Perform analysis to evaluate the ability of GIC flow calculated as specified in TPL-007 to represent worst-case transformer hot-spot heating conditions
  - Evaluate 75 A per phase criteria
  - Evaluate effects of harmonic currents
- Develop enhancements to models and data to improve accuracy of transformer thermal impact assessments
  - Improve models
  - Additional modeling parameters
  - Guidance, Performance Criteria
- Develop a Transformer Thermal Modeling Tool (2017)

Task 6 – Section 1600 Data Request

- Order No. 830 includes directives for collecting data to “improve our collective understanding” of GMD risk
  - Includes GIC and Magnetometer data
  - NERC is to make data available to the public
- EPRI project will develop guidance for the measurement of GIC and geomagnetic field

Task 7 – Geoelectric Field Calculation Tool

- Evaluate commercially available tools for calculating geoelectric field from magnetic field data for given earth conductivity structure
- Develop open source tool capable of performing geoelectric field calculations using more complex earth conductivity models and time series geomagnetic field data
- Perform time-series simulations to evaluate scaling factors

Task 8 – Harmonic Analysis Capabilities

- Develop harmonics analysis guidelines and tools for system-wide assessments
- Develop models and methods to improve capability of performing harmonic assessments of benchmark GMD events

Task 9 – Harmonic Impact Studies

- Impacts of harmonics on power system equipment (power transformers)
- Perform transformer tank vibration measurements on transformers when subjected to GIC
- Determine:
  - Feasibility of using tank vibration measurements to monitor GIC impact
  - Impact of vibrations due to GIC on integrity of the transformers
- May result in additional screening and/or monitoring criteria that can be used to determine GMD impacts