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Space Weather Impacts on the Power Grid

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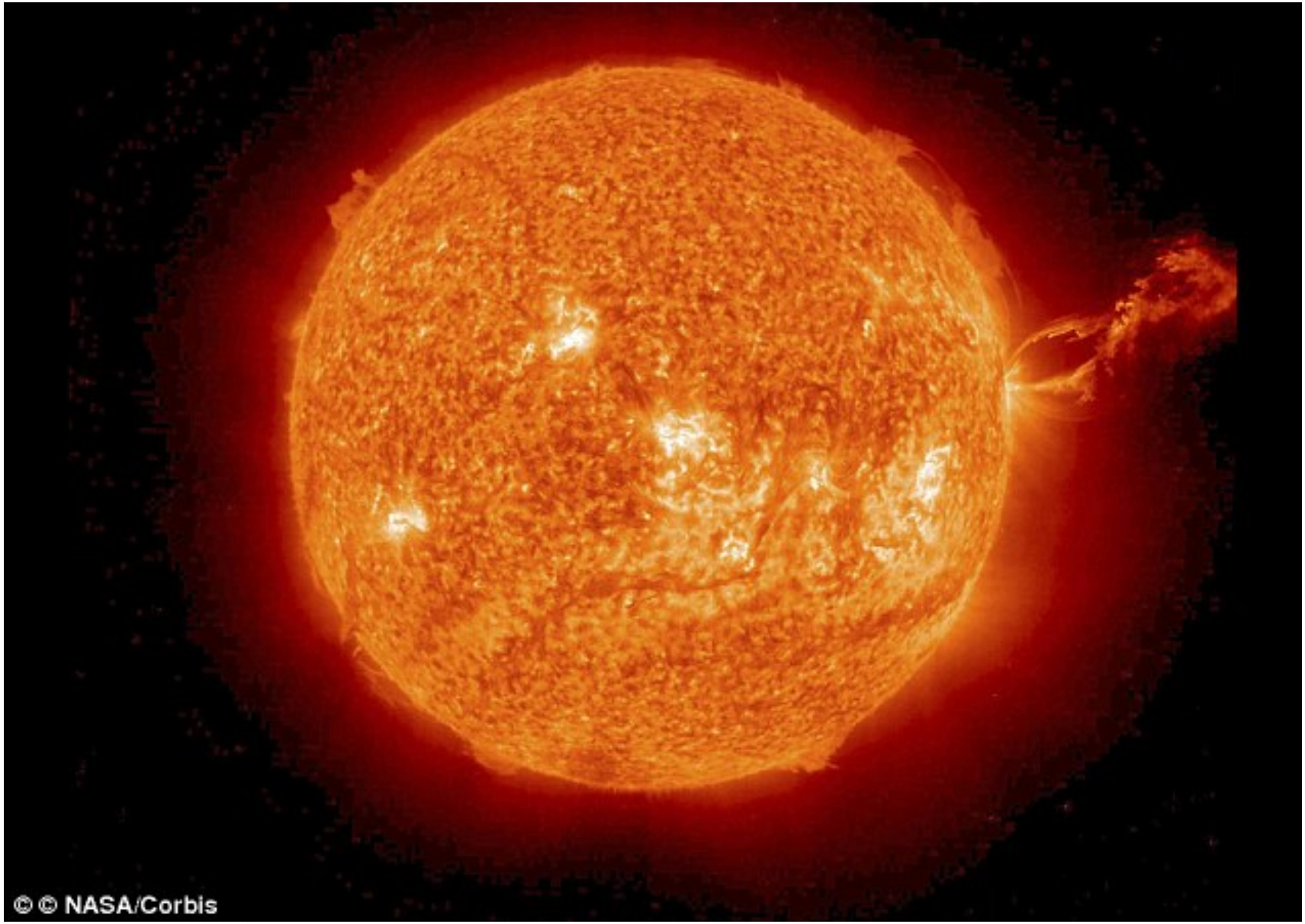
David Bertagnolli

PRINCIPAL ENGINEER, ISO NEW ENGLAND, INC.

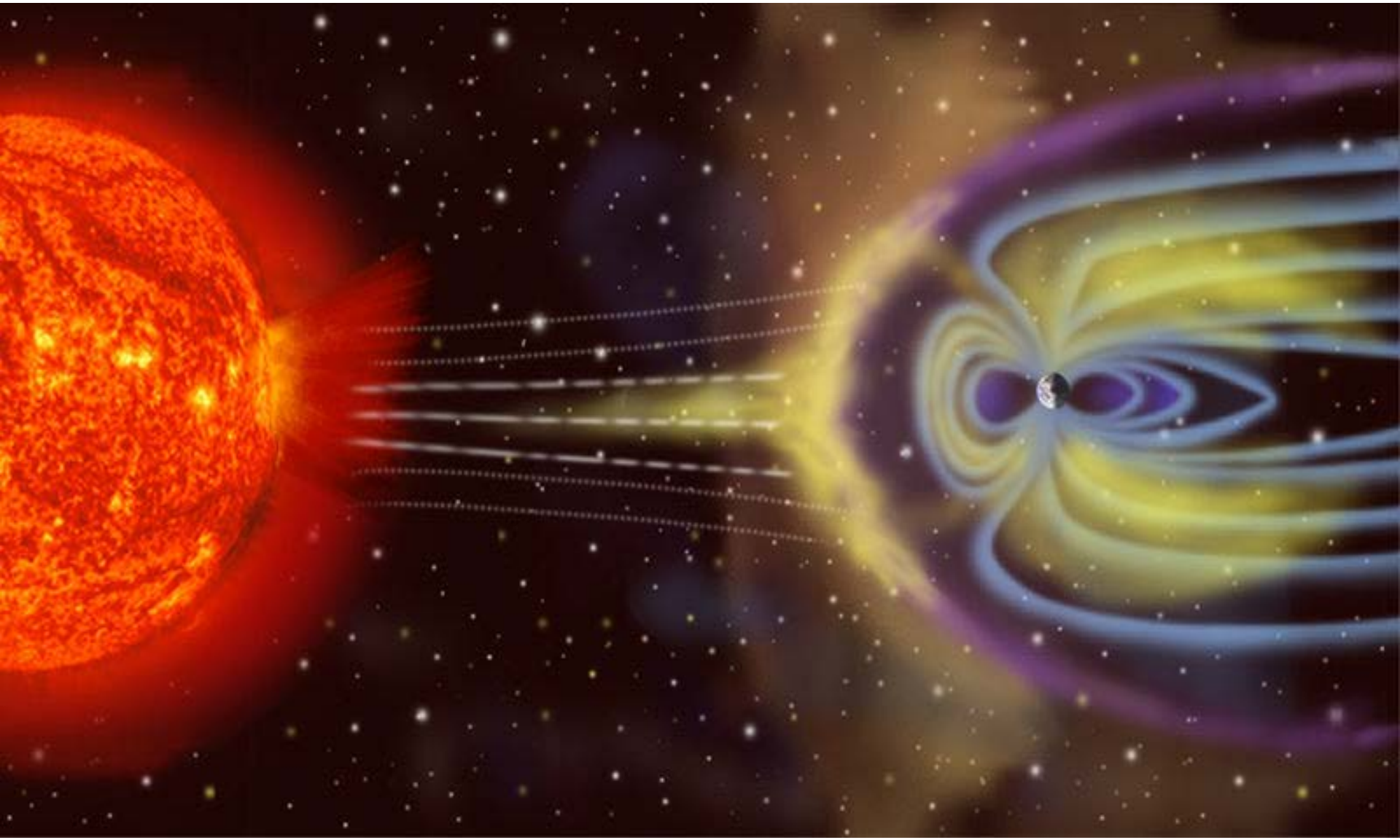
Presentation Overview

- Introduction to phenomenon
- Modeling
- Monitoring
- Where to get more info

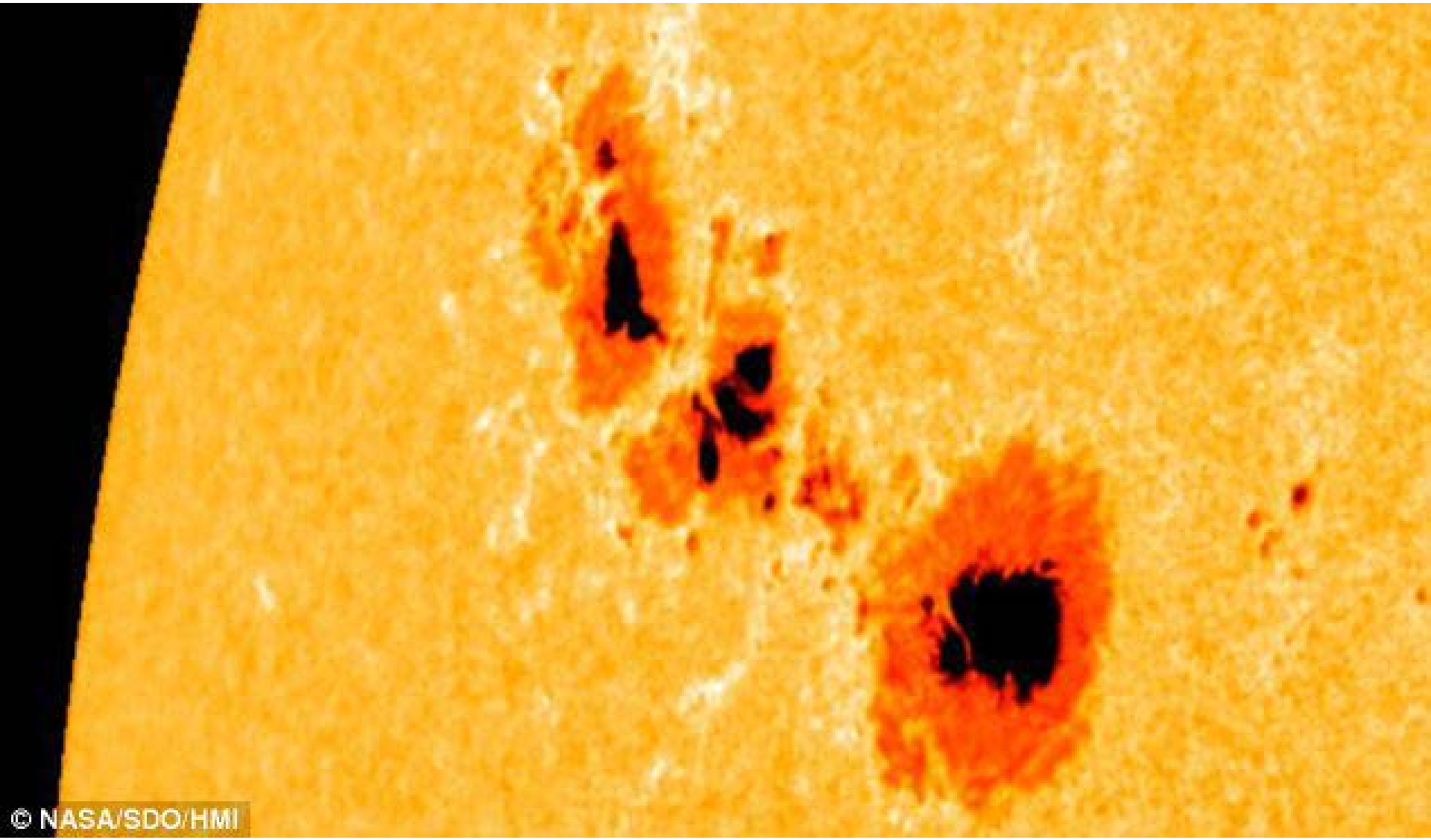
Coronal Mass Ejection



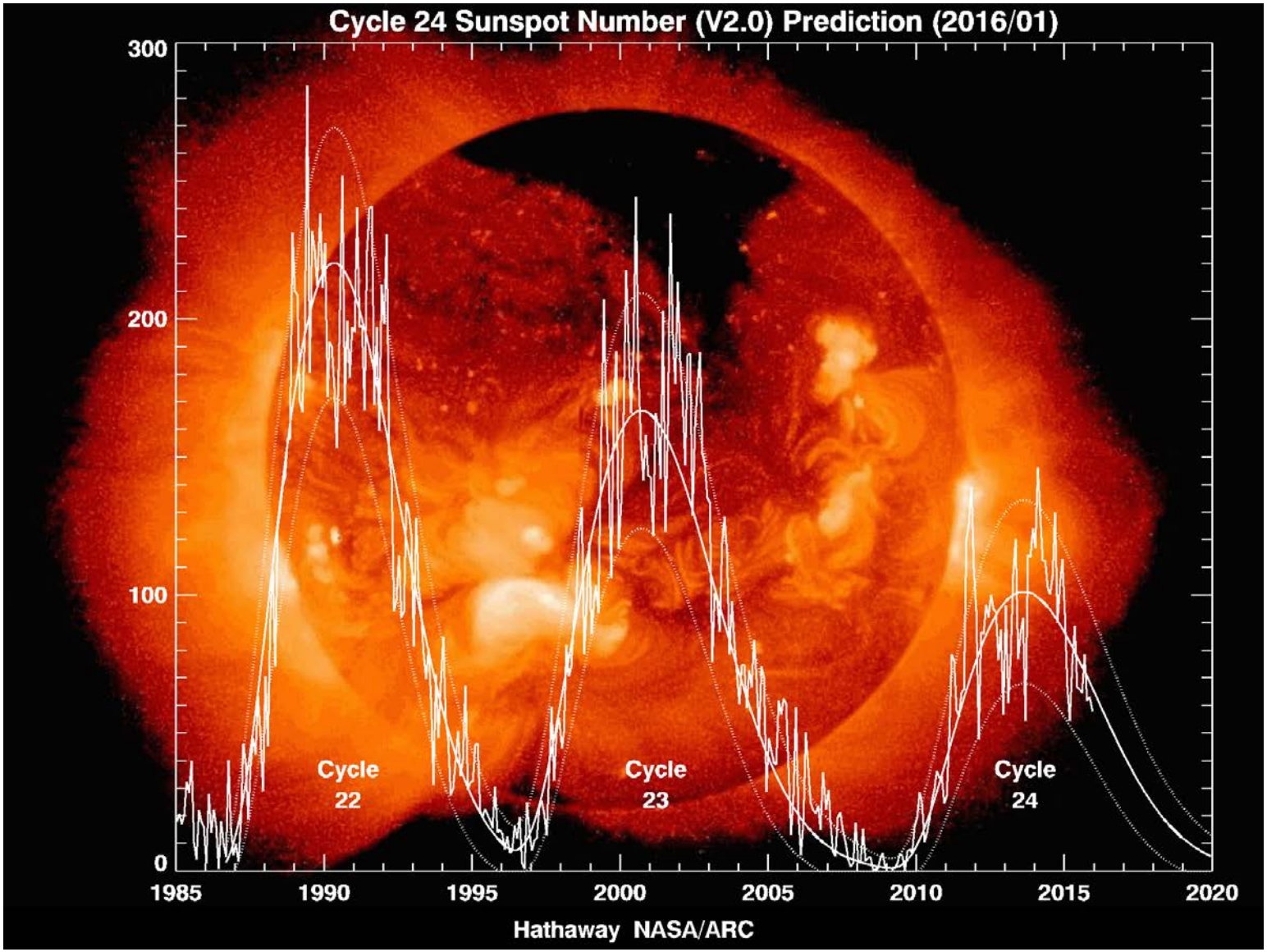
Coronal Mass Ejection interacts with Earth's Field



Sunspot Activity correlated to CME

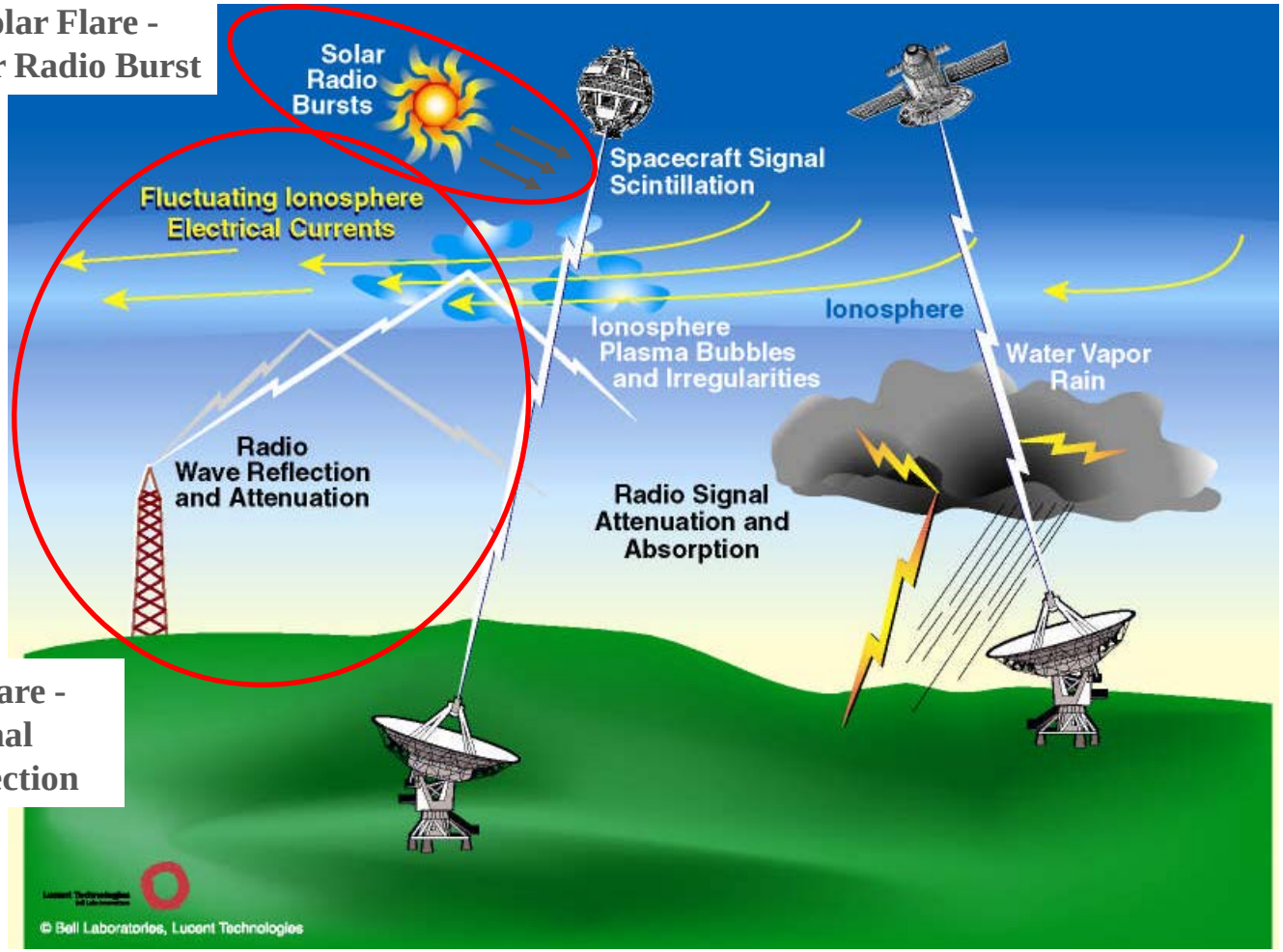


Sunspot Cycle – 11 years



Solar Magnetic Storm Effects On Radio Communications Systems

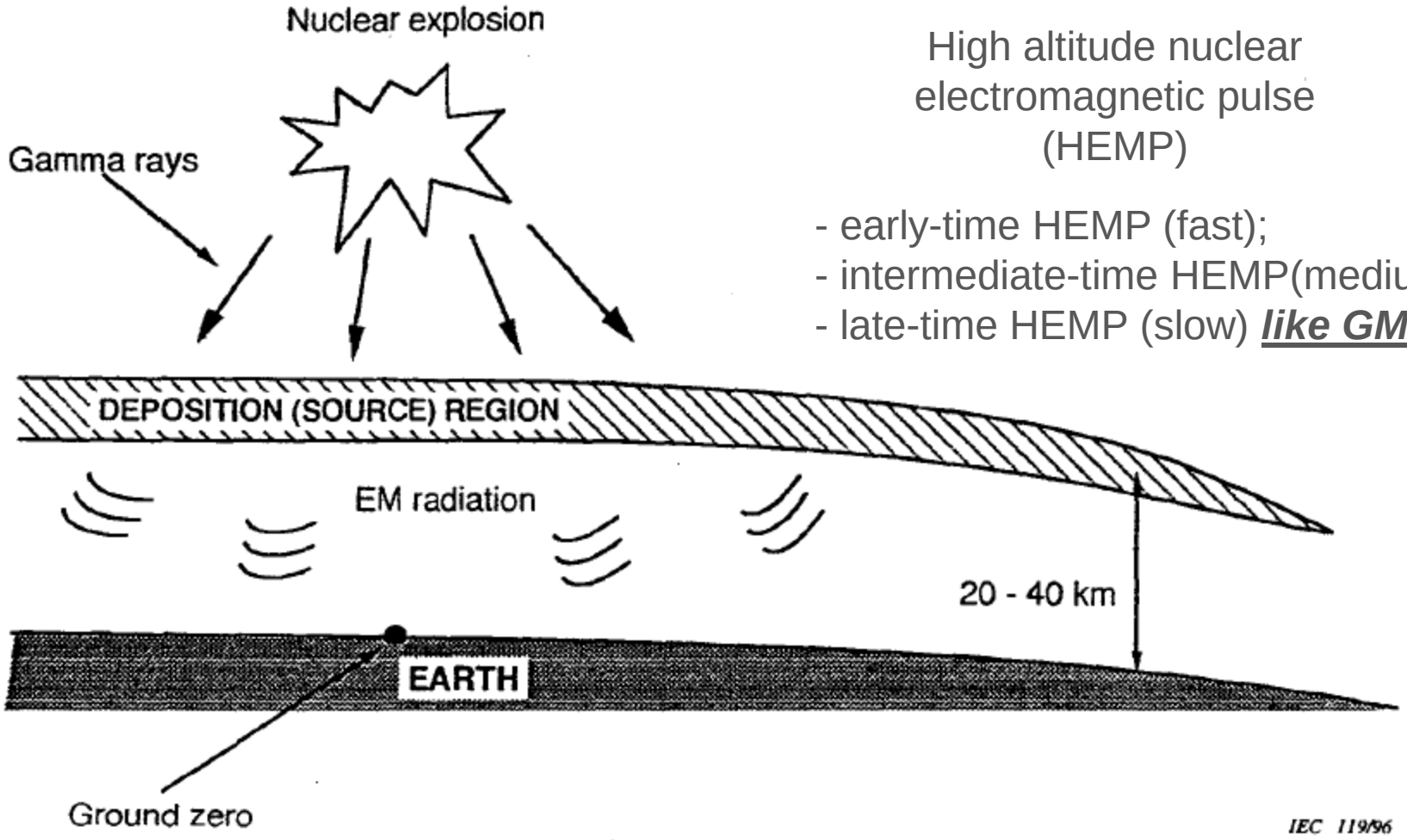
Solar Flare - Solar Radio Burst



Solar Flare - Coronal Mass Ejection

[Lanzerotti 2005]

GMD is associated with Electro-Magnetic Pulse (EMP)



High altitude nuclear electromagnetic pulse (HEMP)

- early-time HEMP (fast);
- intermediate-time HEMP(medium)
- late-time HEMP (slow) ***like GMD***

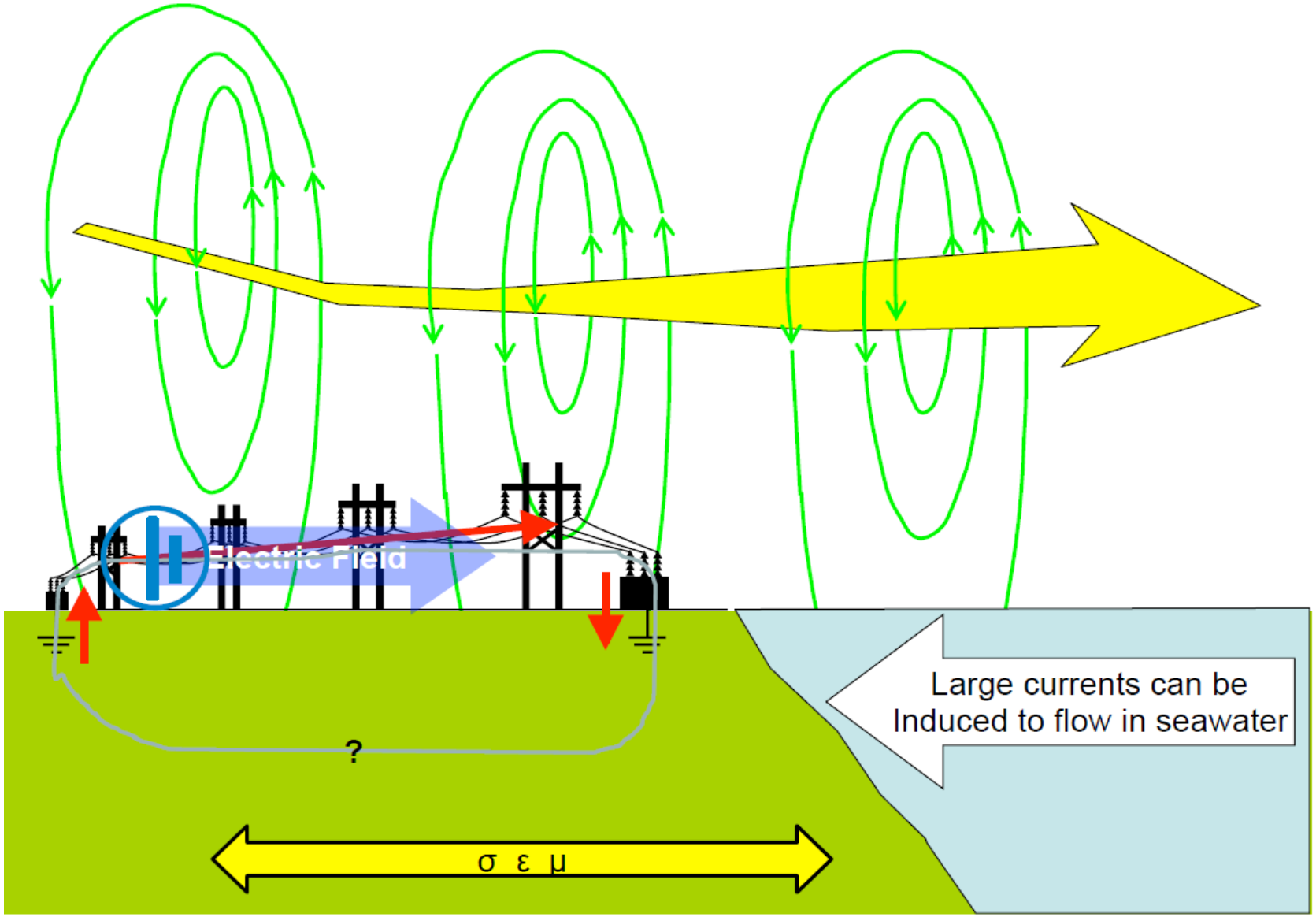
Also see Radasky & Kappenman

Figure 4 – Schematic representation of the early-time HEMP from a high-altitude burst

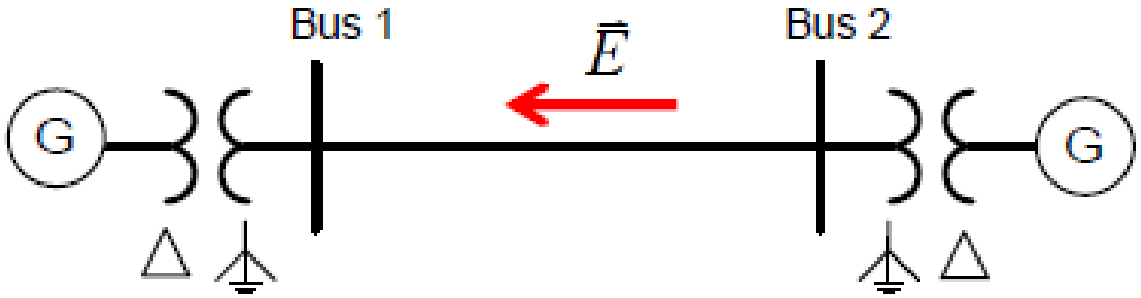
GMD is not Intentional Electro-Magnetic Interference

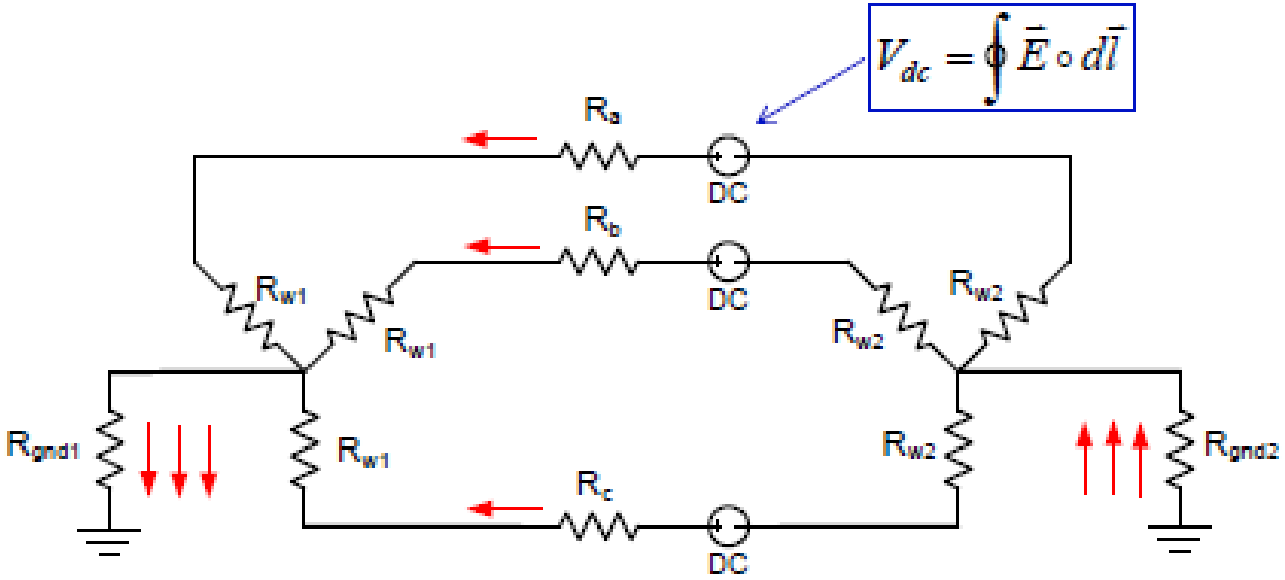
- Intentional Electro-Magnetic Interference (I-EMI)
- *Radasky & Savage, Meta Tech – January 2010:*
  - *IEEE EMC Society, technical committee TC-5: "High Power Electromagnetics"*
  - *IEC Subcommittee 77C: "EMC: High power transient phenomena" – standard to protect commercial equipment and systems under IEMI*

Change of Electrical Currents in the Ionosphere



Geomagnetically Induced Current Example





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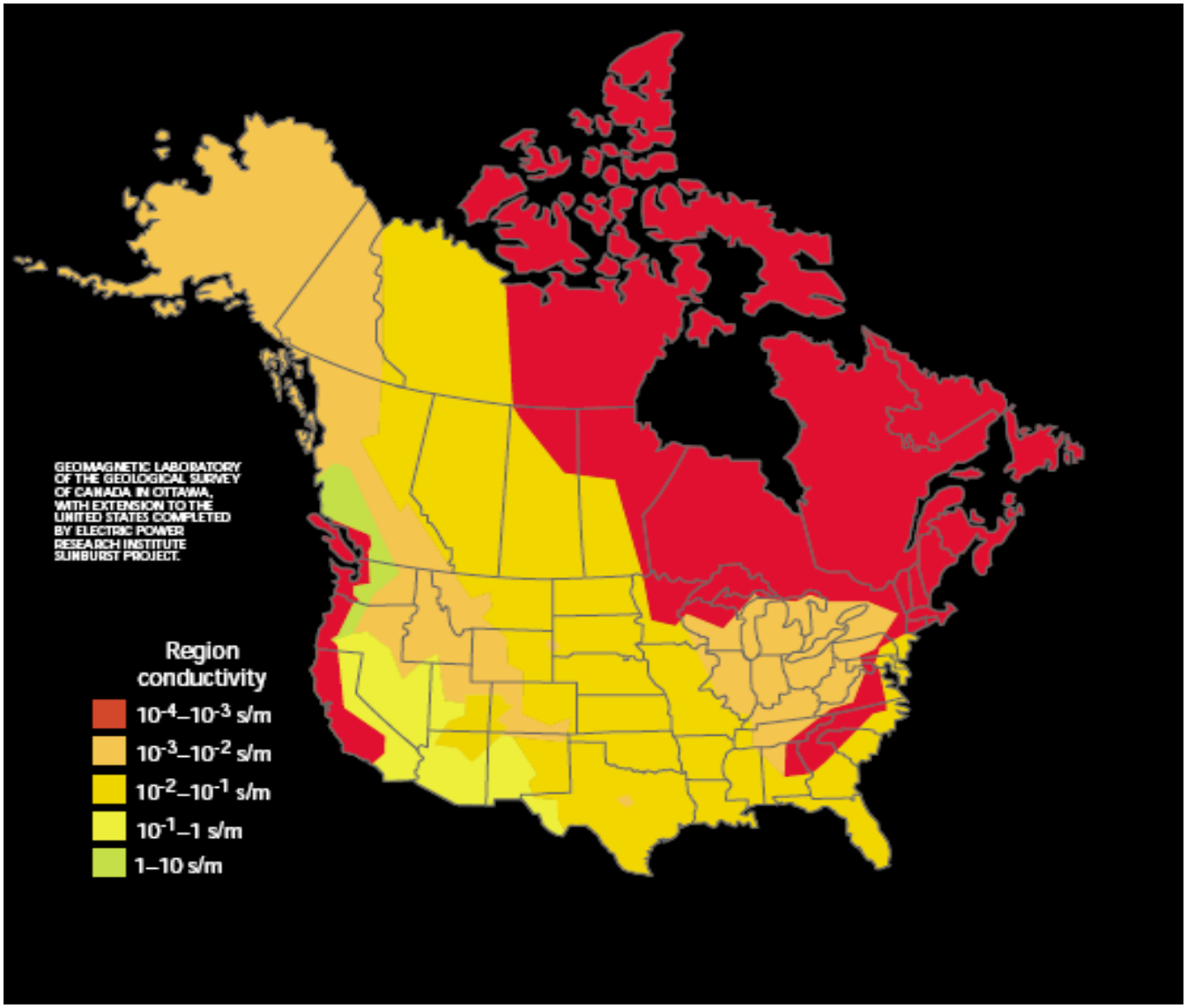
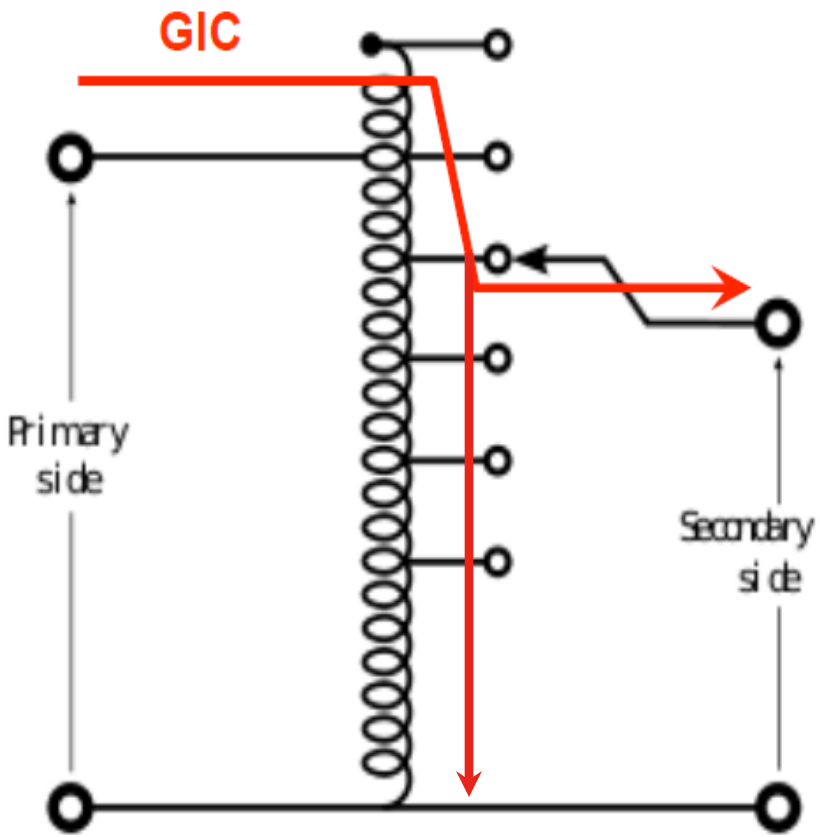
Earth Conductivity In The US & Canada



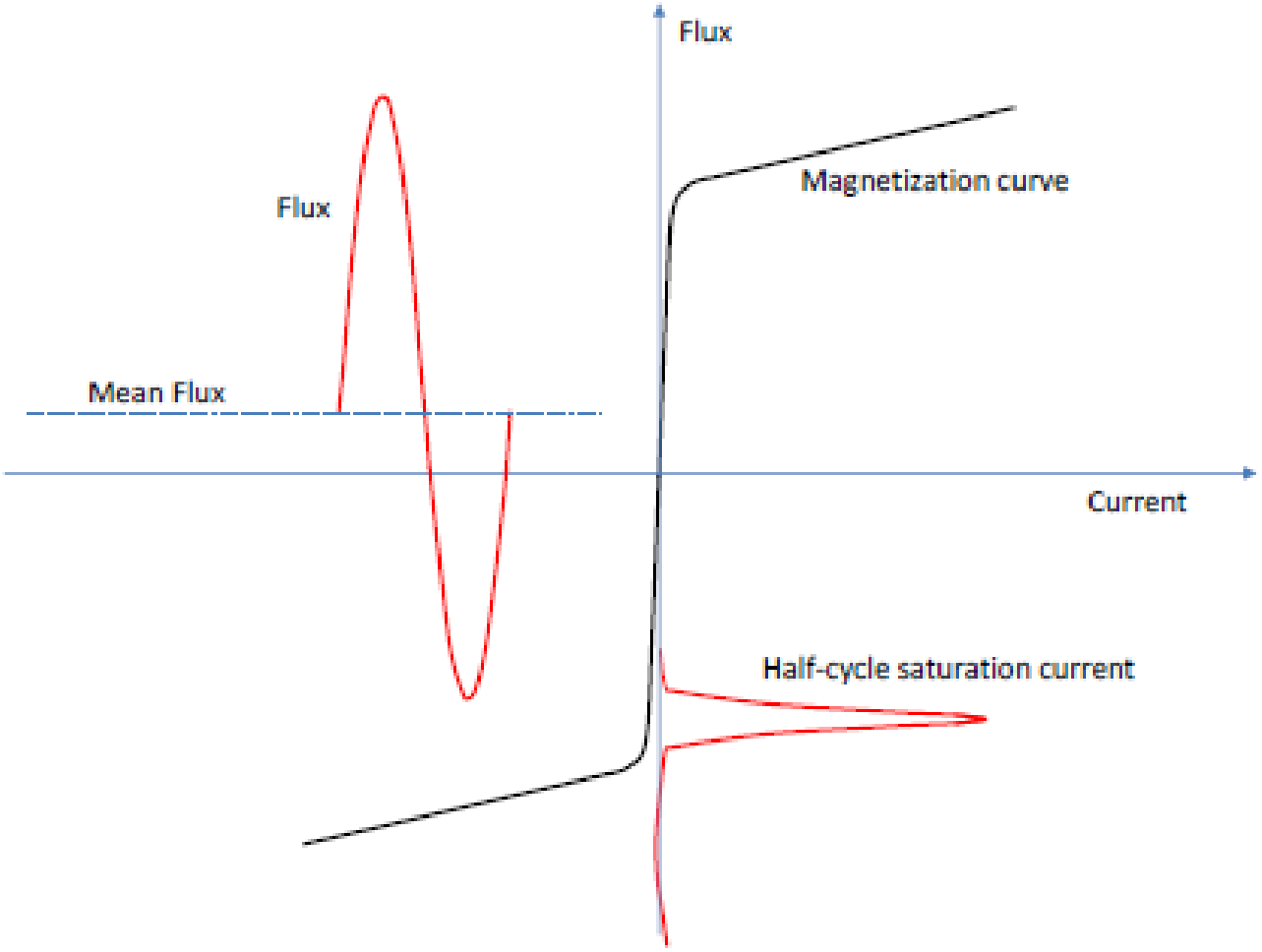
Auto Transformers



GIC flows from high side through series winding to low side, and through common winding to ground

Symmetric current becomes offset

Half-Cycle Saturation Caused by the Flow of GIC



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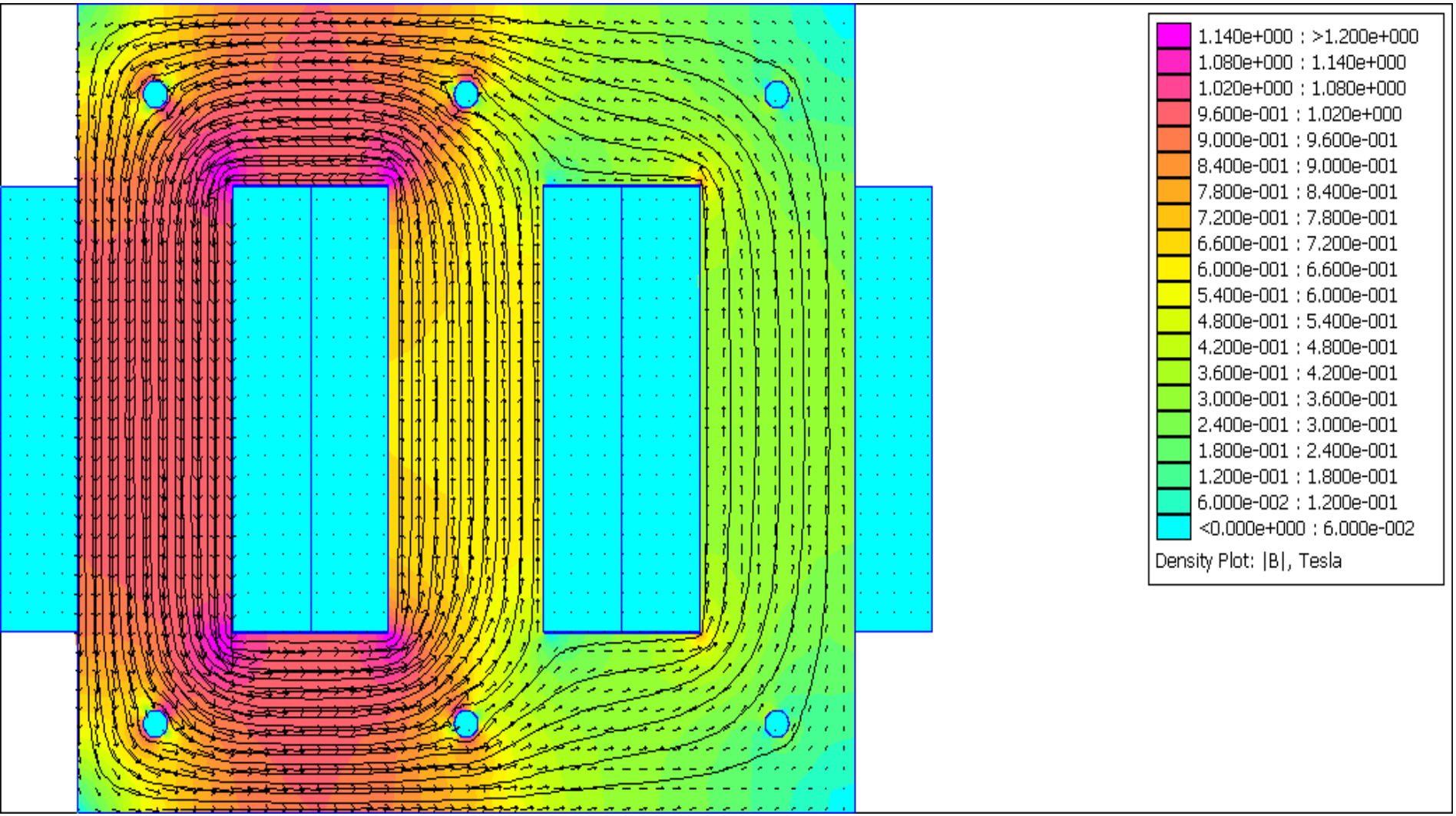
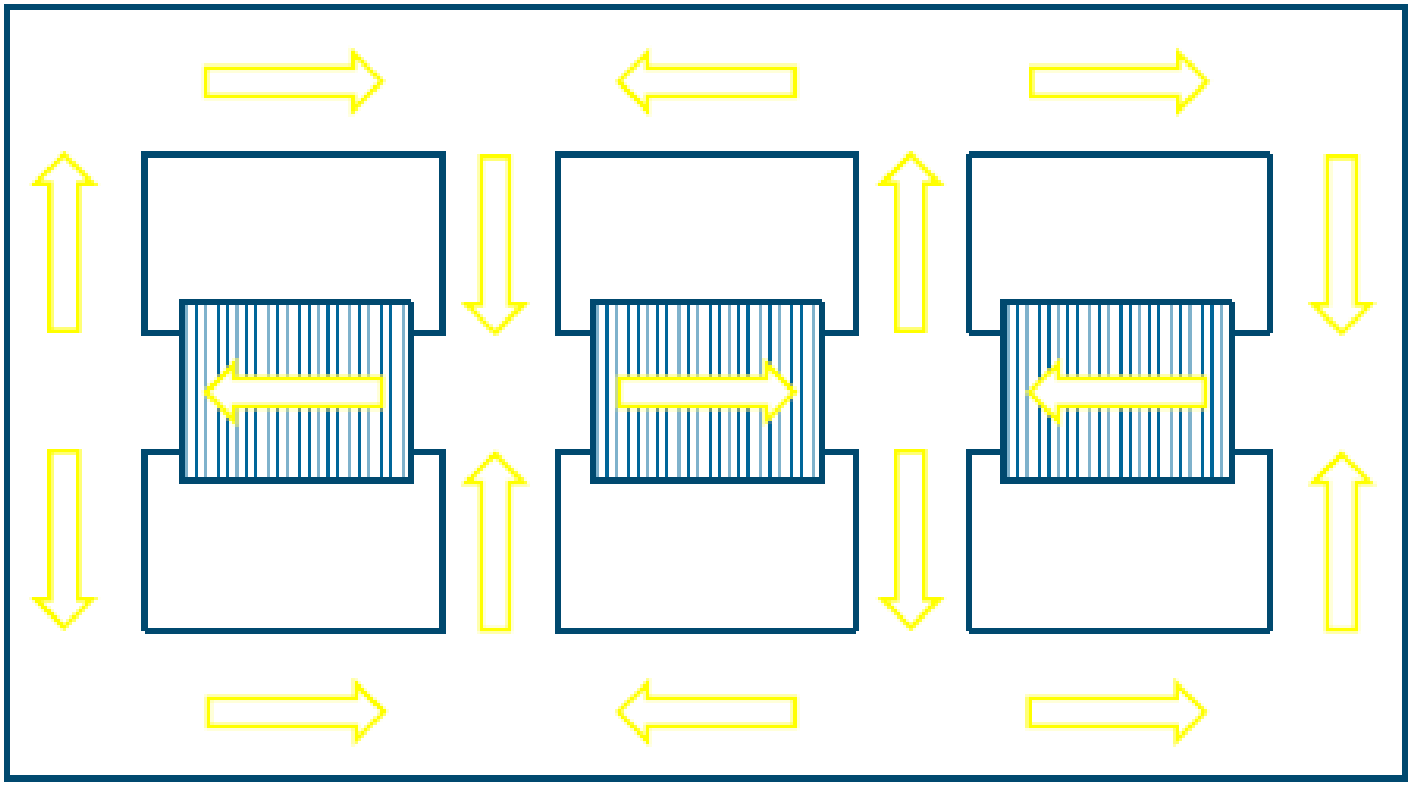
Transformer flux map

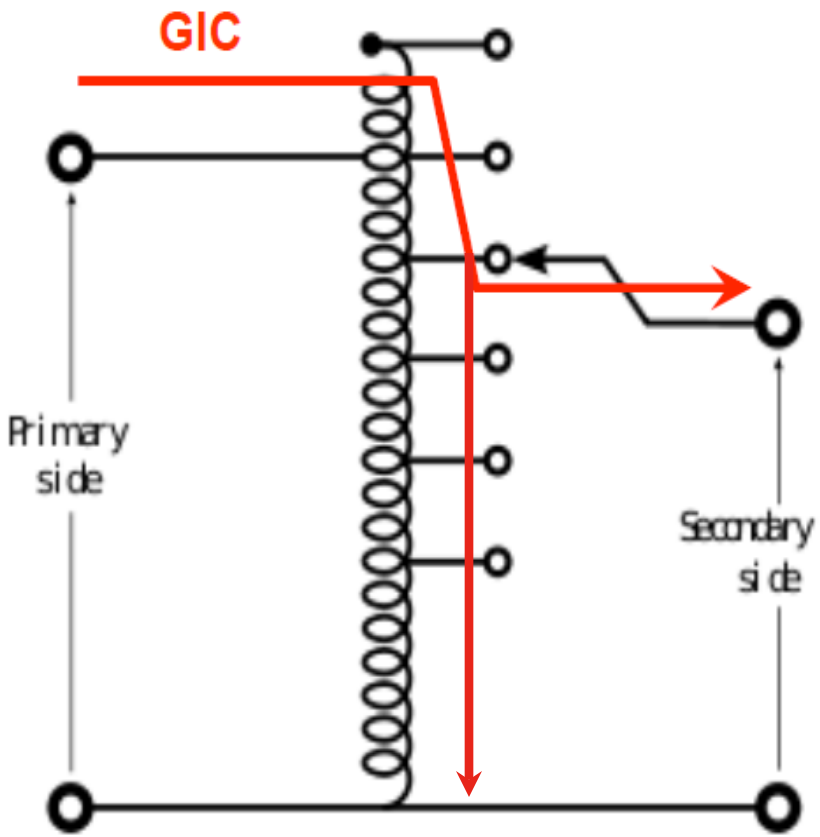


Shell-form design



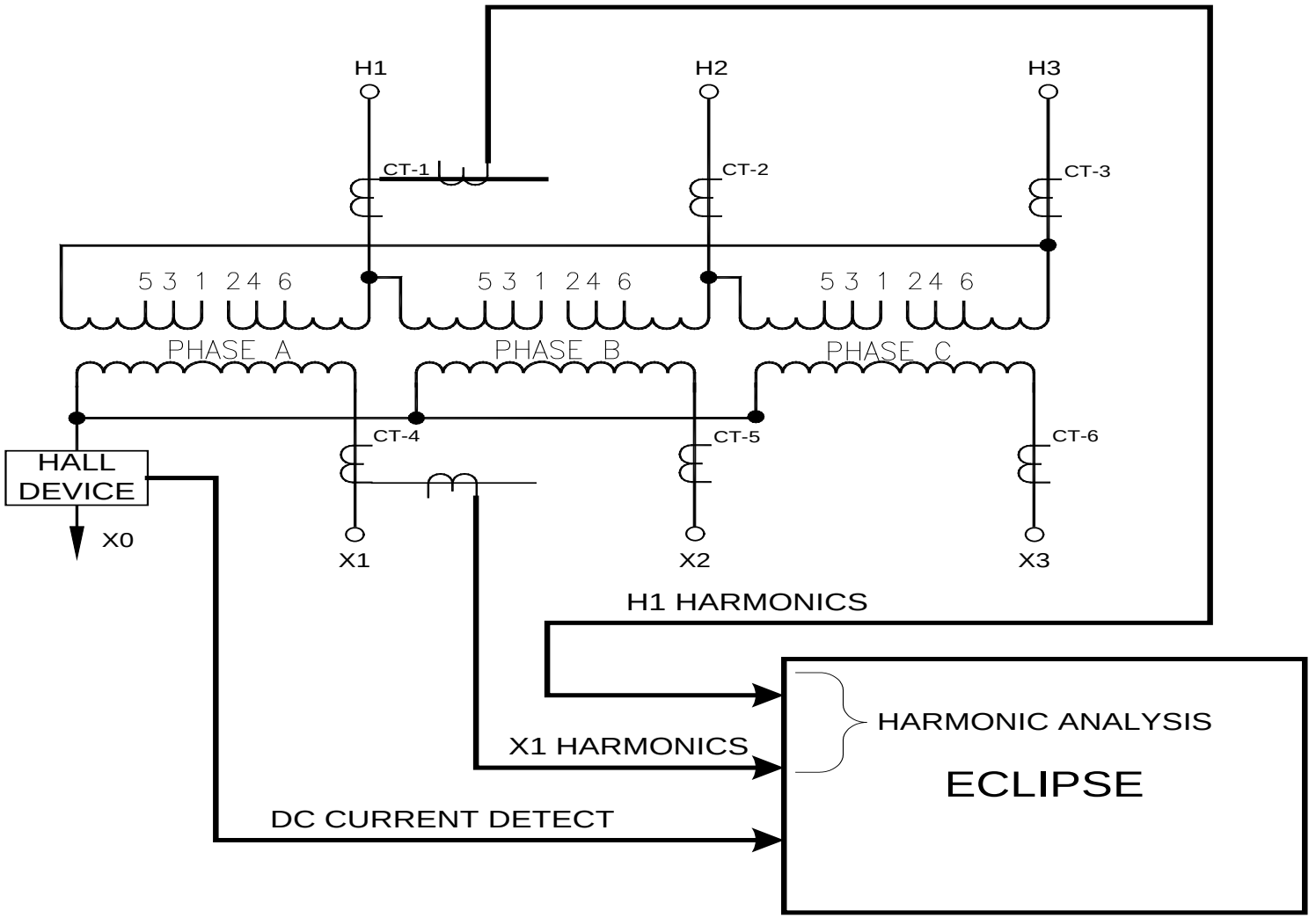
16

Auto Transformers



- Measuring GIC to ground is relatively easy using Hall Effect current transformer on neutral conductor

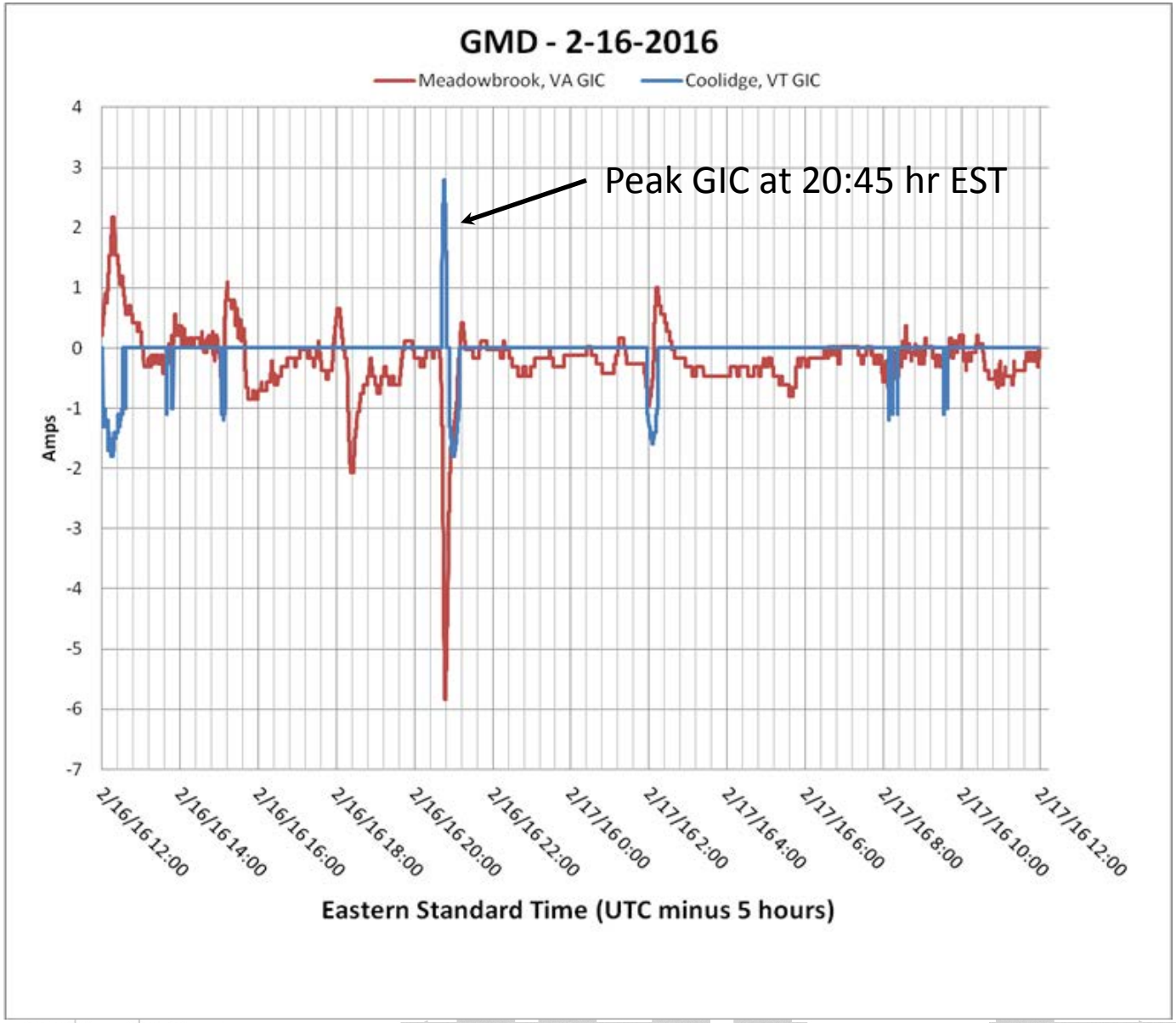
- Harmonics generated by the transformer during saturation can be measured using conventional current transformers


H1
H2
H3
CT-1
CT-2
CT-3
5 3 1 2 4 6
5 3 1 2 4 6
5 3 1 2 4 6
PHASE A
PHASE B
PHASE C
CT-4
CT-5
CT-6
HALL DEVICE
X0
X1
X2
X3
H1 HARMONICS
X1 HARMONICS
DC CURRENT DETECT
HARMONIC ANALYSIS
ECLIPSE

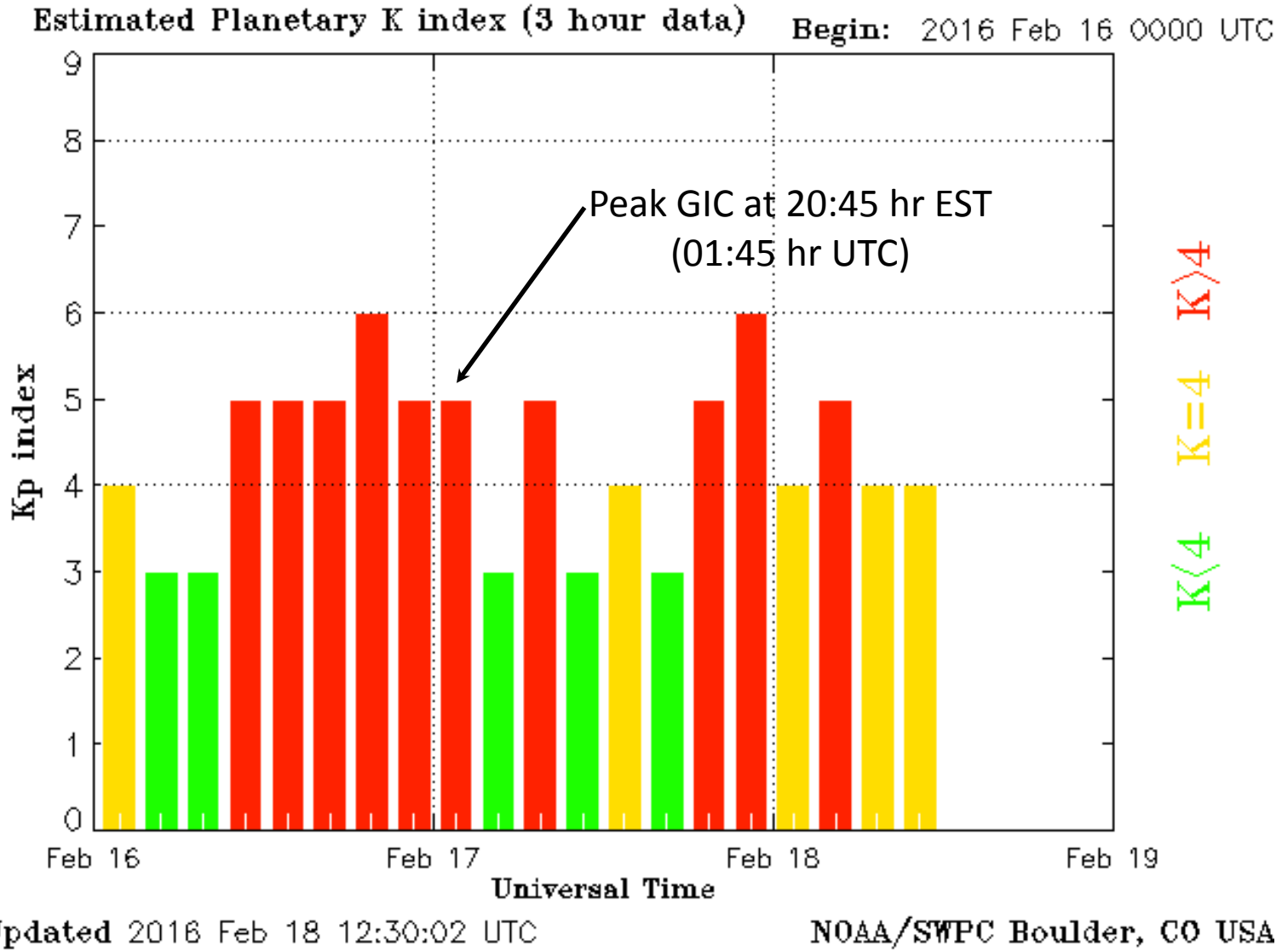
GIC Monitoring

- Real-time information to guide operators
- GIC relay cabinet added to transformer

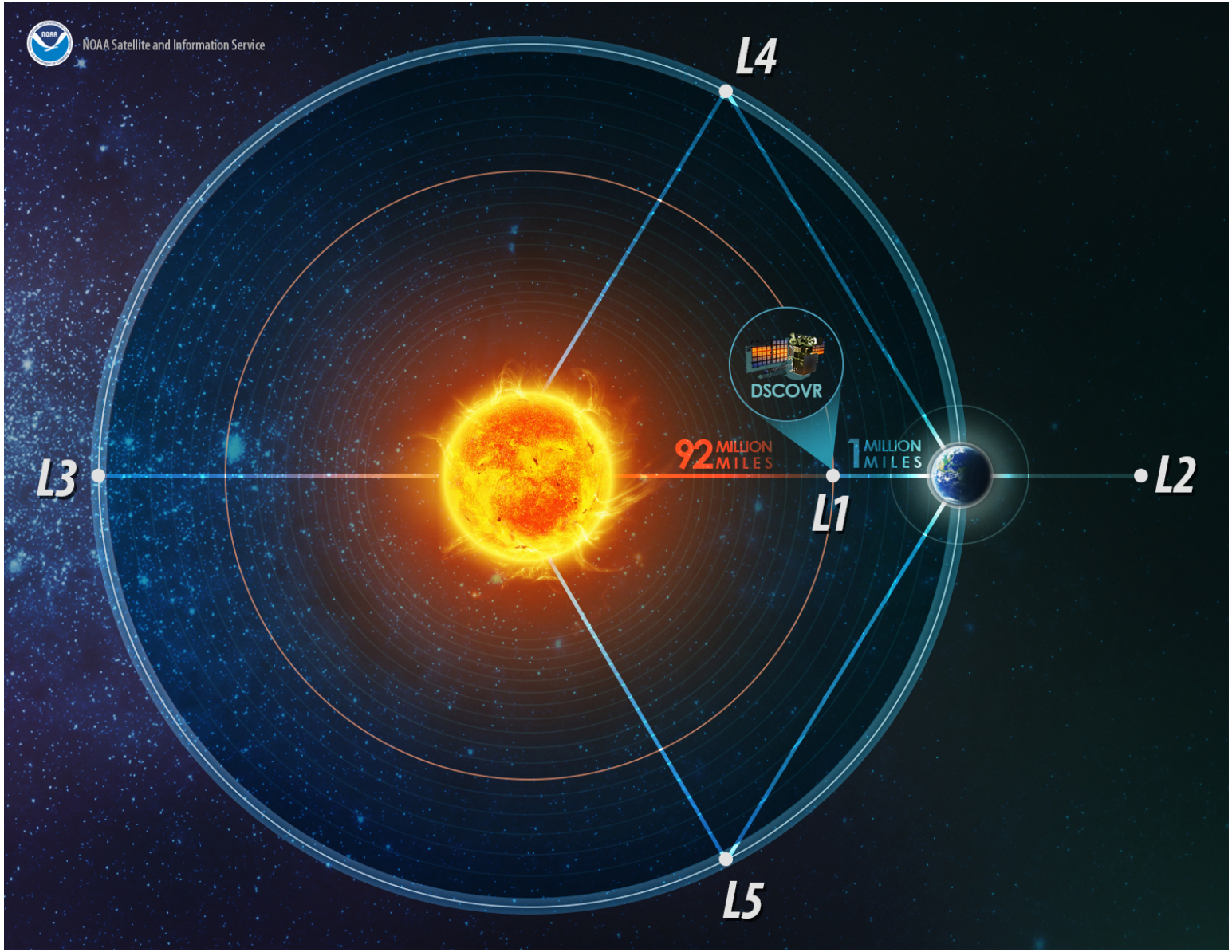
GIC at two locations



Early Warning



Space Weather Service – satellites



Terrestrial Measurements - Magnetometers

BOU - Boulder
BRW - Barrow
BSL - Stennis
CMO - College
DED - Deadhorse
FRD - Fredericksburg
FRN - Fresno
GUA - Guam
HON - Honolulu
NEW - Newport
SHU - Shumagin
SIT - Sitka
SJG - San Juan
TUC - Tucson

National Space Weather Strategy & Action Plan

- *"…details national goals for leveraging existing policies and ongoing research and development efforts regarding space weather while promoting enhanced domestic and international coordination and cooperation across public and private sectors…"*

1. Establish Benchmarks for Space-Weather Events
2. Enhance Response and Recovery Capabilities
3. Improve Protection and Mitigation Efforts
4. Improve Assessment, Modeling, and Prediction of Impacts on Critical Infrastructure
5. Improve Space-Weather Services through Advancing Understanding and Forecasting
6. Increase International Cooperation

FERC Order 779 on GMD – May 2013

- Requires electric utilities in **ALL** areas of the country to address Geo-Magnetic Disturbances (GMD)
- Two stage approach:
  - Stage 1 – develop operating procedures to address GMD impacts on your system
    - ***Utilities in the northeast developed these types of procedures in early 1990's in response to 1989 GMD event in Quebec***
      - NERC Standard EOP-010 implemented 2014
  - Stage 2 – study how GMD might impact your system

Stage 1: EOP-010 (Operator Actions)

- **R1. Each Reliability Coordinator shall develop, maintain, and implement a GMD Operating Plan**
- **R2. Each Reliability Coordinator shall disseminate forecasted and current space weather information**
  - *subscribe to Space Weather Service*
- **R3. Each Transmission Operator shall develop, maintain, and implement a GMD Operating Plan to mitigate the effects of GMD events**:
  - Discontinue maintenance work and restore out of service high voltage transmission lines. Avoid taking long lines out of service
  - Maintain system voltages within acceptable operating range to protect against voltage swings
  - Review the availability of the SVCs and capacitor banks to respond to voltage deterioration, if necessary
  - Reduce the loading on ties, on other internal critical transmission lines, and interfaces to 90%, or less, of their security limits
  - …consider increasing Ten Minute Spinning Reserve forcing more units with reactive reserves online.
  - Consider posturing Generators operating at their Eco Max to provide room for reserves and reactive capacity.
  - Dispatch generation to manage system voltage, tie line loading, and to distribute operating reserve
  - Bring equipment capable of synchronous condenser operation on-line to provide reactive power reserve
  - Ensure the monitoring equipment is in service
  - Closely monitor Voltage contingencies and consider the impact of tripping large shunt and series capacitor banks and static VAR compensators.
  - If conditions are severe enough, consider reclosing tripped capacitor banks and SVCs ASAP that are likely tripped by erroneous relay action and **not** damage.

Stage 2: TPL-007-1 (Vulnerability Assessment)

- NERC Standard TPL-007 in final draft: expected 2016
- Analysis is similar to traditional power flow
- Refers to Benchmark Event:
  - Start with 8 V/km, scale for location & geology
    - **R1: Determine *who* does what:**
      - Who: Transmission Planner? Planning Coordinator? etc.
      - What: Develops models, perform analysis, etc.
    - **R2: Develop the models**
    - **R3: Perform analysis**
    - **R4: Develop voltage limits for Benchmark Event**
    - **R5: Identify transformers that could be in jeopardy**
    - **R6: Analyze transformers**
    - **R7: Develop Corrective Action Plan**

Where to get more information

- FERC website: www.ferc.gov
- NERC website: www.nerc.com
- National Space Weather program (http://www.nswp.gov/nswp_agency.htm)
- White House Space Weather Strategy & Action Plan
- IEEE C57.163 Transformer Guide…

IEEE Guide for Establishing Power Transformer Capability while under Geomagnetic Disturbances

Sponsor

Transformers Committee
of the
IEEE Power and Energy Society

Approved 3 September 2015

IEEE-SA Standards Board

Summary

- GMD
- SMD
- CME
- GIC
- EMP
- I-EMI

- FERC
- NERC
- EOP-010
- TPL-007

- Hall Effect
- Faraday Effect
- Magnetometer
- Core saturation
- Harmonics
- Space Weather Prediction Center
- Space Weather Action Plan

Thank You !