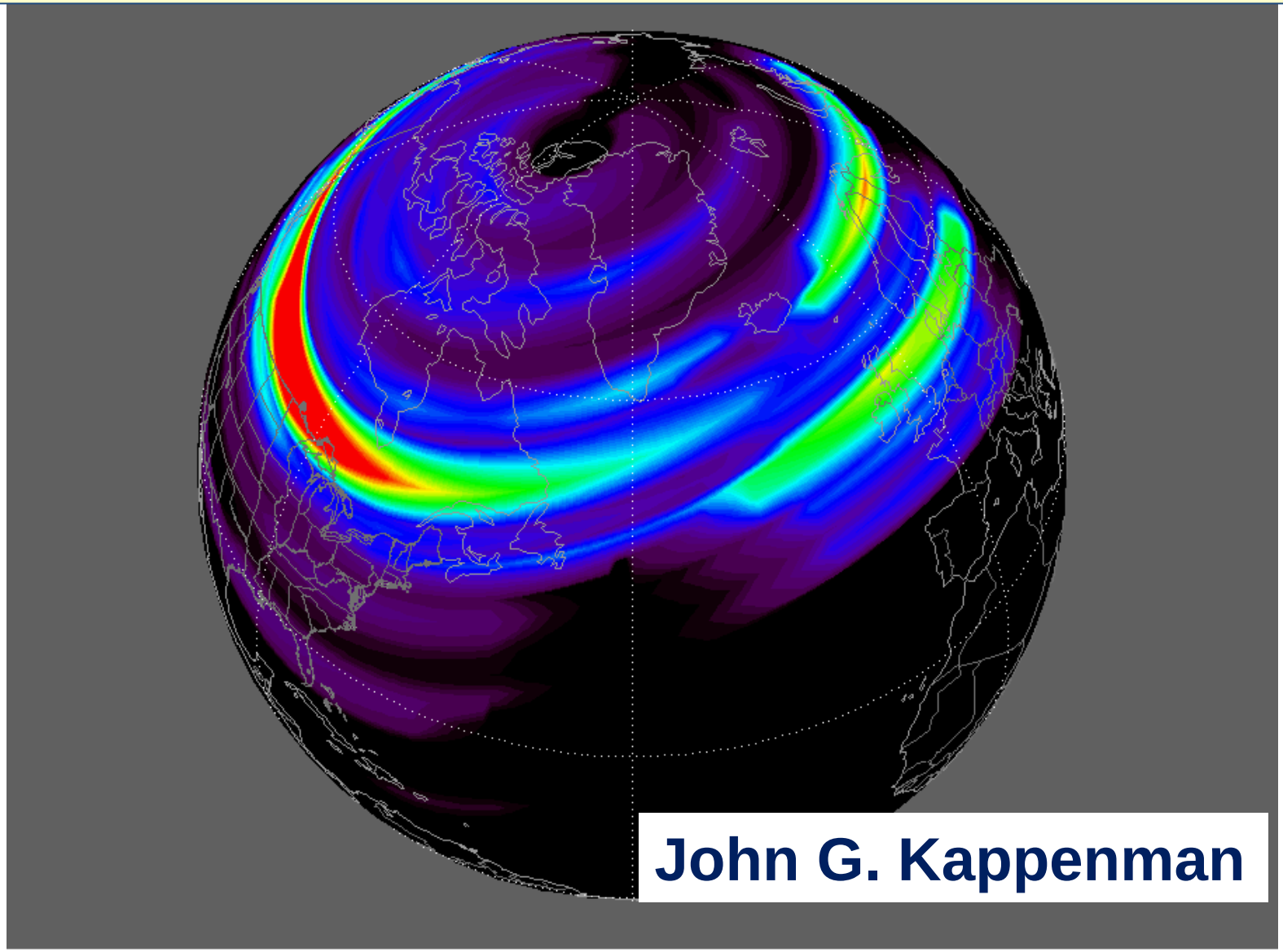
Severe Solar Activity/Space Weather and the Global Threat to Electric Grids

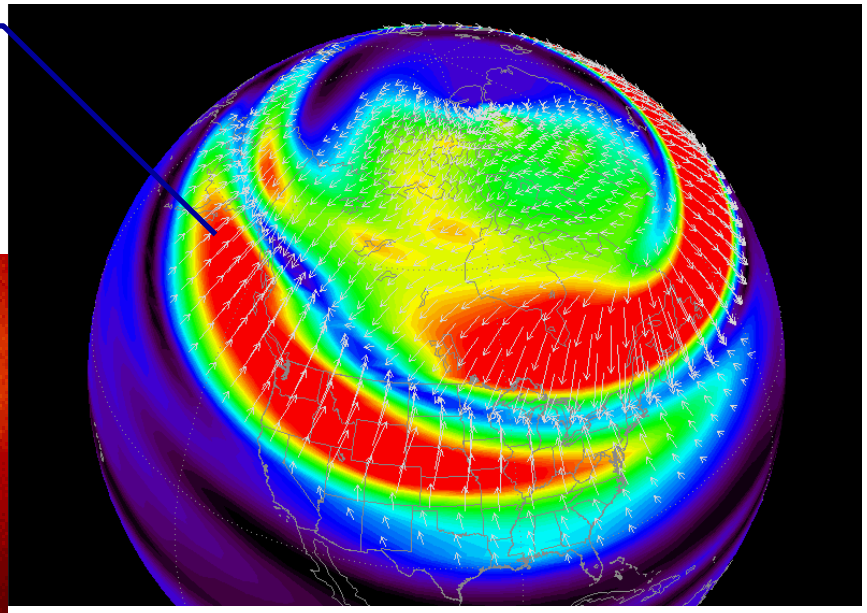


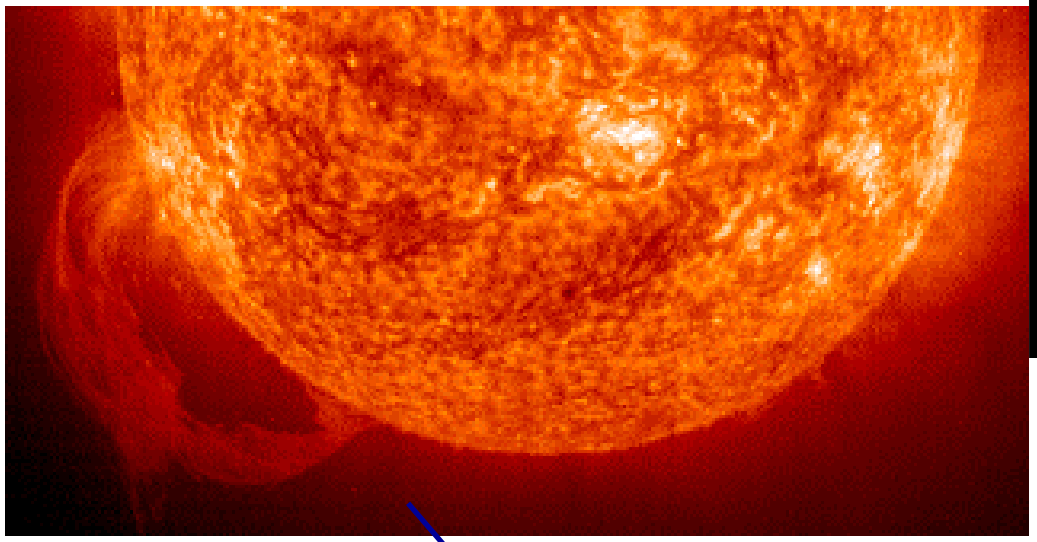
John G. Kappenman

A Review of Power Grid Vulnerability to Solar Activity & Geomagnetic Storms

Geomagnetic Storms are disturbances in the Earth's normally quiescent geomagnetic field caused by intense Solar activity

Geomagnetic Storms have Continent-Wide & Planetary Footprints

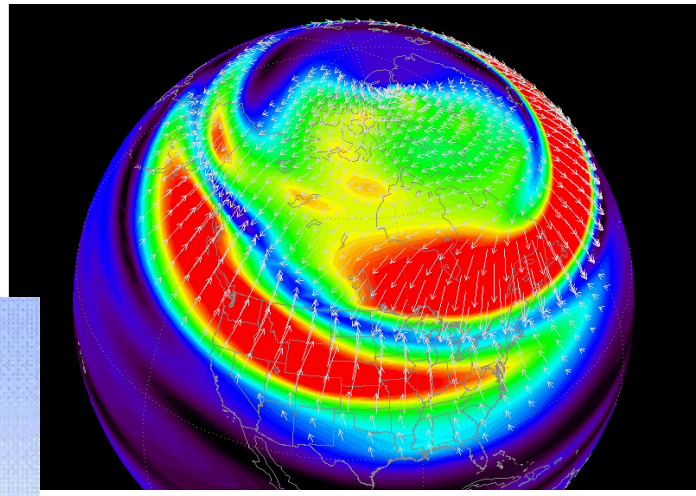


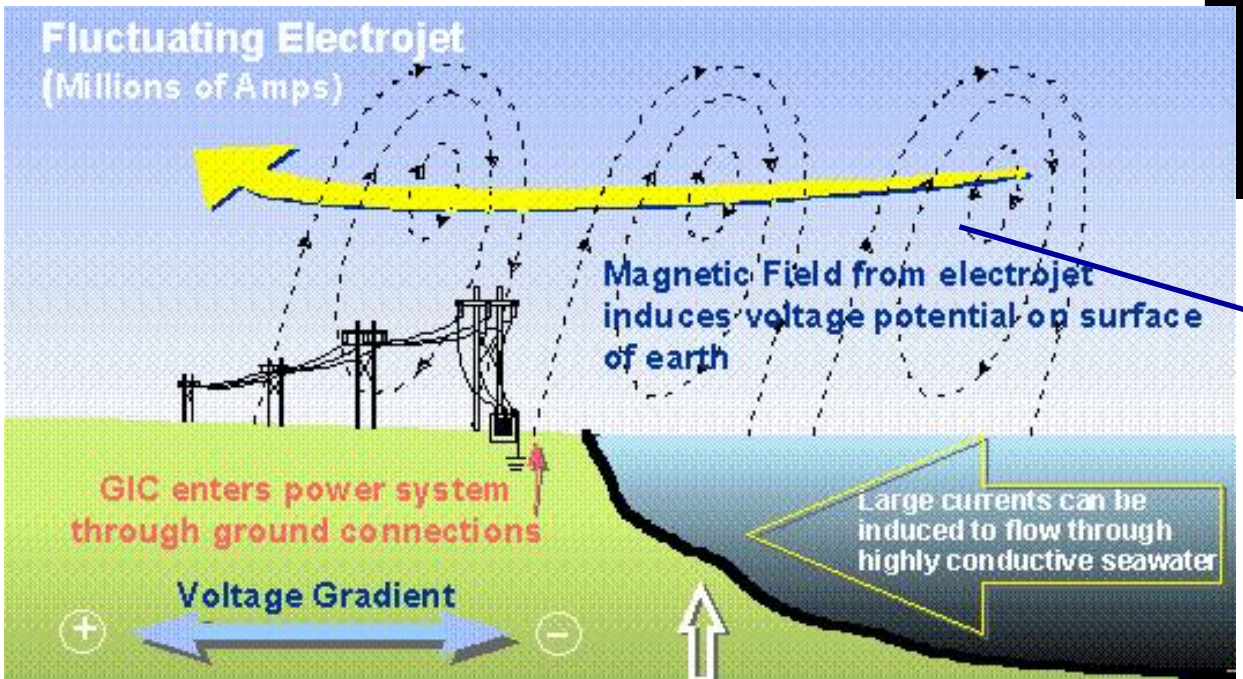


Intense Solar Activity

A Review of Power Grid Vulnerability to Solar Activity & Geomagnetic Storms

A rapidly changing geomagnetic field over large regions will induce Geomagnetically-Induced Currents (i.e. GIC a quasi-DC current) to flow in the continental interconnected Electric Power Grids

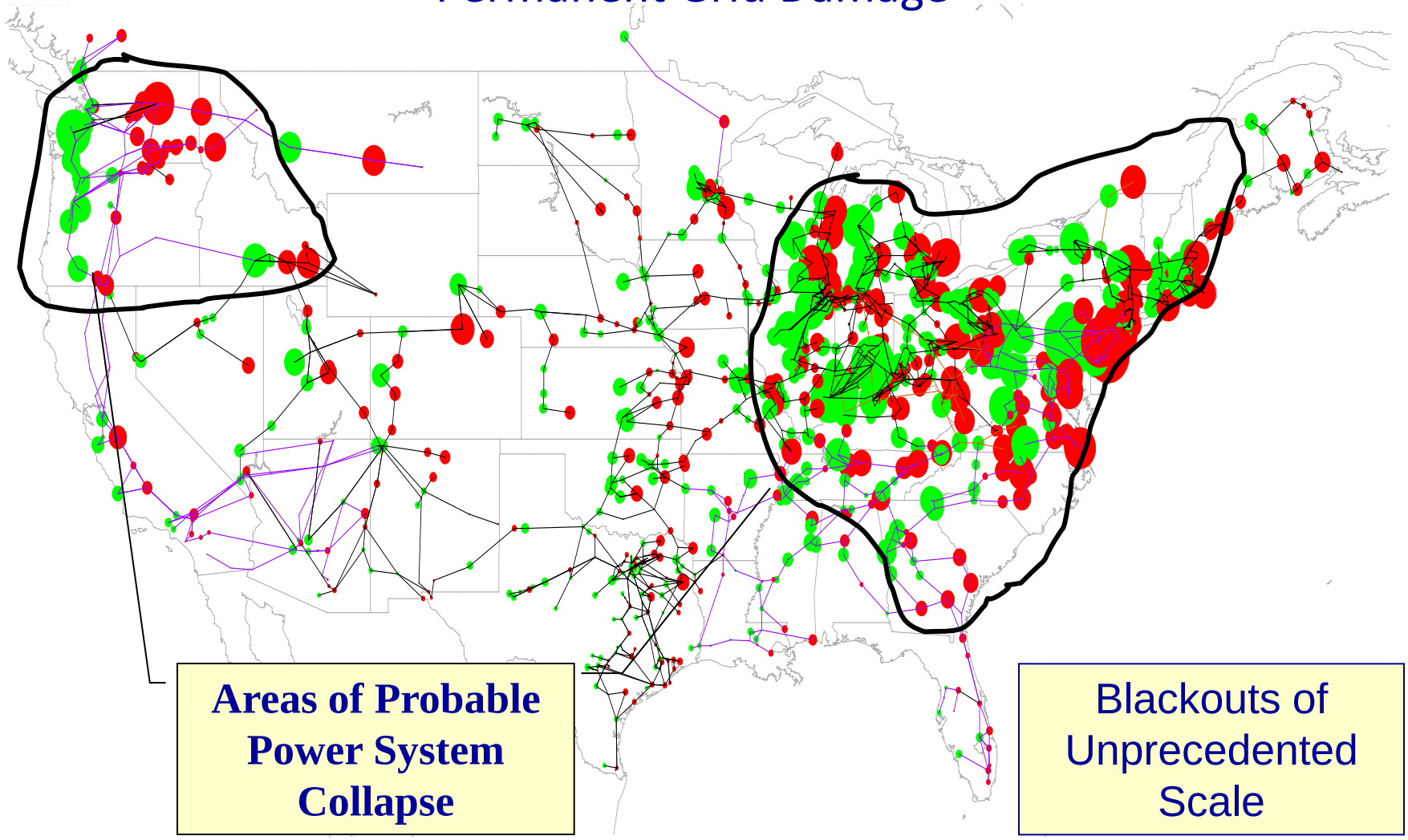




Storm causes Geomagnetic Field Disturbances from Electrojet Current that couple to Power Systems

A Review of Power Grid Vulnerability to Solar Activity & Geomagnetic Storms

GIC flow in transformers can cause Power Grid Blackouts & Permanent Grid Damage



A Review of Power Grid Vulnerability to Solar Activity & Geomagnetic Storms

GIC flow can also has potential to cause wide-spread catastrophic damage to key Power Grid Transformers Causing Restoration Problems

Salem Nuclear Plant GSU Transformer Failure, March '89

These Key Assets may take a *Year or More to Replace*

Internal Damage due to one storm

Great Geomagnetic Storms

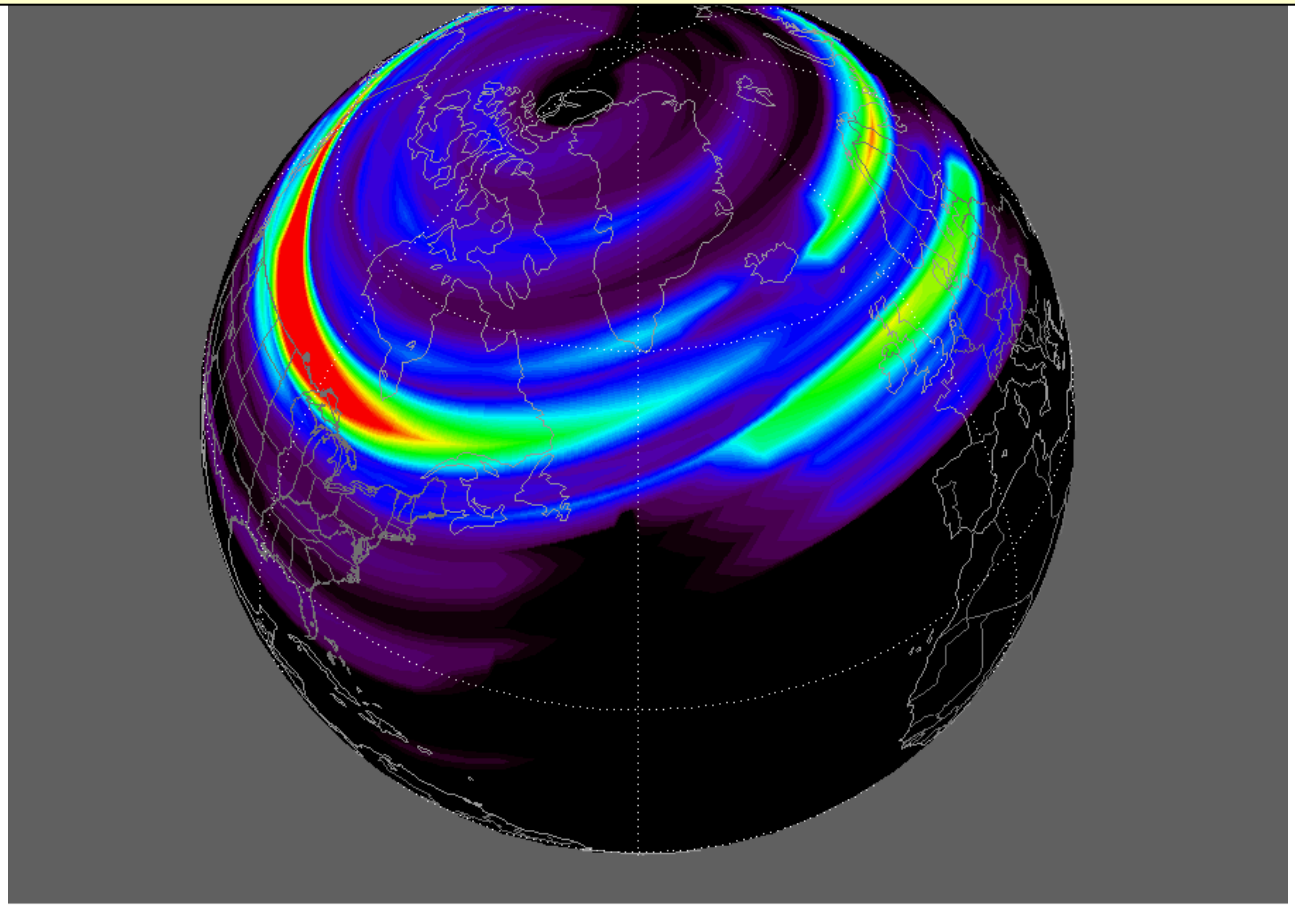
US Electric Grid Vulnerability Trends and Preparedness

- **Threat**
  - New Awareness that Geomagnetic Storm Severity is 4 to 10 Times larger than previously understood – Past Metrics did not measure risks correctly for power industry
- **Vulnerability**
  - Power Grid infrastructures have experienced a “Design Creep” over past few decades that have unknowingly escalated vulnerability to these threats – No Design Code Yet Exists
- **Consequences**
  - Power Supply is an essential scaffolding of modern society
  - All other Critical infrastructures will also collapse with long-term loss of Electricity

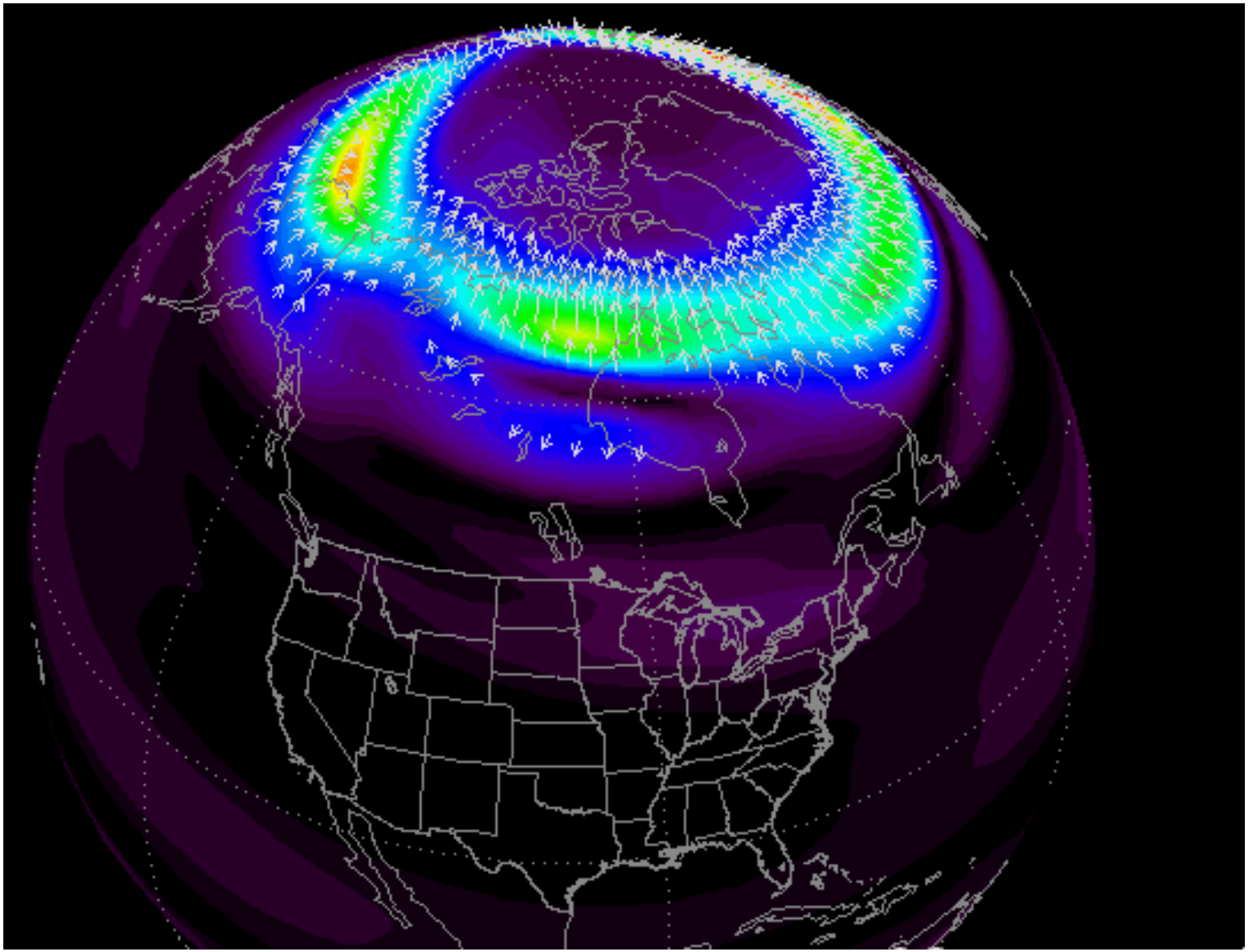
- **Risk** – Events have catastrophic potential, the ability to take the lives of hundreds of people in one blow, or to shorten or cripple the lives of thousands or millions more, impact future generations of society

Historic Storm Impacts

A Brief Overview of a Geomagnetic Superstorm & North American Power Grid Impacts March 13-14, 1989



March 13, 1989 – Storm 7:39UT



Time 2:39-2:58 EST (7:39-7:58 UT)

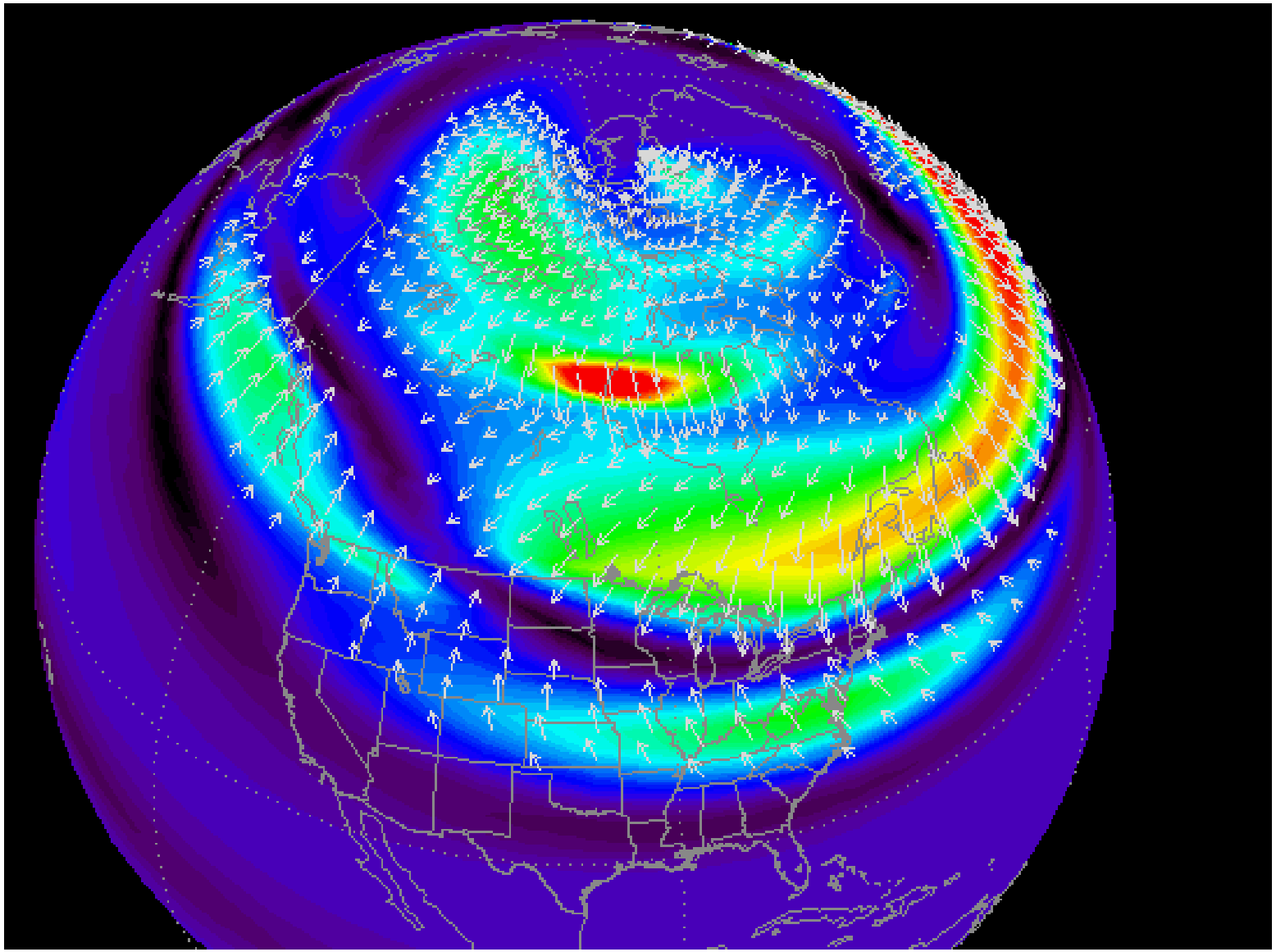
20 Minutes of Bad Space Weather

Reported Power System Events – March 13, 1989

Time 2:39-2:58 EST (7:39-7:58 UT)

Quebec Blackout in 92 Seconds at Intensity 0f ~480 nT/min

March 13, 1989 – Storm 21:40UT



Time 4:40-5:30 PM EST (21:40-22:30 UT)

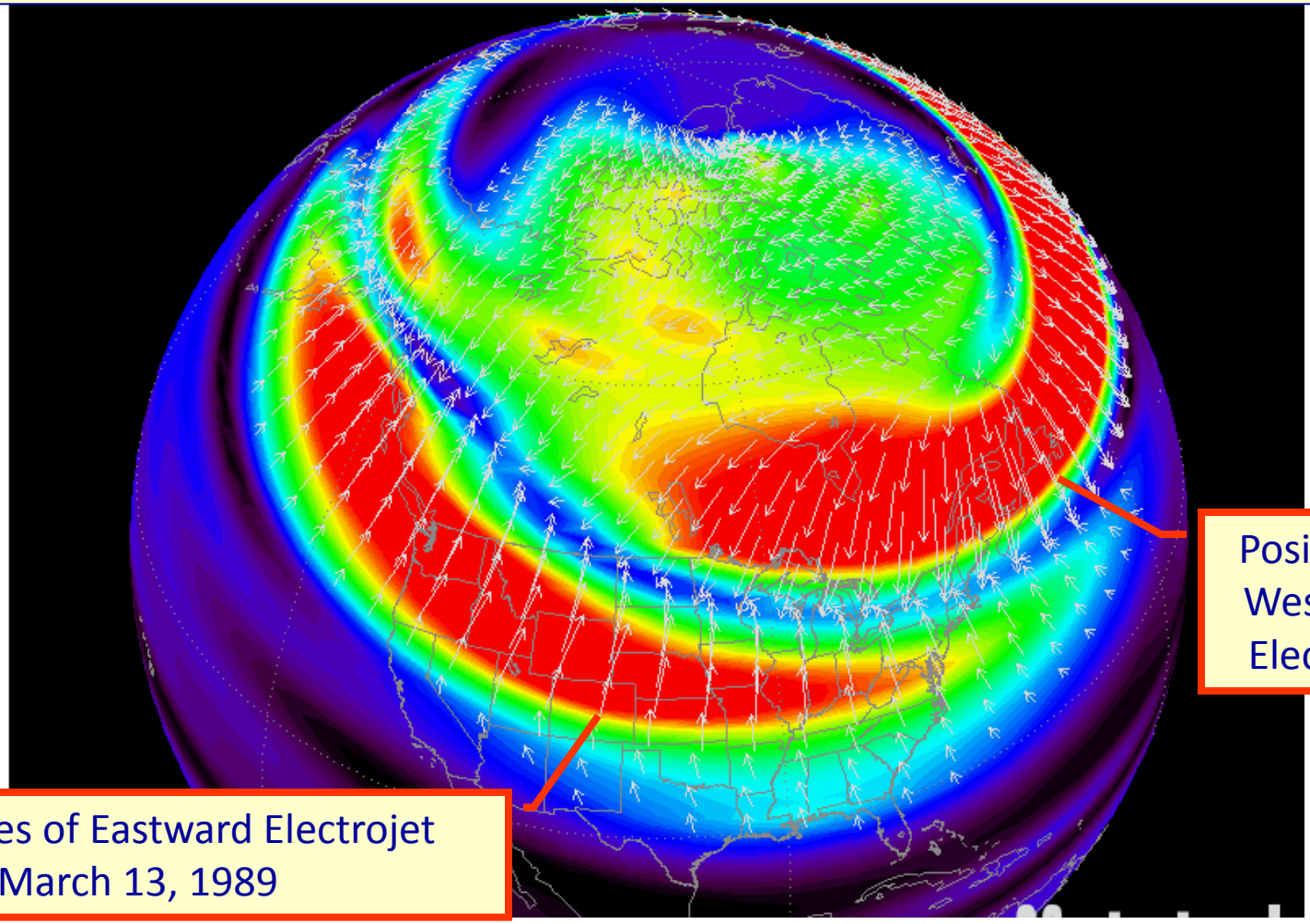
Reported Power System Events – March 13, 1989

Time 16:03-17:30 EST (21:03-22:30 UT)

Intensity over Mid-Atlantic Region
~300 nT/min

Great Geomagnetic Storms

March 1989 Superstorm & May 1921 Storm Comparisons

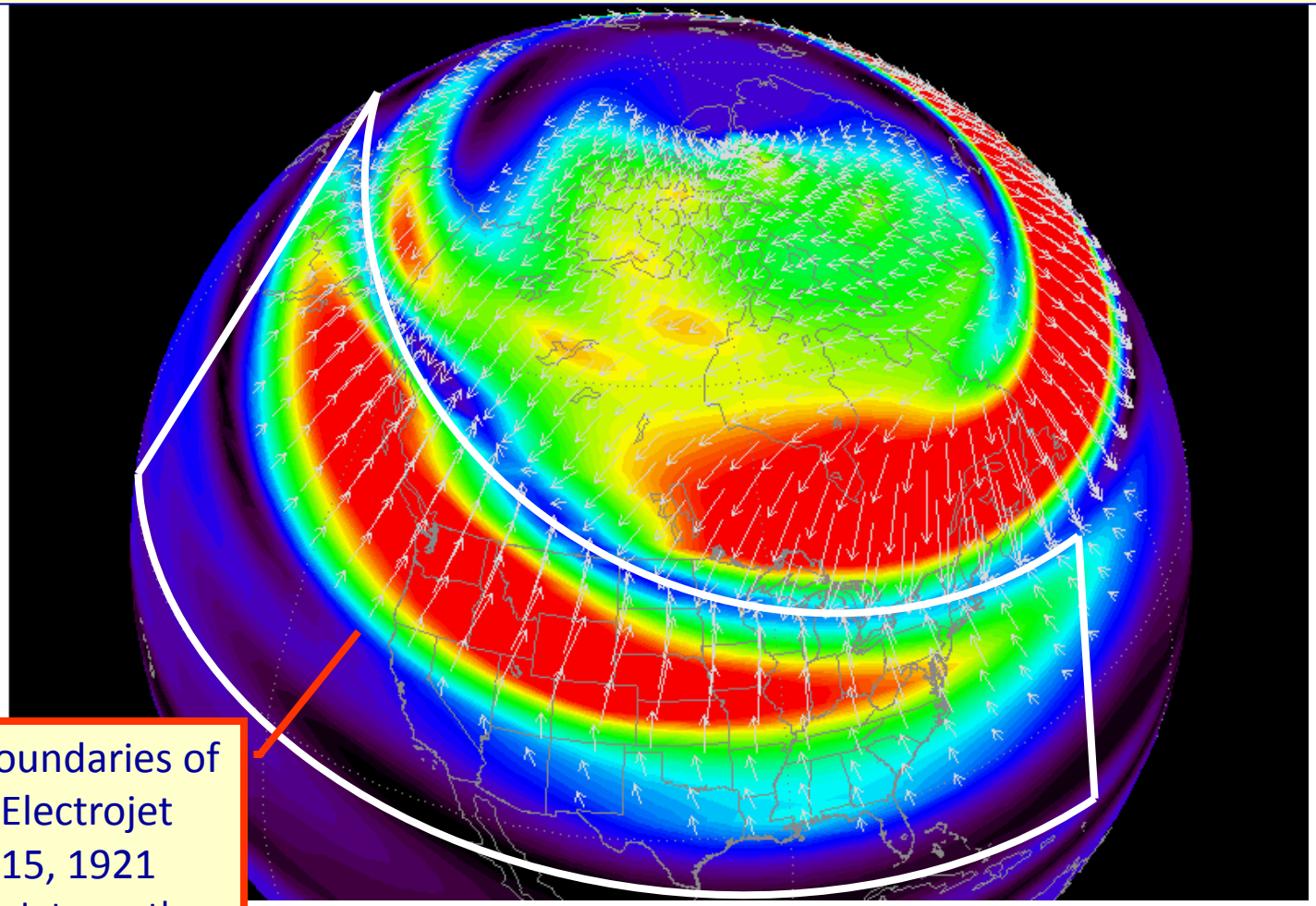


Position of Westward Electrojet

Boundaries of Eastward Electrojet
March 13, 1989

Great Geomagnetic Storms

March 1989 Superstorm & May 1921 Storm Comparisons

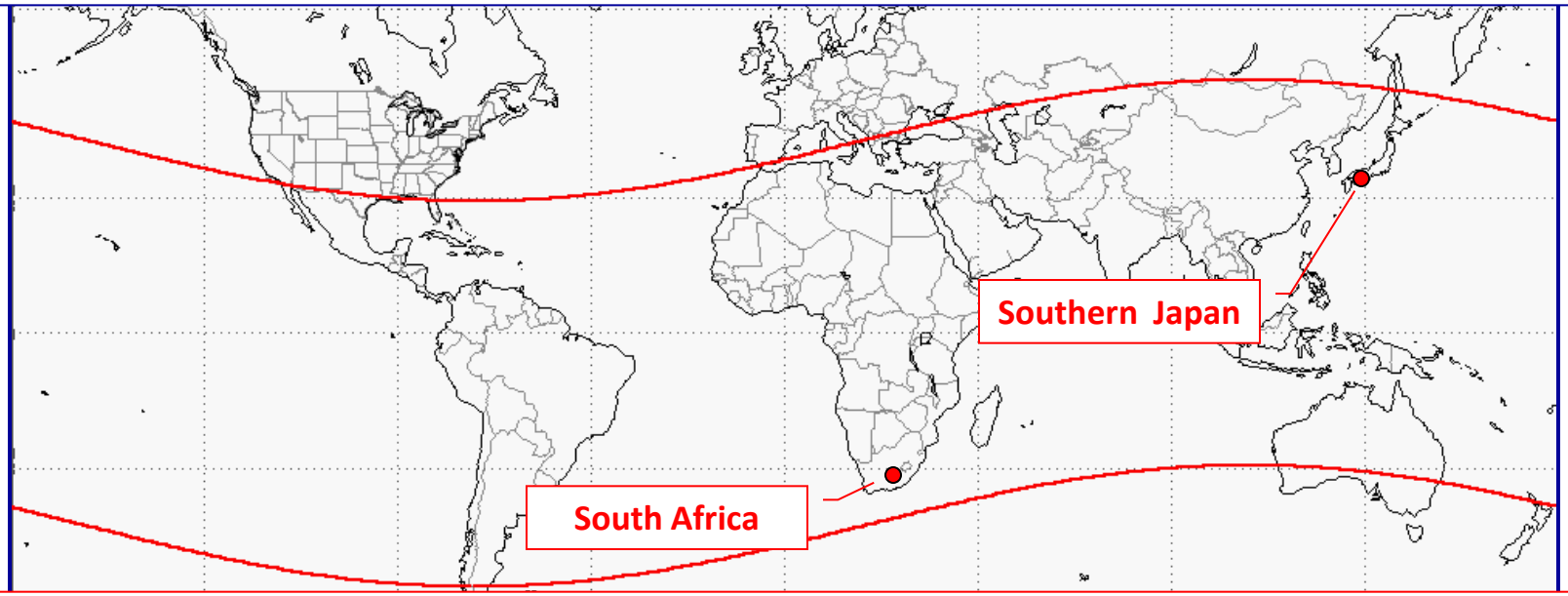


Estimated Boundaries of
Eastward Electrojet
May 14-15, 1921
Larger & More Intense than
March 1989

Geomagnetic Storms – GIC & Conventional Wisdom

Conventional Wisdom

- **Proximity to Electrojet Intensifications – Large Magnetic Field Disturbances**
- **High to Mid-Latitude Locations - Largest Magnetic Field Disturbances**
- **Power Grids at these Locations – Measured Large GIC's – Related Problems**
- **This did not explain Power Grid Problems Reported at Low-Latitudes**



A New Class of GIC Risks

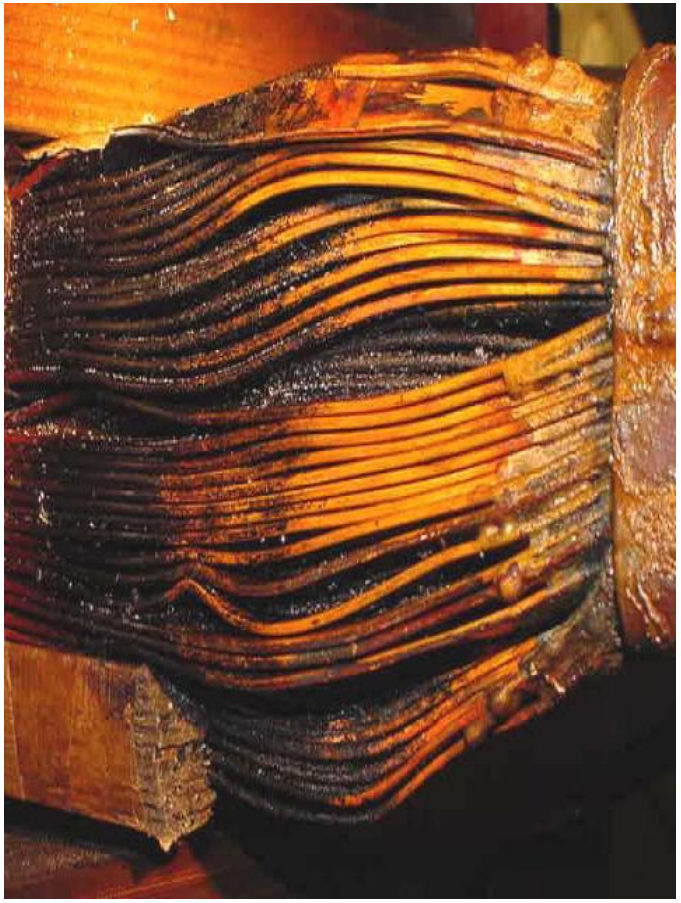
- **Large GICs are possible at Low-Latitudes**
- **Significant and Long Duration GIC's have been observed at Low Latitude Locations**
- **Differing Magnetospheric Processes are the Drivers for Geomagnetic Field disturbances**

Overview of South Africa EHV Transformer Failures due to Oct-Nov 2003 Geomagnetic Storms

Failures linked to Long Duration / Low Intensity GIC Exposure

Station 3 Gen Transformer 4
HV winding failure

Station 3 Gen. Transformer 5
evidence of overheating



Courtesy Eskom, Makhosi, T., G. Coetzee

Nuclear Plant GSU Transformer Incidents

Within 25 months after the March 1989 Storm

1. Salem
2. Oyster Creek
3. South Texas
4. Shearon Harris
5. Surry 1
6. Zion 2
7. WNP 2
8. Peach Bottom 3
9. D.C. Cook 1
10. Susquehanna
11. Maine Yankee
12. Nine-Mile

Latent Impacts of March 1989 Storm – Delayed Failures of Large Transformers at Nuclear Plants suspected across US

Nuclear Plant GSU Transformer Incidents

Nuclear Plants have some special vulnerability issues

- Severe Storms could initiate a Long Term Outage to large portions of the US electric grid **– Including many Nuclear Power Plants all at the Same Time**
- The Large Transformers in Nuclear Plants also have higher Exposure to GIC, making them more Vulnerable to damage/failure
- Transformer Damage could lead to large Fire & Disruptive Failure of the Exposed Transformer which could cause Collateral Damage to Vital Back-up and Cooling Systems at the Nuclear Plant
- The events at Fukushima have demonstrated that loss of outside power (Grid Blackout) and associated Plant Damage to Back-up Systems has severe consequences for both reactors and spent fuel pools
- Trends of Increasing EMP and RF Weapon Vulnerabilities for Nuclear Plant Control Systems (Fast Transient Vulnerability in addition to GIC Vulnerability)

Nuclear Plant GSU Transformer Incidents

Movie of Transformer Disruptive Failure – NOT DUE TO GIC

Above Movie is Disruptive Failure of ~3MVA Transformer
Nuclear Plant Transformers can be 400 Times Larger Capacity