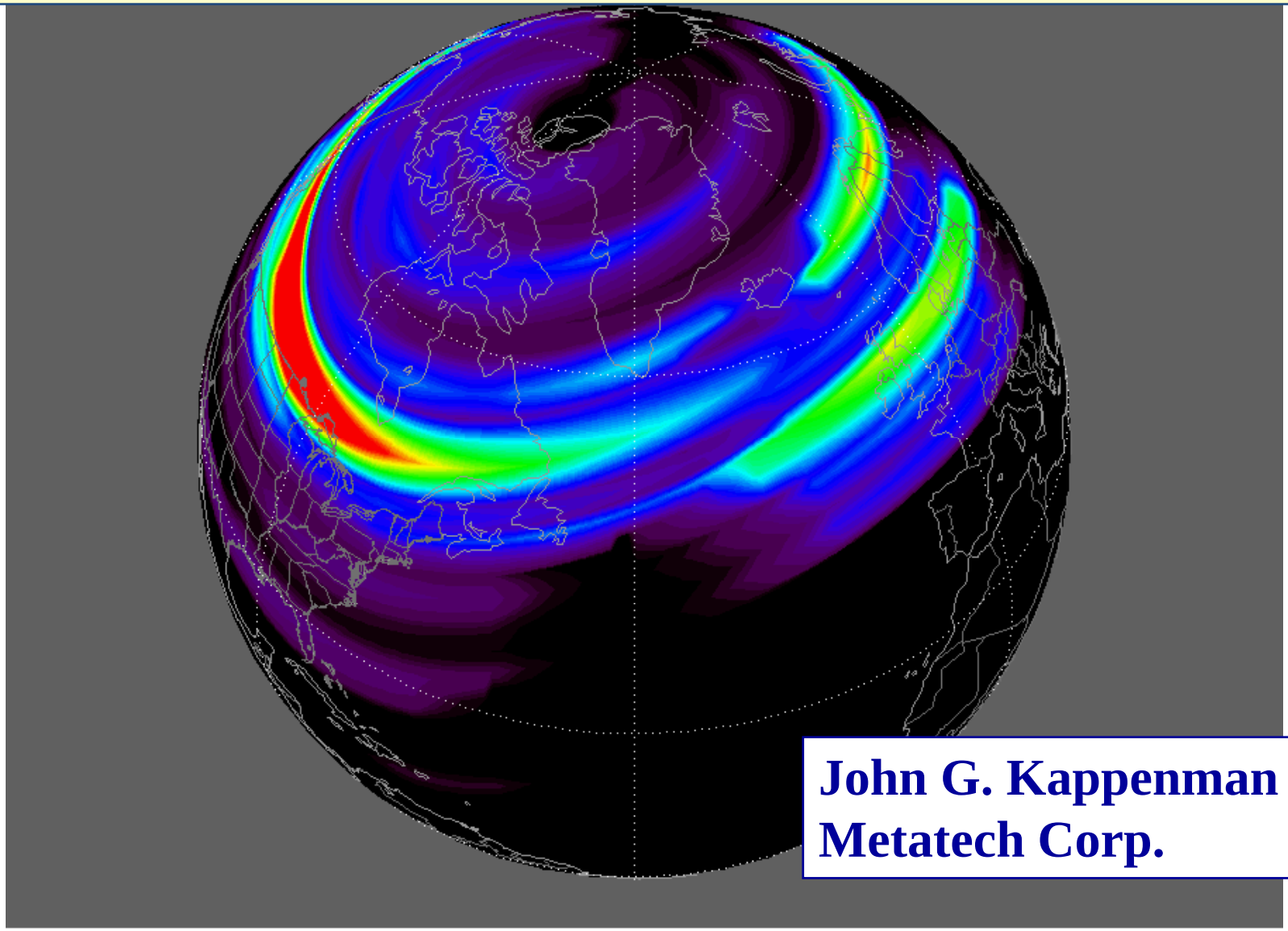
The Vulnerability of the US Electric Power Grid to Severe Space Weather Events



John G. Kappenman
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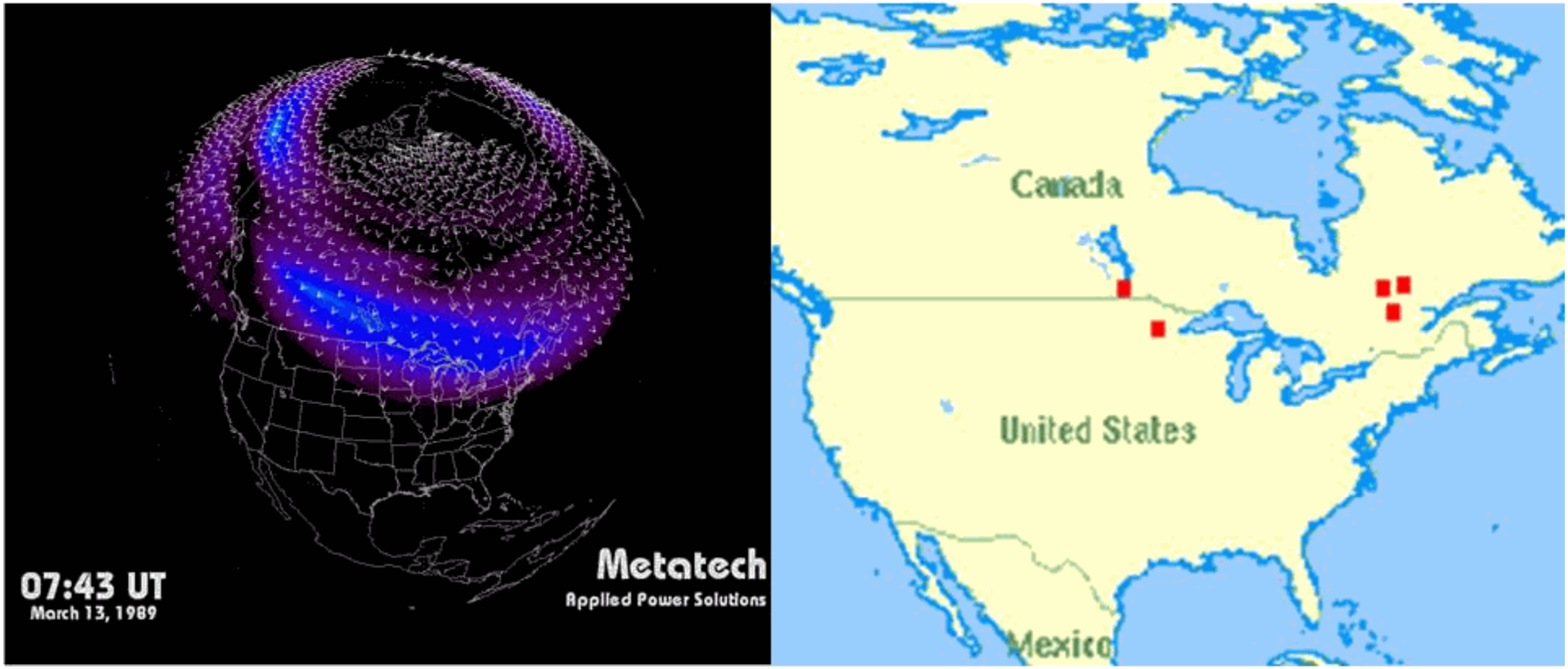
Review of Power Grid Vulnerability to Space Weather

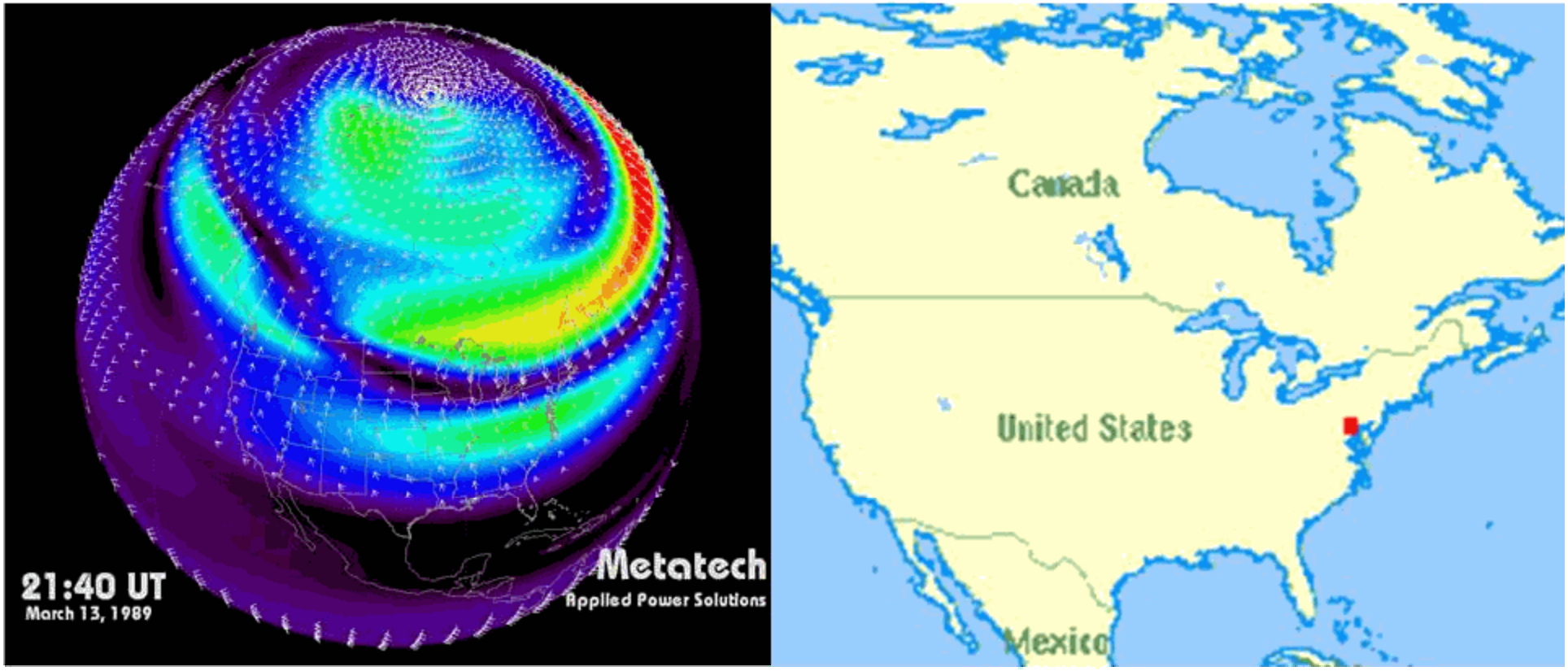
- The US Electric Power Grid is a Critical Infrastructure & Vulnerable to Space Weather
  - Electricity is largest energy segment of US ~40% of all energy consumed (petroleum only 22% of current US energy consumption)
- EMP Commission and FEMA Exec Order 13407 Investigation Results Indicate
  - Space Weather Risks have potential to create Large Scale Blackouts,
  - Permanent Damage to Transformer Assets and Lengthy Restoration
- Loss of Electric Supply will Impact all other Interdependent Infrastructures
  - Potable Water distribution, waste treatment impacted within several hours,
  - Loss of perishable foods and medications in about 12-24 hours,
  - Immediate or eventual loss of heating/AC, sewage, phones, transportation, fuel resupply, etc.

A Quick Overview of the March 13-14, 1989 Geomagnetic Storm and North American Power Grid Impacts



5 minutes of storm conditions that precipitated the Quebec blackout

A Quick Overview of the March 13-14, 1989 Geomagnetic Storm and North American Power Grid Impacts



30 minutes of storm conditions later that day and impacts observed across the US

Great Geomagnetic Storms
Disturbance Intensity Perspectives

•Impacts on North American Power Grid on March 13-14, 1989 occurred at disturbance intensities of ~300-500 nT/min

•Disturbance intensities of >2000 nT/min have been observed at latitudes of concern for US power grid infrastructure on at least 3 occasions since 1972

•Disturbance intensity of ~5000 nT/min was estimated for storm on May 14-15, 1921 (estimated to be largest storm of 20th Century and comparable to Carrington Event of 1859)

•Power Grids should expect Storms 4 to 10 Times More Intense than the March 1989 Storm

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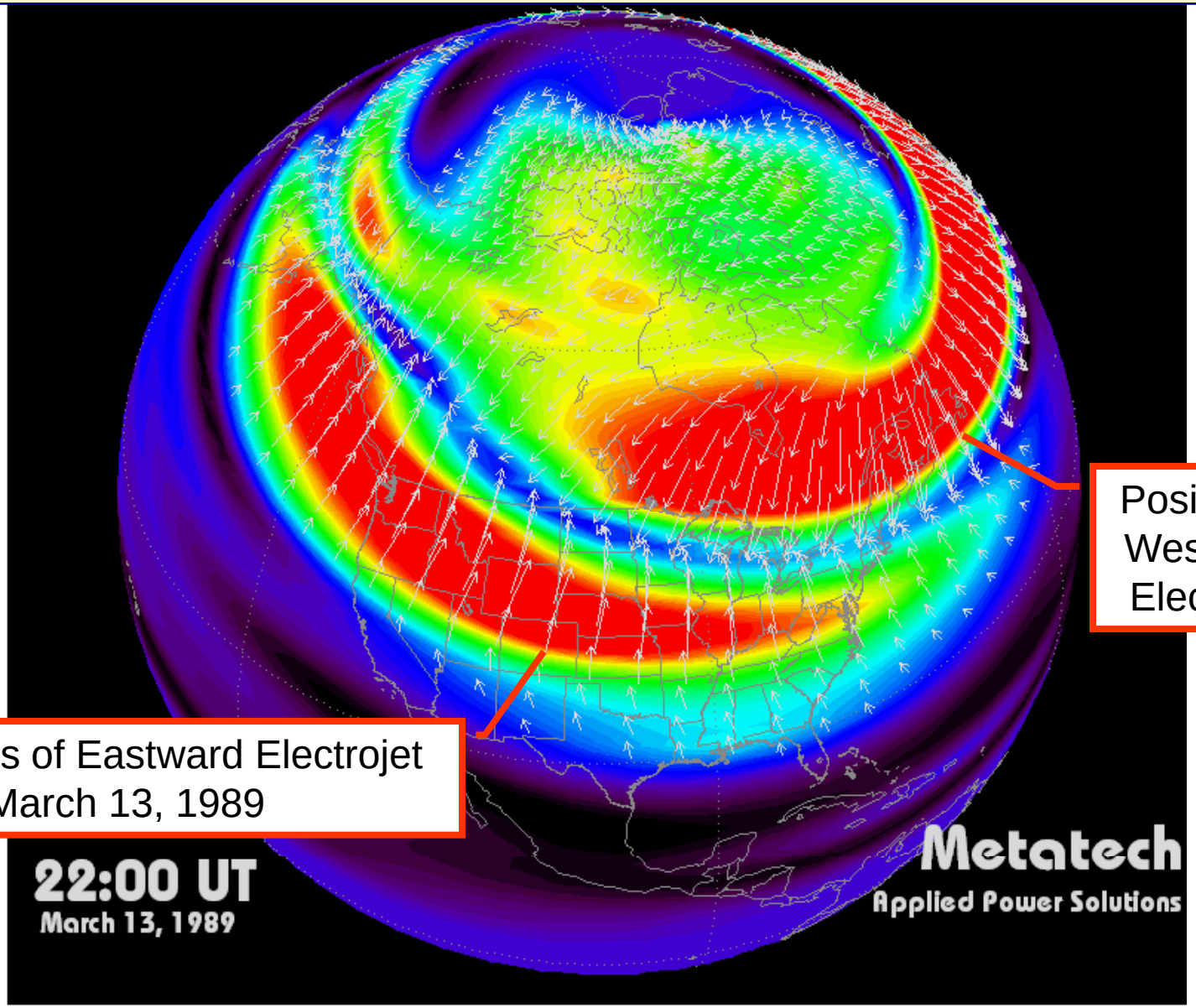
Great Geomagnetic Storms

March 1989 Superstorm & May 1921 Storm Comparisons



Great Geomagnetic Storms

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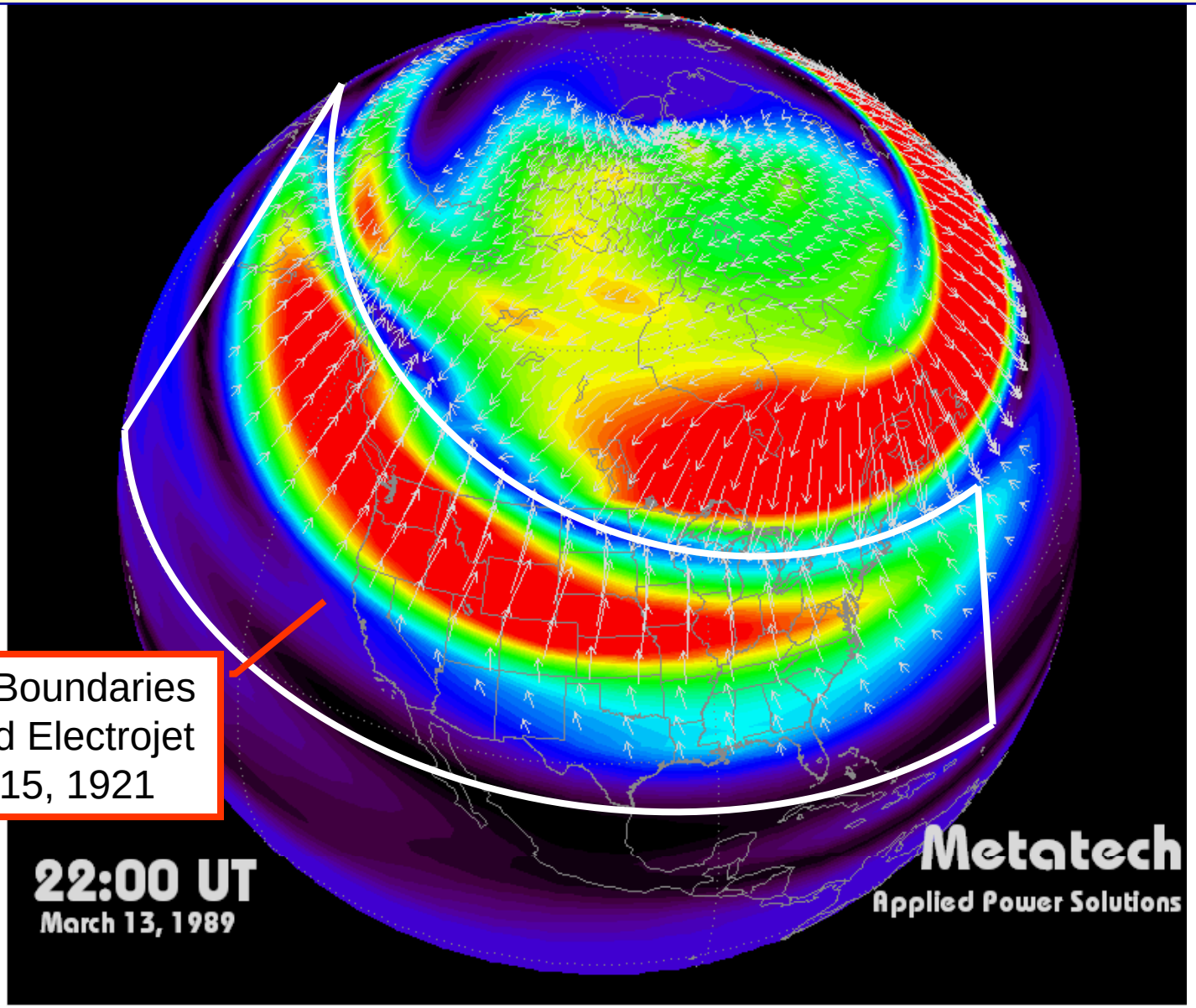

Estimated Boundaries
of Eastward Electrojet
May 14-15, 1921

Great Geomagnetic Storms

US Electric Grid Vulnerability Trends and Preparedness

- New Awareness has developed on the Extremes of Severe Geomagnetic Storms

- Current Design Practices of Electric Grids have unknowingly and greatly escalated the Risks and Potential Impacts
  - Un-Recognized Systemic Risk – No Design Code Yet to minimize this Threat
  - Present Operational Procedures are based upon limited experience, do not reduce GIC levels and are inadequate for Severe Storms

- Space Weather Community use of K and G Indices have also not communicated the real risks to the Electric Power Industry
  - Indices saturate and reach Maximum Levels at Low Thresholds
  - Many K9 Storms (post March 1989) have been less intense than March 1989 Storm – with unintended consequences for power grid operators
  - False Sense of Security & Complacency by Power Grid Operators

- **Power Grids should expect Storms 4 to 10 Times More Intense than the March 1989 Storm**

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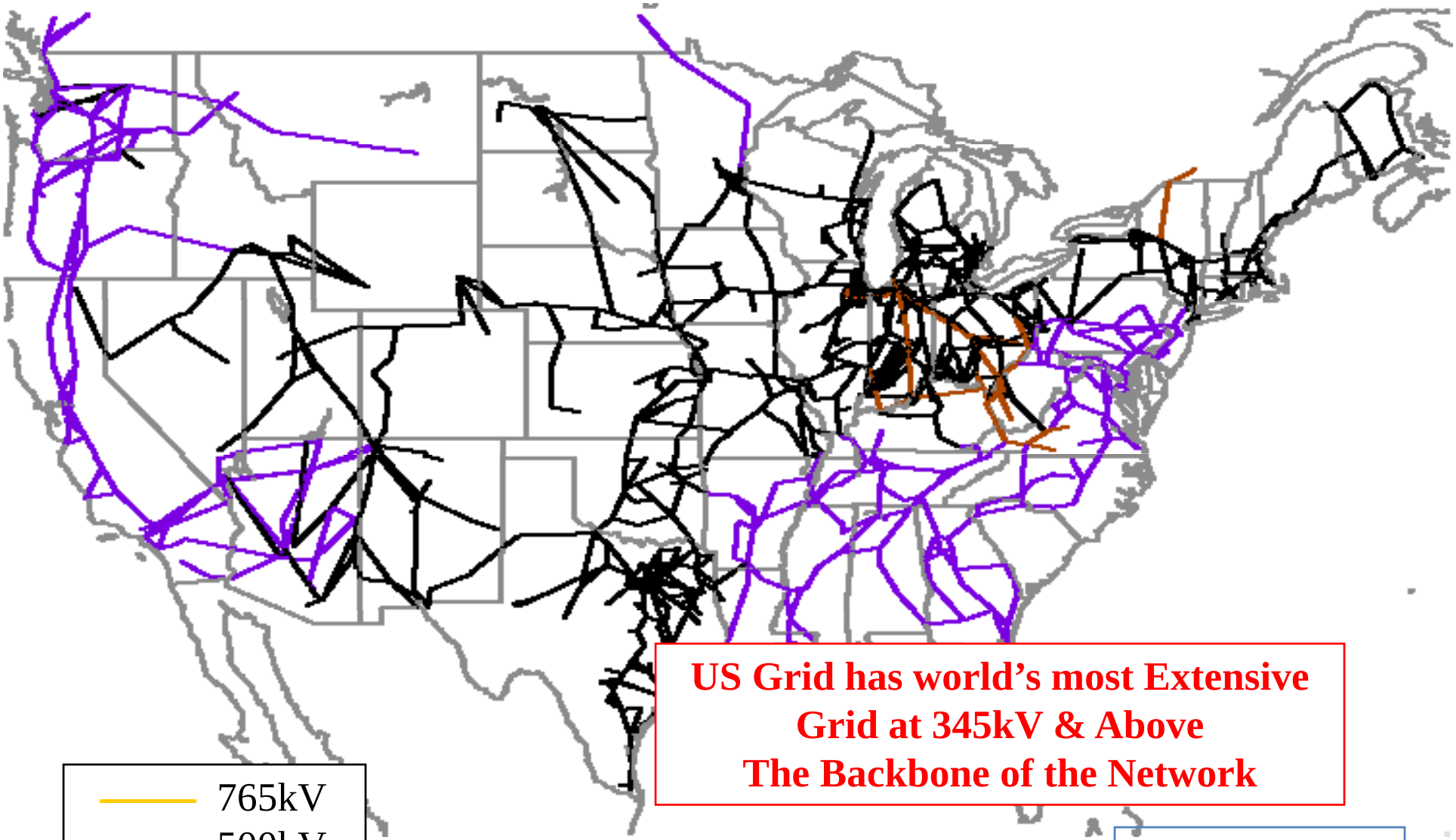
US High-Voltage Transmission Network Model for GIC Simulation



US Grid has world's most Extensive Grid at 345kV & Above The Backbone of the Network

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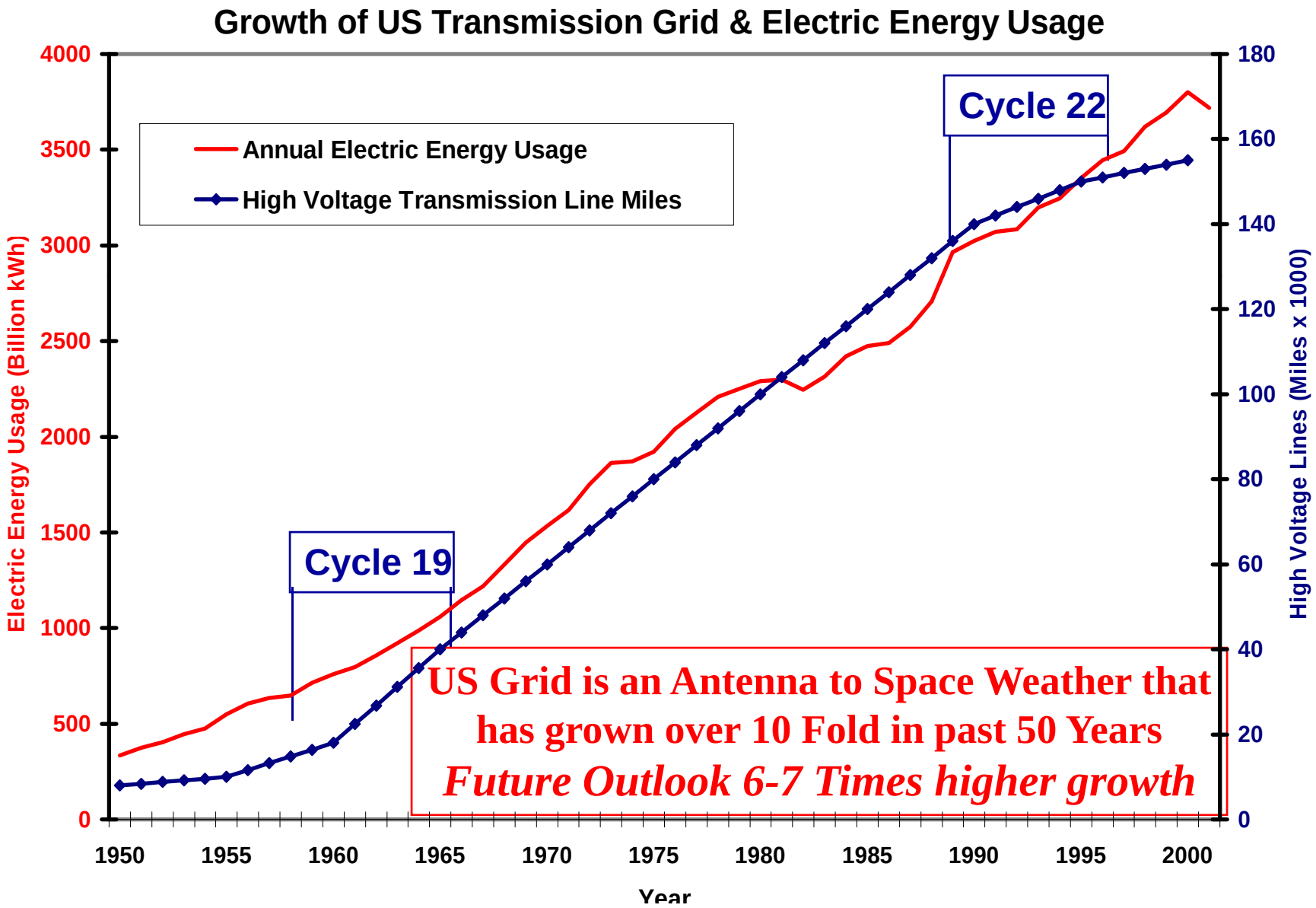
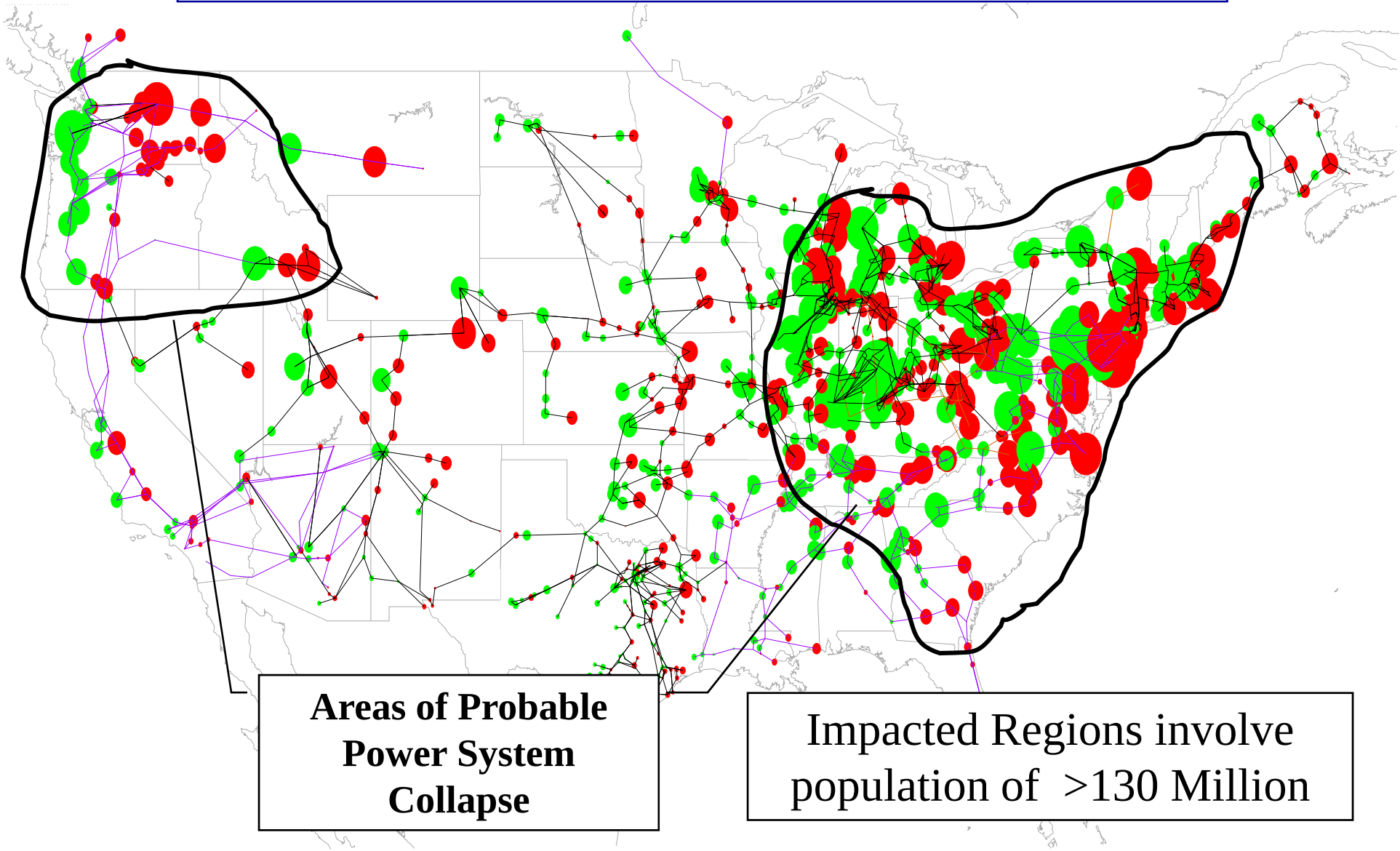
GIC Risk Factor – Growth of Transmission Network

The larger the Grid – the Larger the Antenna to cause GIC



Severe Geomagnetic Storm Disturbance Scenario

Power System Disturbance and Outage Scenario of Unprecedented Scale

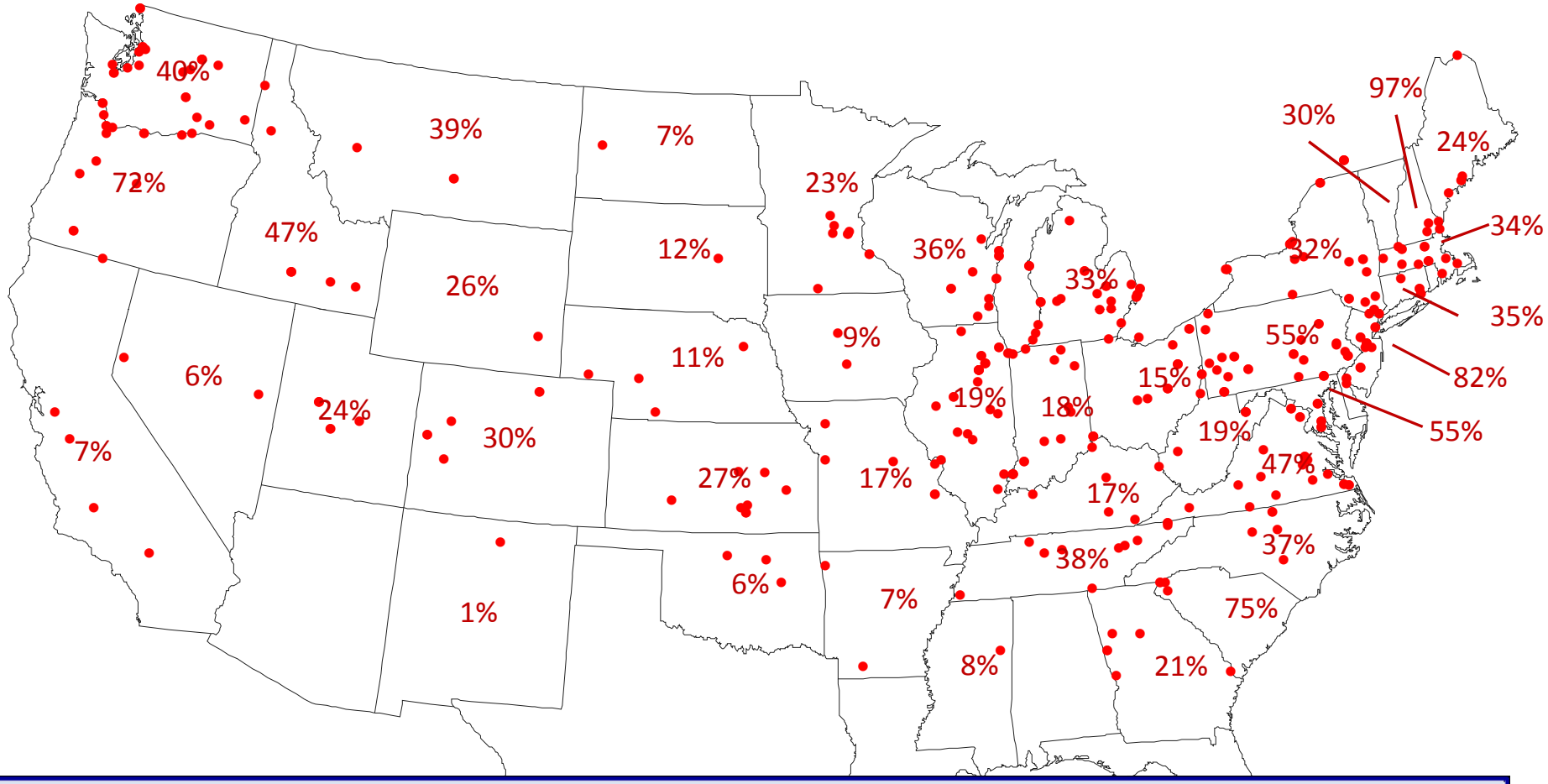


Areas of Probable Power System Collapse

Impacted Regions involve population of >130 Million

Severe Geomagnetic Storm Scenario

At-Risk 345kV, 500kV, & 765kV Transformers



Estimated that ~365 large EHV Transformers would have sufficient GIC exposure to be At-Risk of permanent damage & loss – replacement could extend into 4-10 years at current world production rates

Power Grid Vulnerability and Future Outlook Summary

- Historically large storms have potential to create Power Grid Blackouts and Transformer Damage of unprecedented proportions
  - Long term blackout, lengthy restoration times, and
  - Chronic shortages & associated social impacts (multiple years) are possible

- Economic and societal costs could be also of unprecedented levels;
  - August 14, 2003 Northeast Blackout Cost Estimate - **$4 - $10 Billion**
  - Hurricane Katrina Cost Estimate - **$81 - $125 Billion**
  - **Severe Geomagnetic Storm Scenario ~$1 - $2 Trillion in 1st Year**
    Depending on Damage, Full Recovery could take 4 – 10 Years

- Improved Situational Awareness for Power Grid Operators is needed and is readily available
  - Emphasis on disturbance environments/GIC levels instead of ambiguous K/G Indices

- **Major Emphasis should be focused on Preventing Storm-Related Catastrophic Failure** - Remedial Design measures for the Grid (transformer neutral resistors) are readily feasible and cost effective

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