Space Weather Hazards to the Electric Grid

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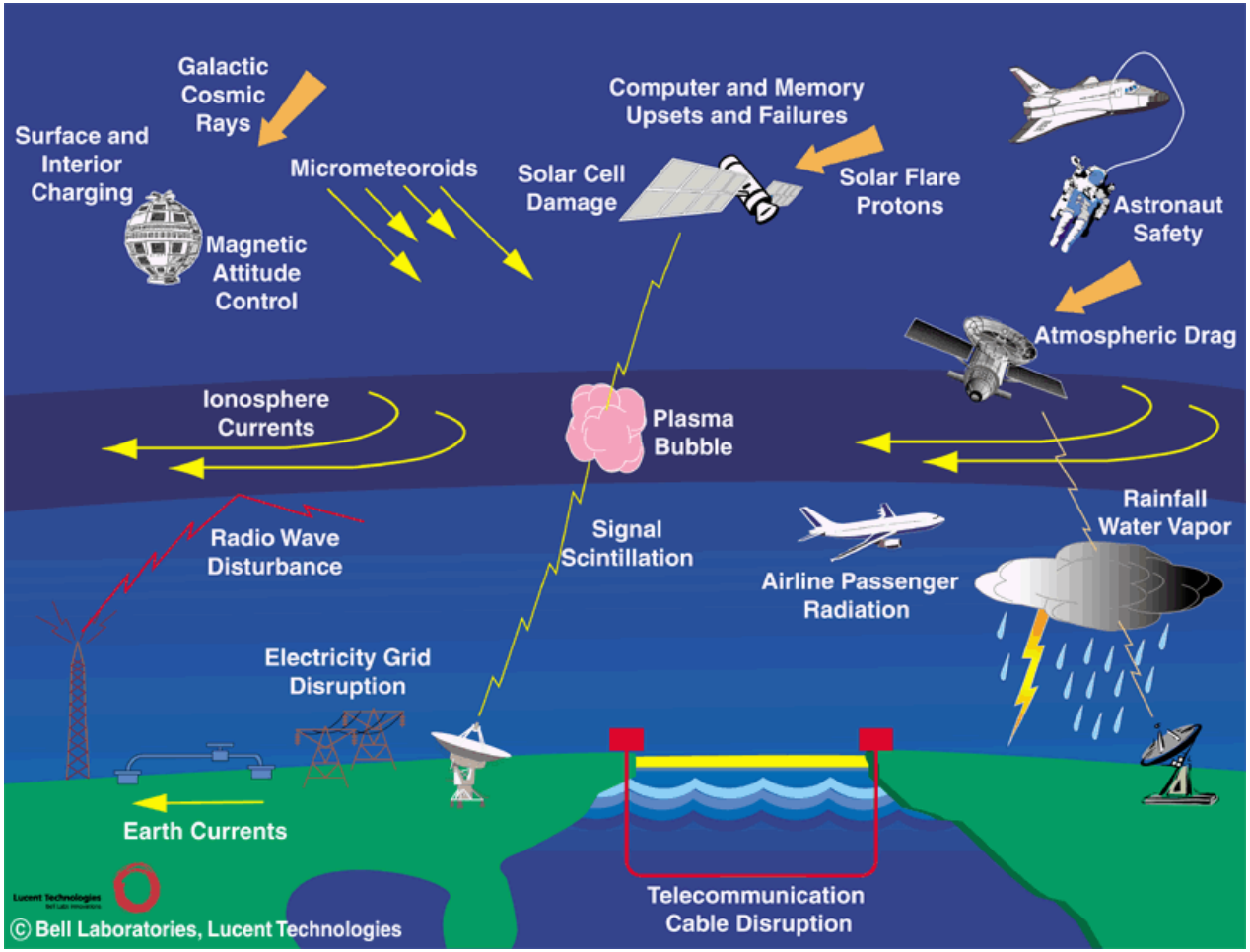
Space Weather Effects



Space Weather: Why worry?

- We've had large storms in the past (e.g. 1859, 1921), with no severe impact, why worry about it now?
- Because our vulnerability to solar storms has increased dramatically.
  - Power grid
    - More, and longer, power lines
    - Power lines with higher kV rating
    - Aging population of transformers
  - Increased satellite dependence
    - Navigation
    - Communication
    - Transaction timing

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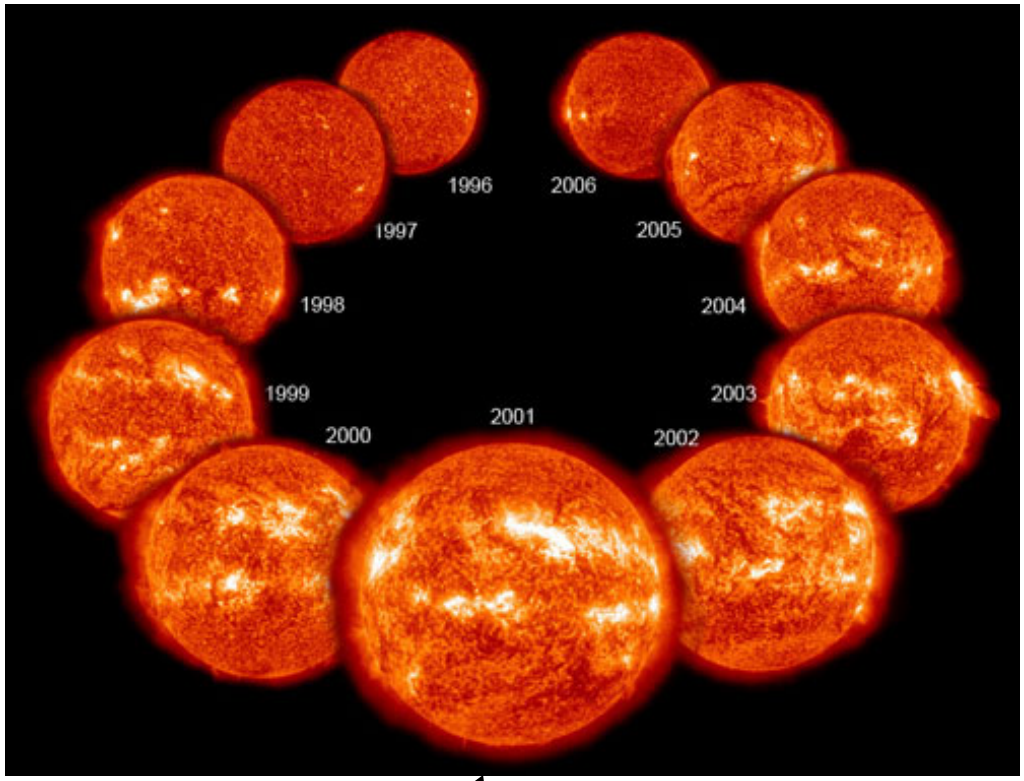
The Solar Activity Cycle

- Our Sun has a magnetic activity cycle
- Average cycle length is 10.5 years
- Sunspots are areas where the magnetic flux breaks through the solar surface

Cycle 23 Schematic



NASA: SOHO EIT 304Å

- Cycle 24 peak predicted to occur late 2013
- High risk of storms within ~3 years of peak
- Risk possibly skewed to after the peak (so 2013 – 2016/17)

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Solar Storm Events

- Solar Flares
- Solar Particle Events
- Coronal Mass Ejections

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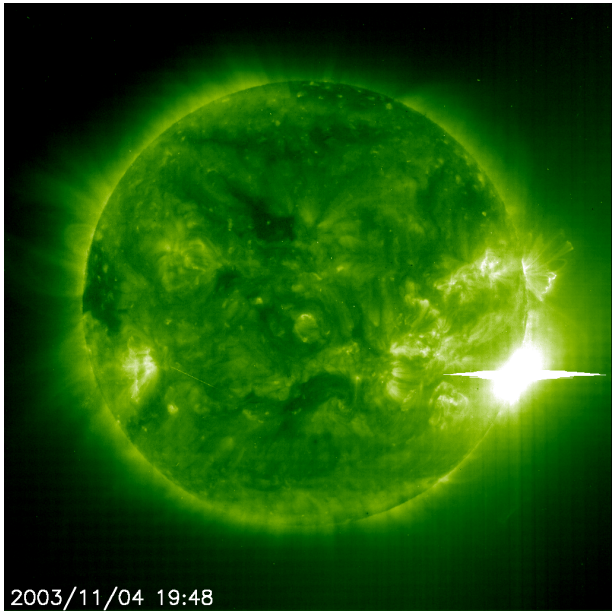
Solar Storm Events

Solar Flares

- A brief, intense burst of energy in the form of photons.
- Energy is released across the entire electromagnetic spectrum from gamma rays to radio waves.
- Travel time to Earth is 8 minutes.
- Strong flares interfere with radio communications.
  - *"Delta reroutes flights as solar storm hits Earth"* – Jan 24, 2012, Wall Street Journal



SOHO EIT 195Å

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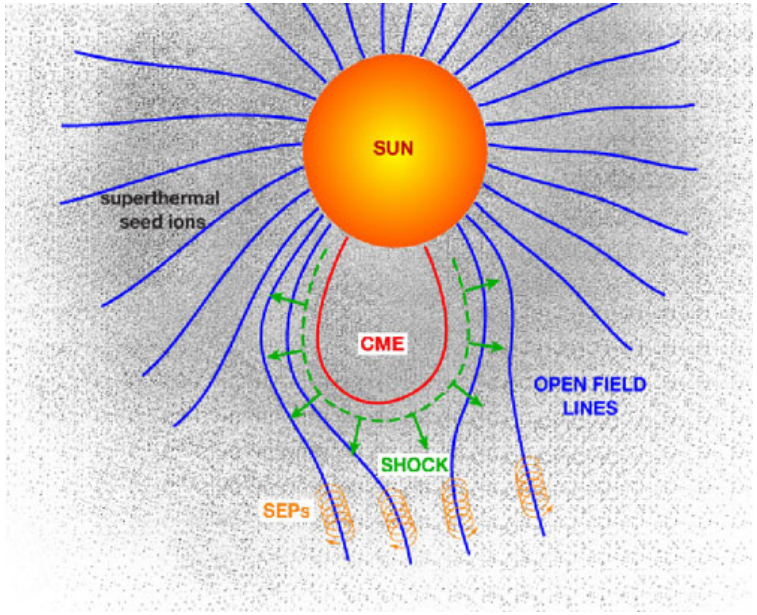
Solar Storm Events

Solar Particle Events

- "Prompt" emission of solar energetic particles (SEPs) along with flare
- SEPs also accelerated by shock waves as CMEs leave the Sun
- Proton energies can reach 1GeV
- Pose a hazard for humans in space and on polar flight routes



Credit: Naval Research Lab

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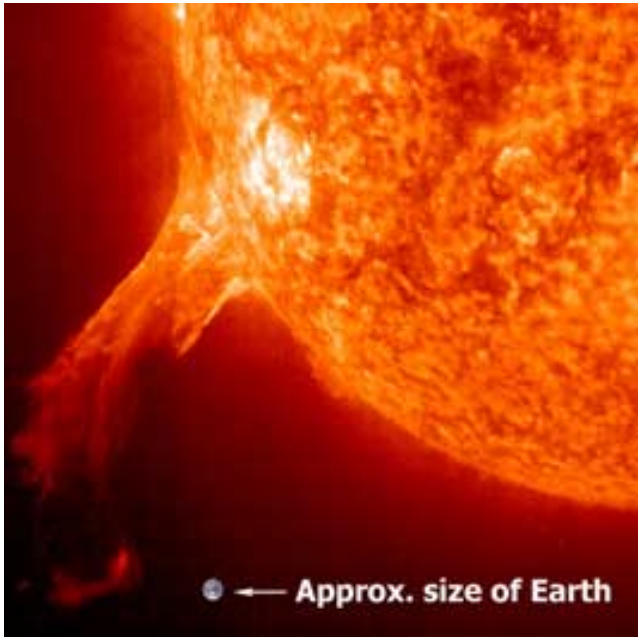
Solar Storm Events

Coronal Mass Ejections (CMEs)

- A large bubble of magnetized plasma is hurled into interplanetary space.
- Variable travel time: the fastest recorded travel time was 14 hours, the slowest 90 hours.
- CMEs are ***a major threat to the power grid***.



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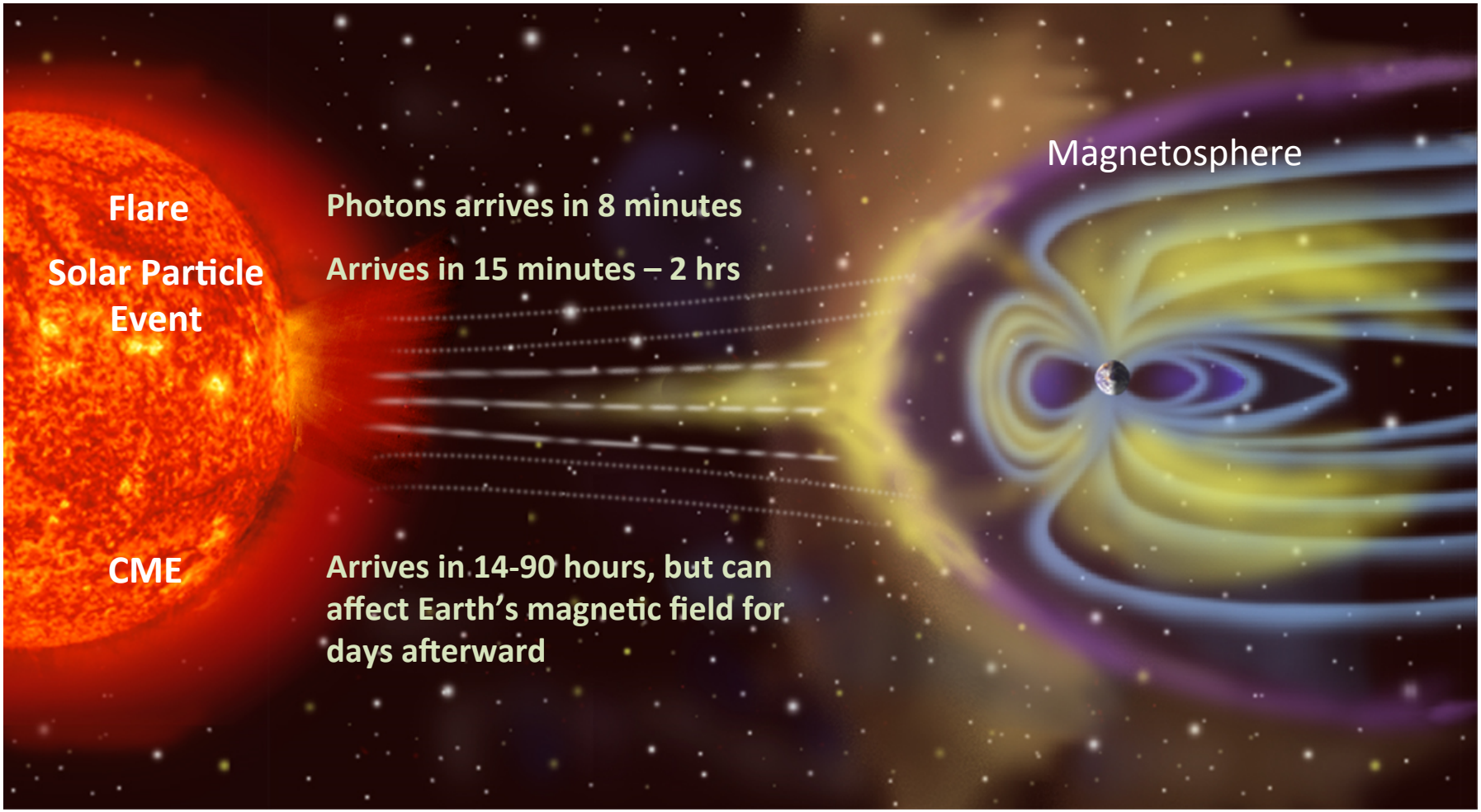
Solar Storm Events



SOURCE: http://sec.gsfc.nasa.gov/popscise.jpg

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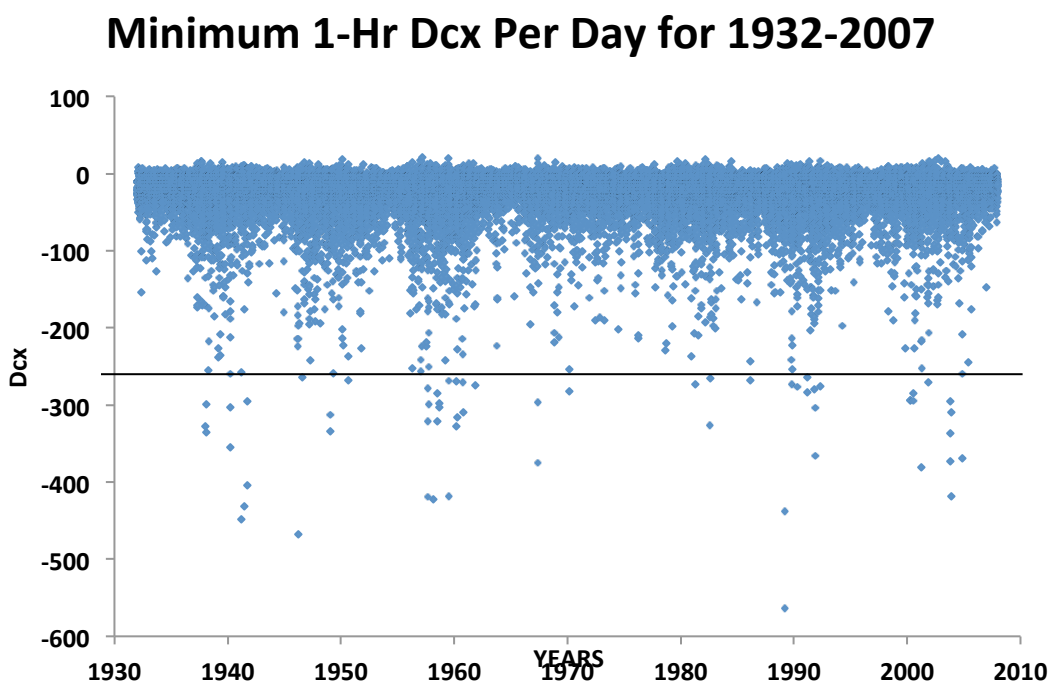
NOAA Geomagnetic Storm Scale

Level	Qualitative Strength	Power System Effects	Frequency
G5	Extreme	Widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage.	4 days per cycle
G4	Severe	Possible widespread voltage control problems. Some protective systems will mistakenly trip out key assets from the grid.	60 days per cycle
G3	Strong	Voltage corrections may be required, false alarms triggered on some protection devices.	130 days per cycle
G2	Moderate	High-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage.	360 days per cycle
G1	Weak	Weak power grid fluctuations can occur.	900 days per cycle

Probability of storms is not constant in time



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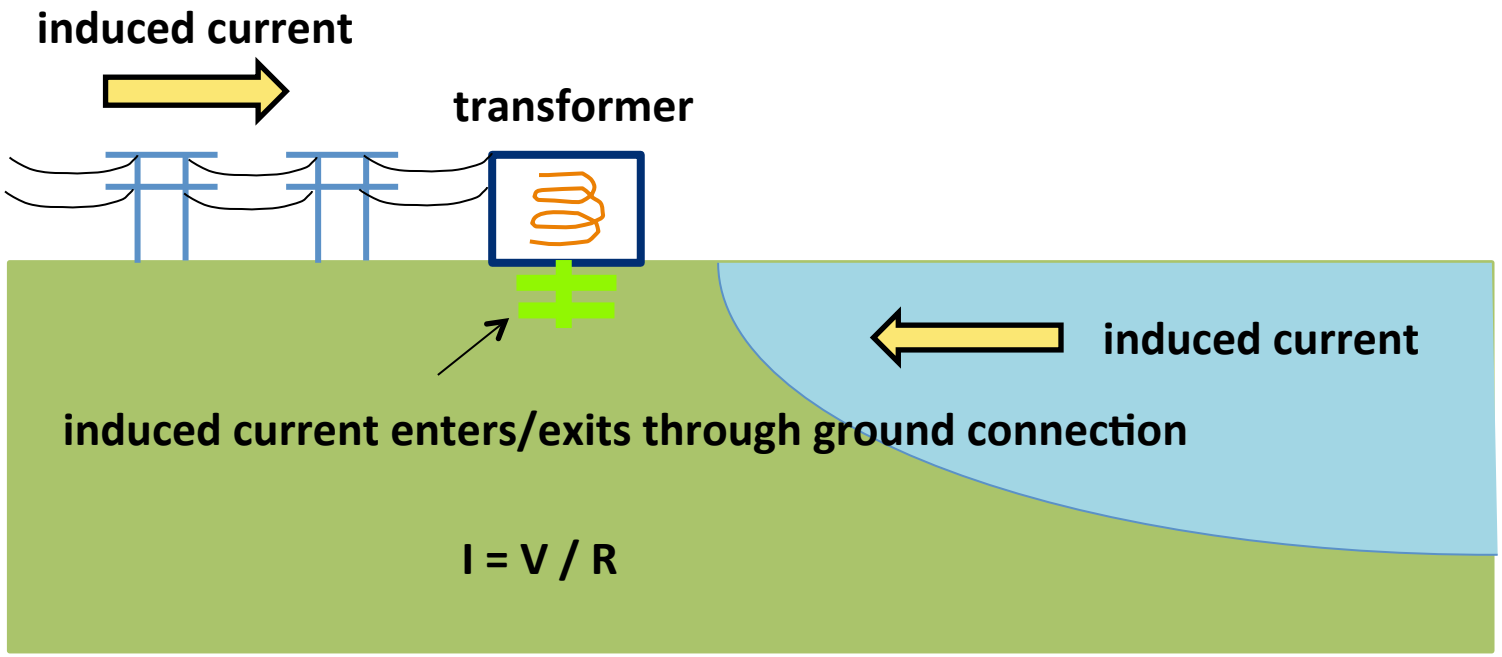
Geomagnetically-Induced Currents

dB/dt - fluctuating magnetic field induces an electric field



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Geomagnetically-Induced Currents

- Transformers run *alternating current (AC)*, but GIC are effectively *direct current (DC)*
- This extraneous DC can cause rapid, extreme heating in transformers
- Outright failure can occur rapidly
- If failure does not occur, cumulative GIC damage still reduces transformer lifetime

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Geomagnetically-Induced Currents

- Characteristics that increase the likelihood of GIC damage
  - Resistive ground
  - Northern latitude
  - Located near coast
  - Single-phase transformer
  - Length of power lines
  - kV rating of power lines

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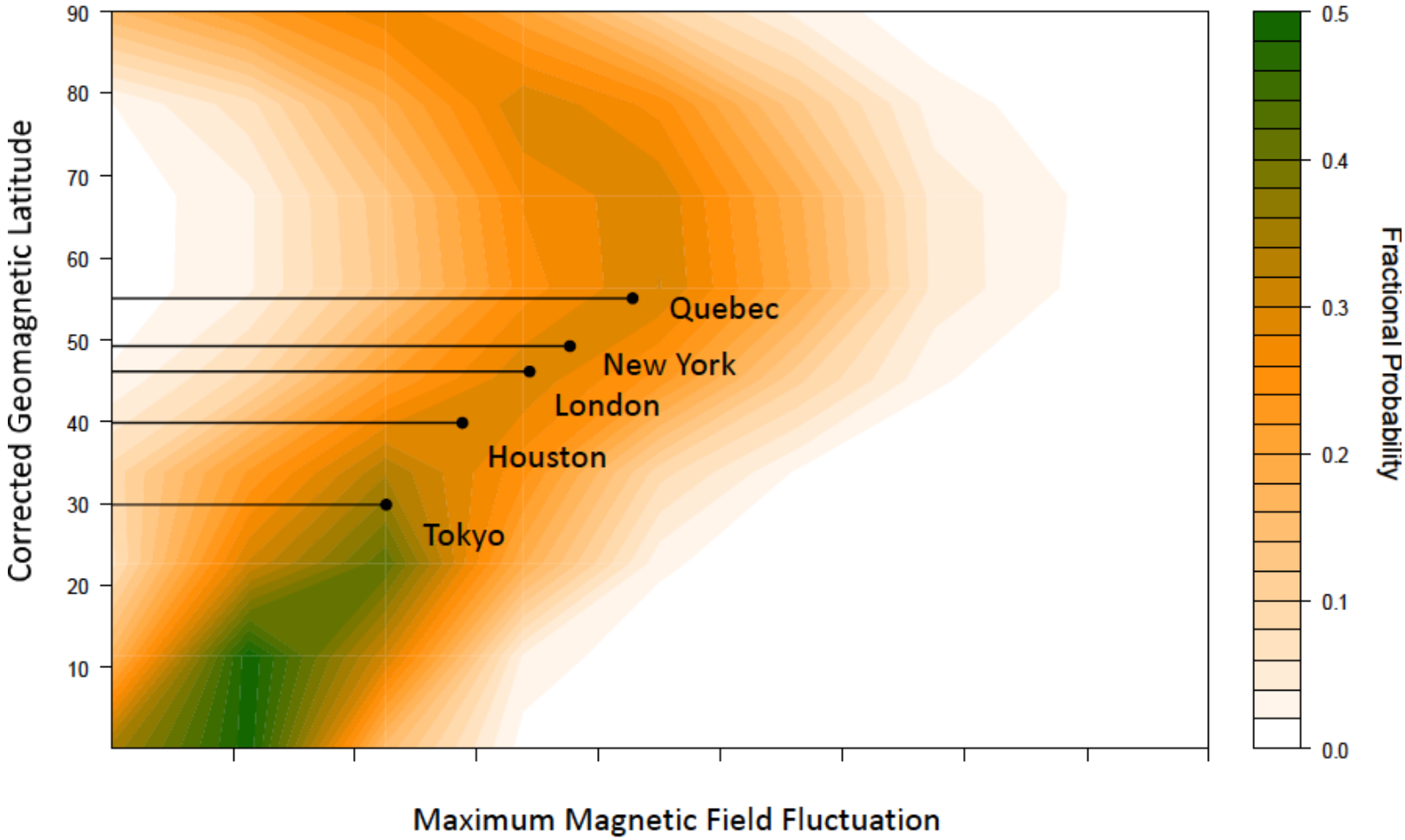
Carrington-level risk map



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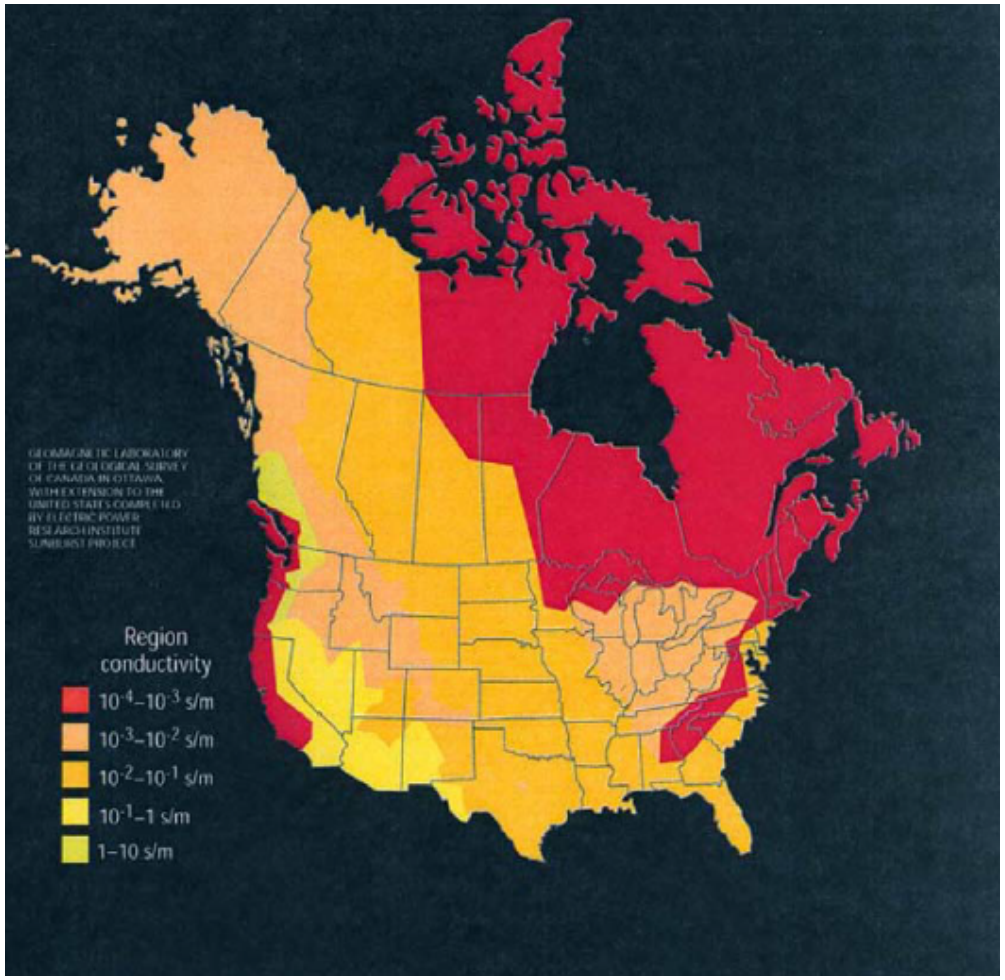
Ground Resistivity



Red = highest risk; Light yellow = lowest risk

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Geomagnetically-Induced Currents

- GIC cause problems in power grids:
  - Tripping of protective equipment
    - Short-term outages
  - Damage to transformers
    - Long-term outages and/or reduced capacity
- Why is the risk so large?
  - Transformers are huge, complicated pieces of equipment.
  - The timescale for manufacture is 1 - 3 years.
  - There is high demand from emerging economies (e.g. China, India), which could complicate restoration.

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Visualizing The U.S. Electric Grid

The U.S. electric grid is a complex network of independently owned and operated power plants and transmission lines. Aging infrastructure, combined with a rise in domestic electricity consumption, has forced experts to critically examine the status and health of the nation's electrical systems.

THE GRID	SOURCES OF POWER	POWER PLANTS	SOLAR POWER	WIND POWER

About This Map »

Click on the links below to switch layers on and off.

EXISTING LINES

- 345-499 kV
- 500-699 kV
- 700-799 kV
- 1,000 kV (DC)

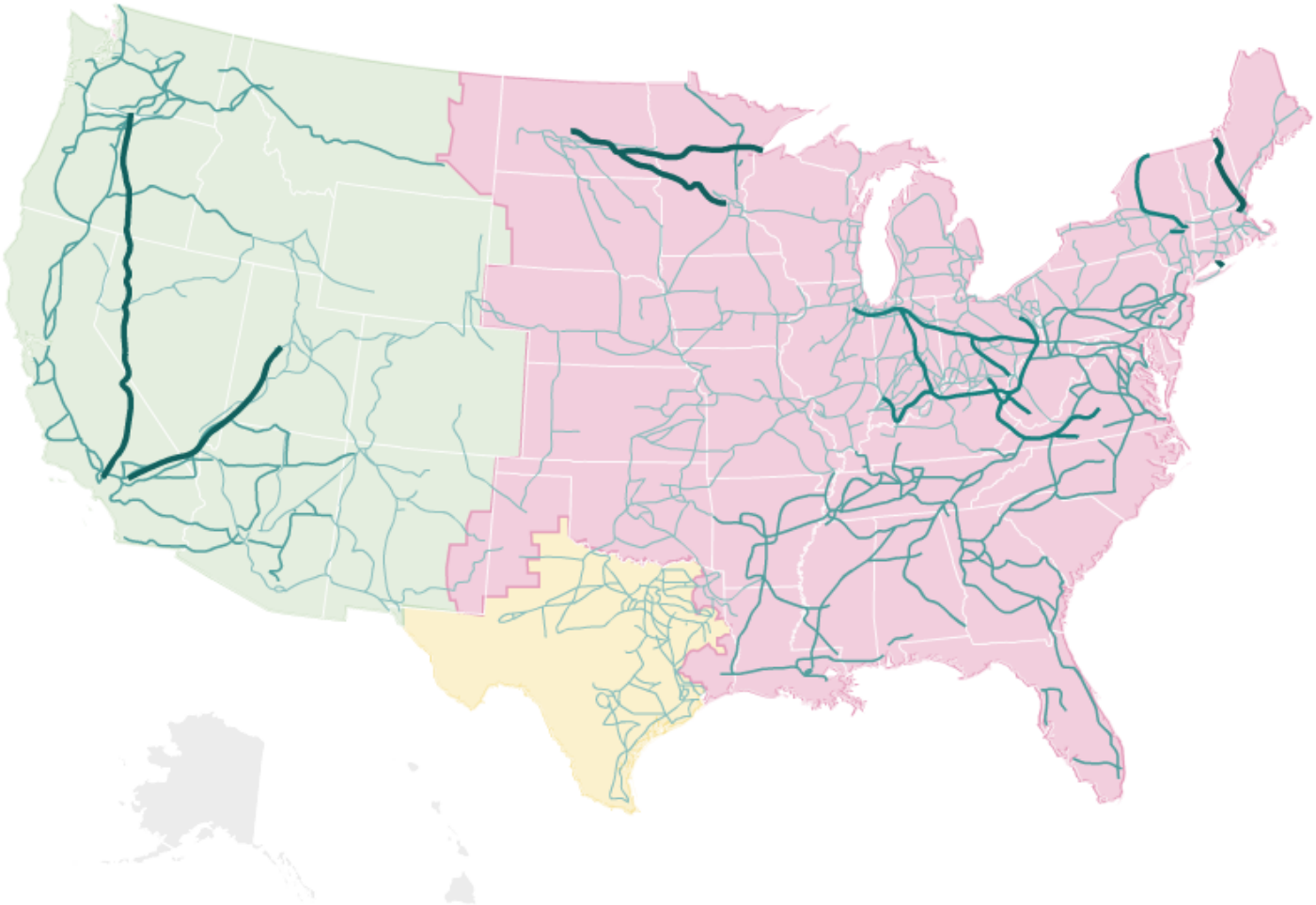
PROPOSED LINES

- New 765 kV
- AC-DC-AC Links

INTERCONNECTIONS

Major sectors of the U.S. electrical grid

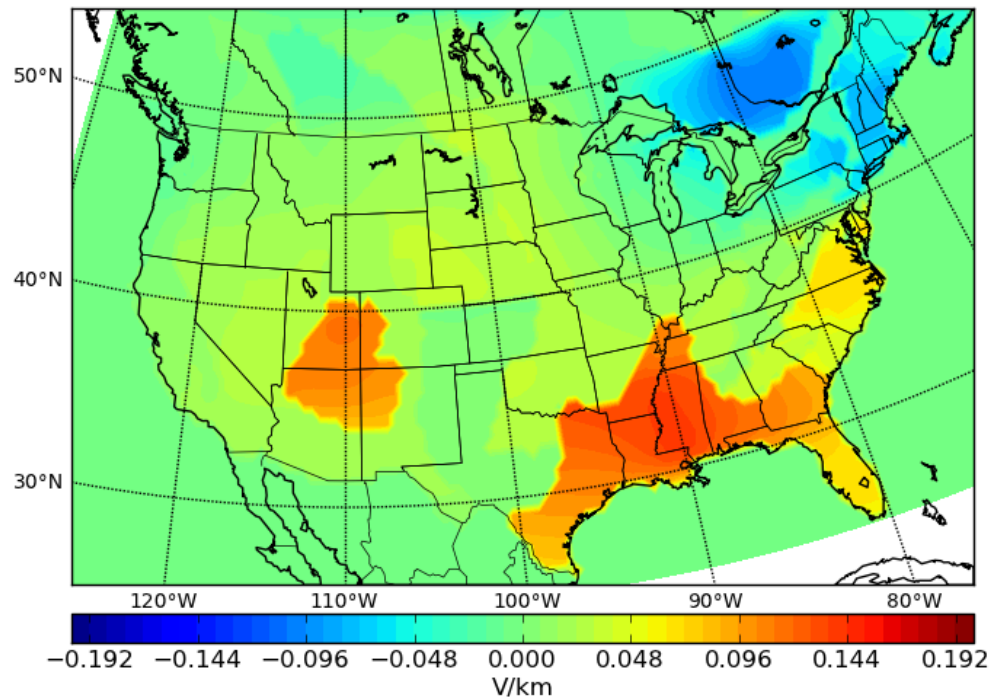
- Eastern
- Western
- Texas (ERCOT)



Source: American Electric Power, American Wind Energy Association, Center for American Progress, Department of Energy, Edison Electric Institute, Energy Information Administration, Electric Power Research Institute, Federal Energy Regulatory Commission, National Renewable Energy Laboratory, U.S. Environmental Protection Agency, Western Resource Advocates
Credit: Producer: Andrew Prince; Designer: Alyson Hurt; Editors: Avie Schneider and Vikki Valentine; Supervising Editors: Anne Gudenkauf and Quinn O'Toole; Additional Research: Jenny Gold; Database and GIS Analysis: Robert Benincasa

AER's toolkit for risk assessment

- Static relative risk maps
- Historical storm scenarios
- Simulated extreme storms
  - Up to Carrington-level
- Working with PowerWorld and Siemens PSSE to have E-field scenarios available to grid clients



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