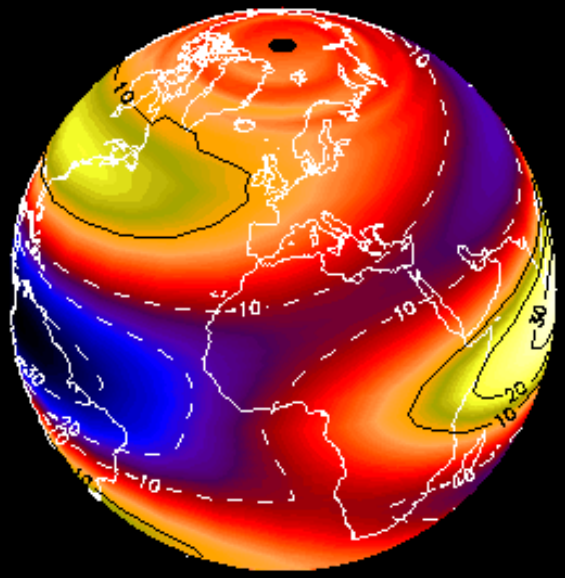
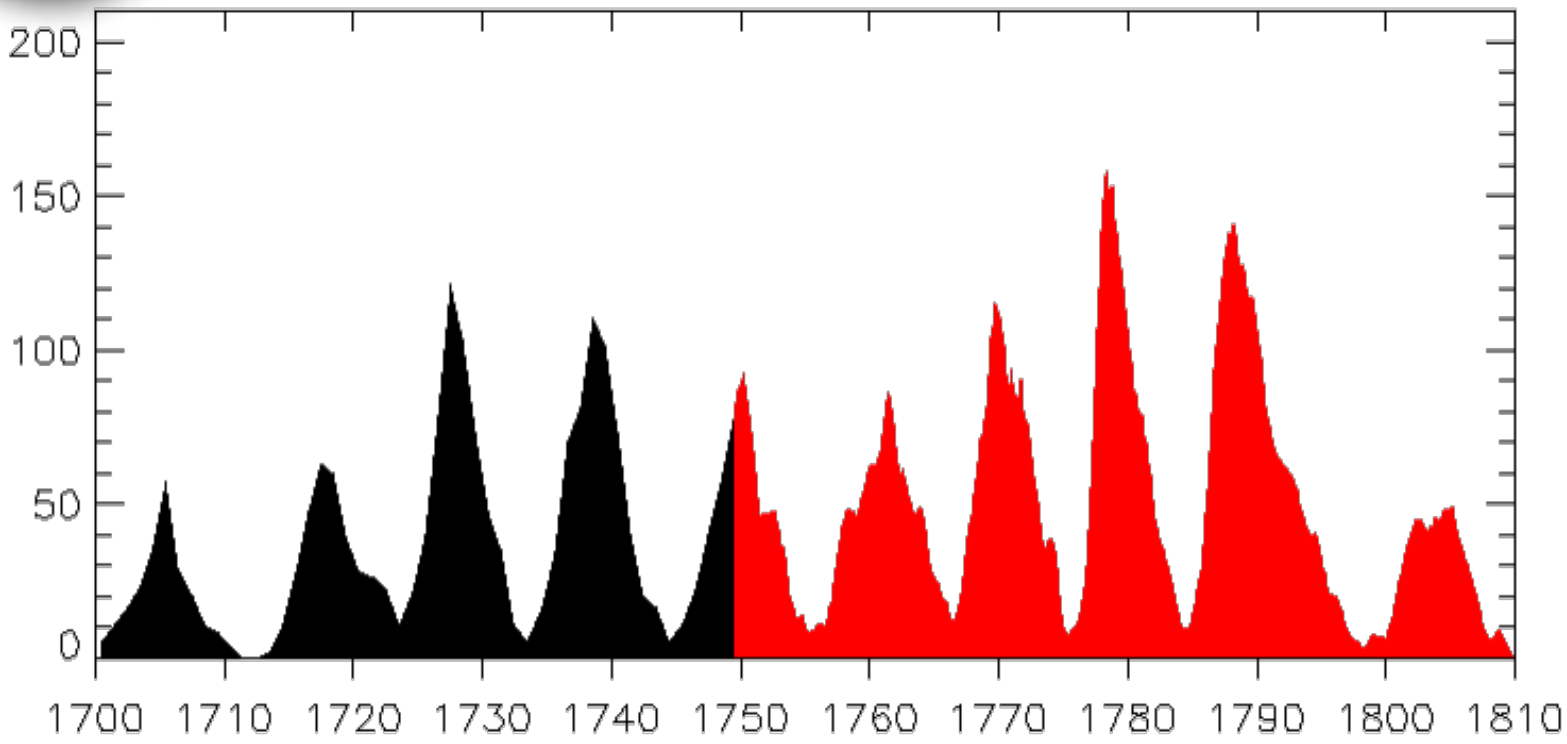
Geomagnetic Storm Threat to the Electrical System



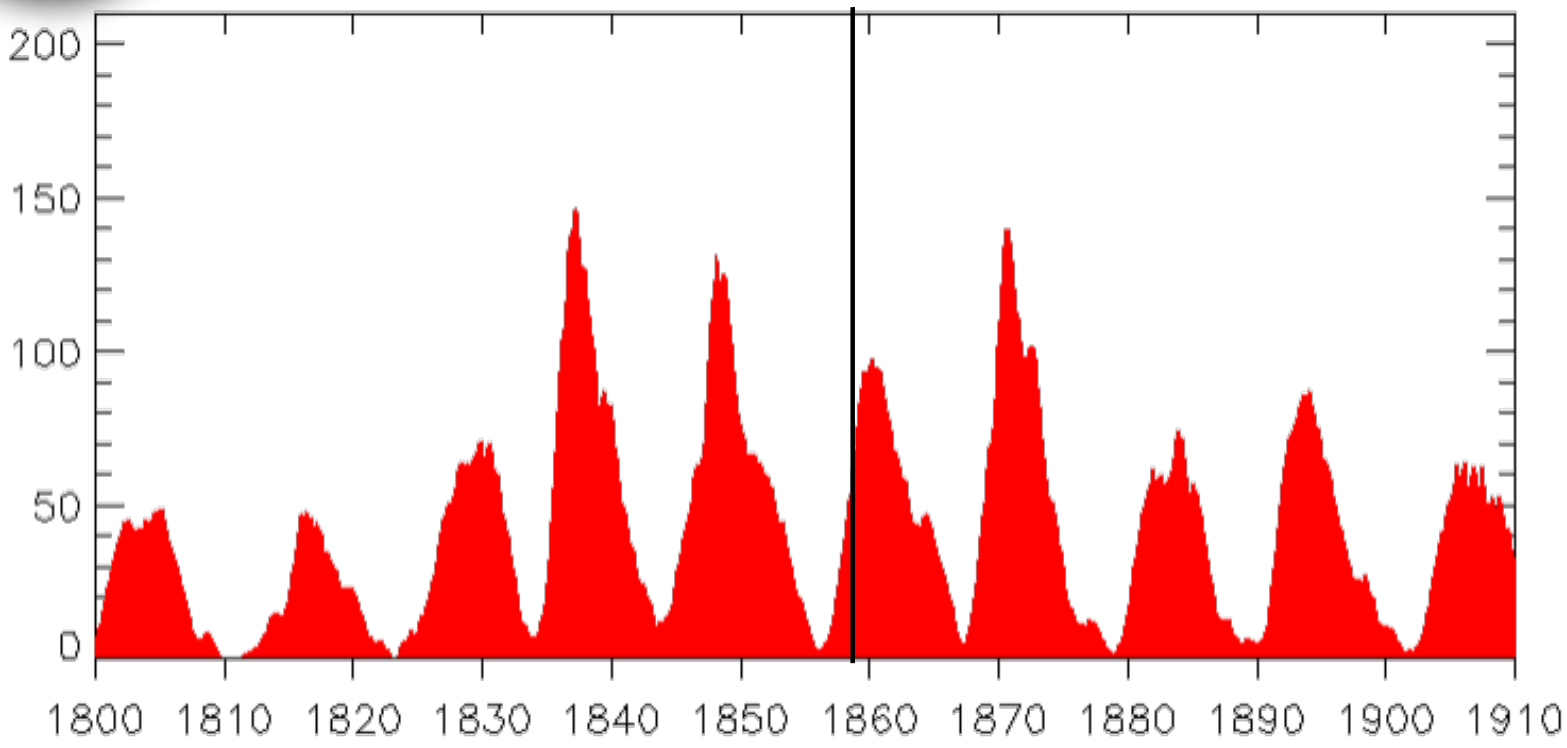
GIC and The Solar Cycle

- Geomagnetic Induced Current (GIC) is the product of solar activity and is strongly tied to the peak of solar cycles.
  - Average 11 year cycle (9-14), now in cycle #24
  - Worst recorded GIC event in 1859 (Carrington event)

Recorded Solar Cycles

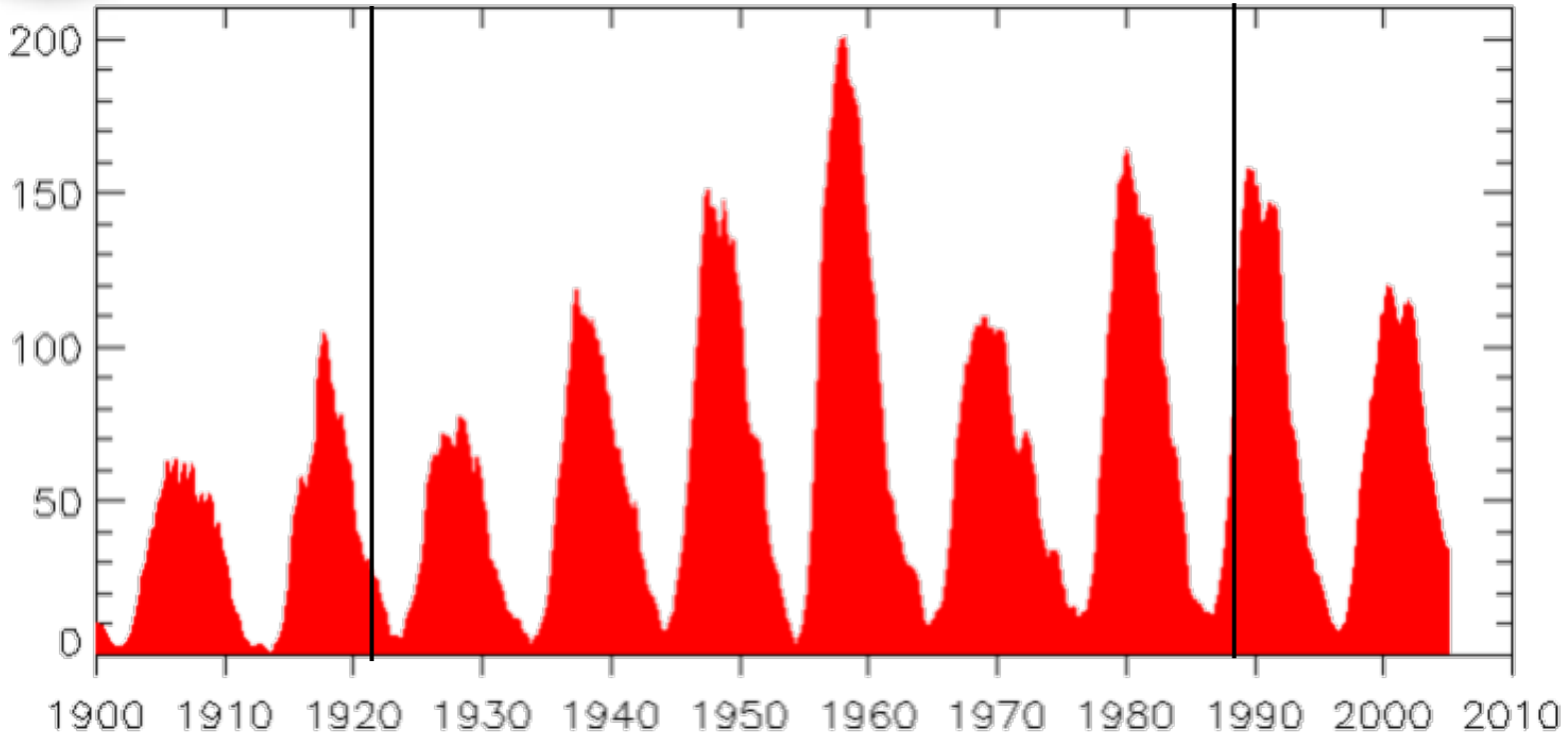


Recorded Solar Cycles



1859

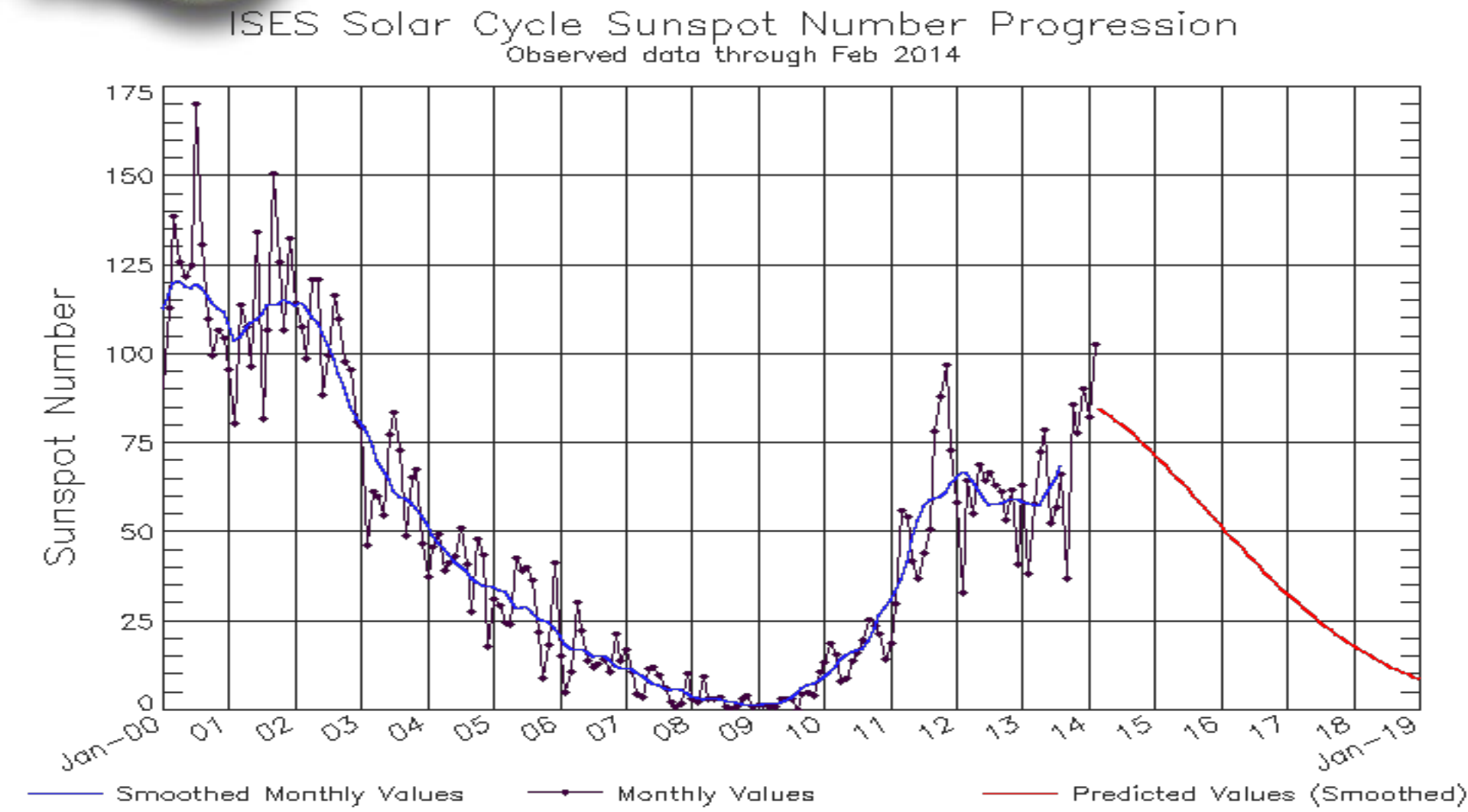
Recorded Solar Cycles



1921

1989

Solar Cycle 24 Prediction Panel

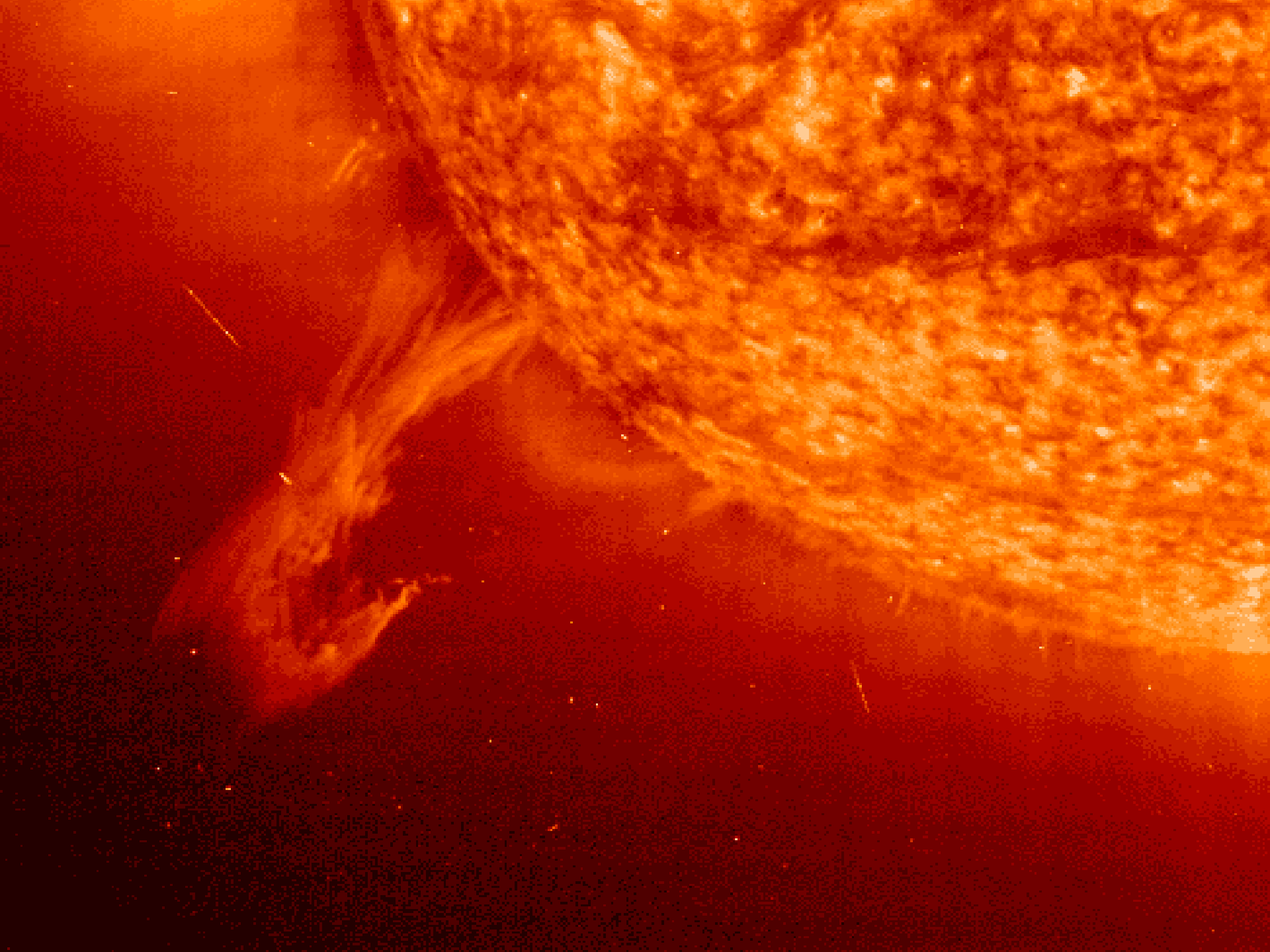


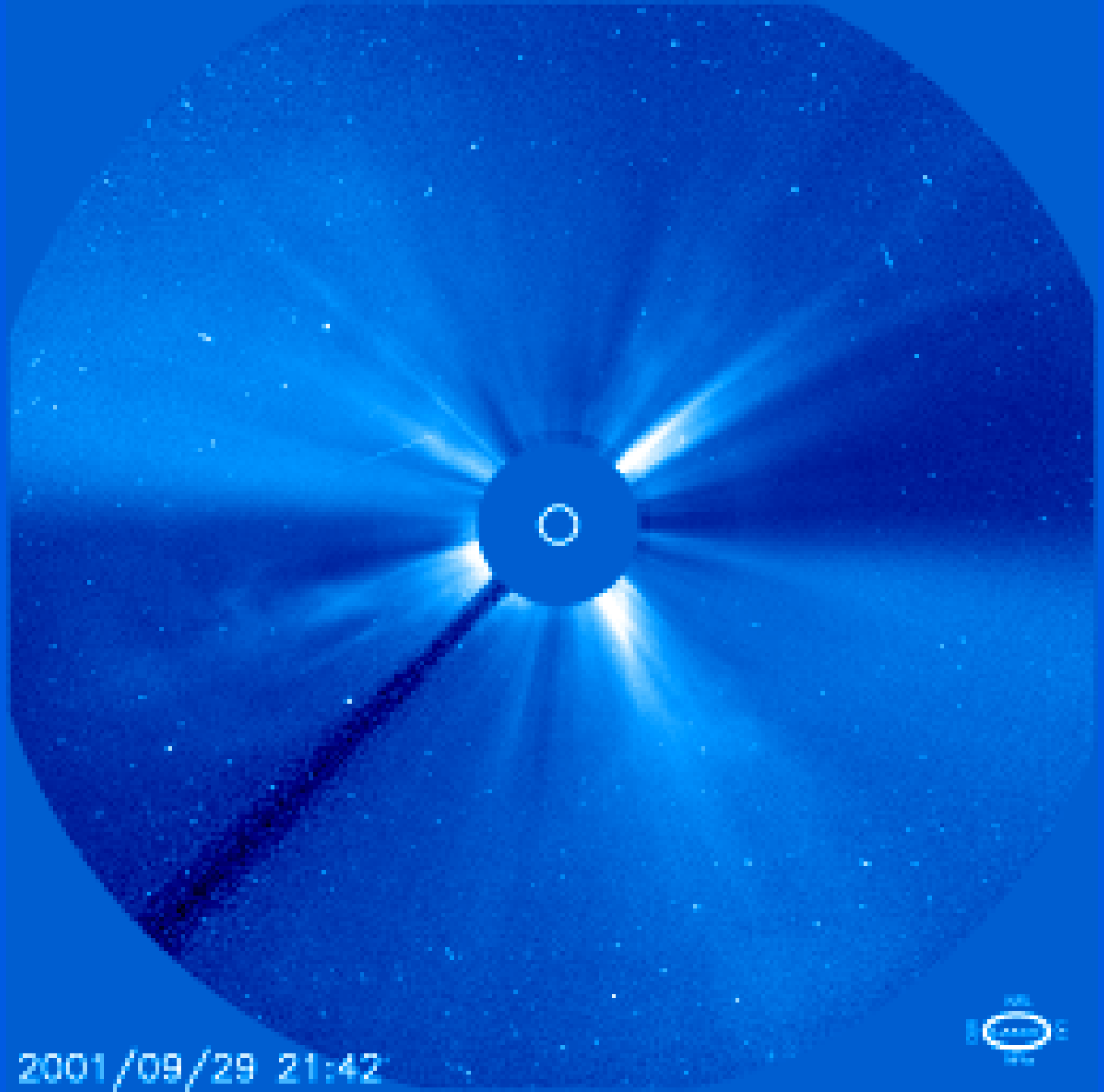
GIC and The Solar Cycle

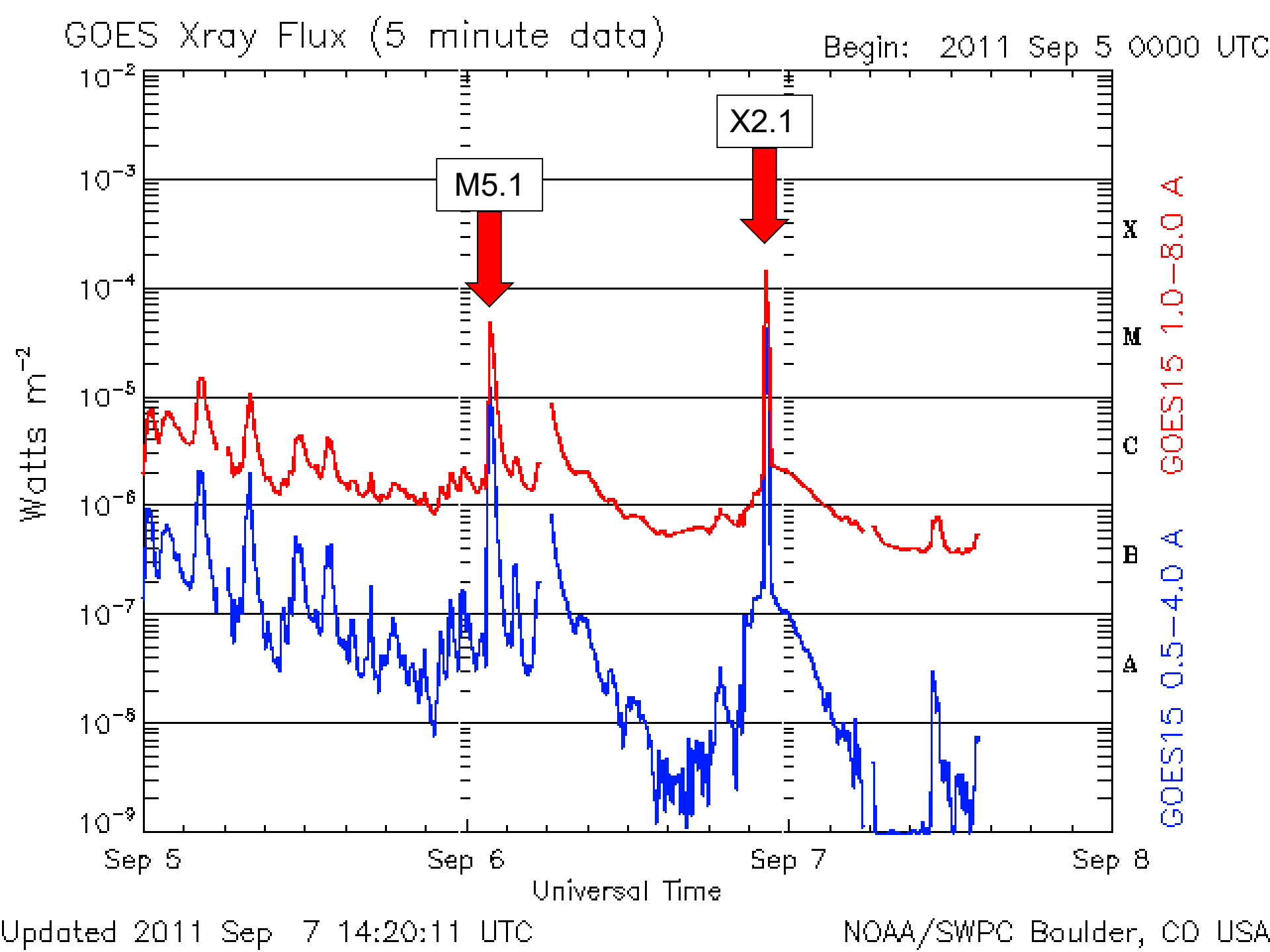
- During peak solar activity large solar flares / coronal mass ejections eject matter from the sun which travels on the solar wind towards earth and interacts with its magnetic field
  - Visually seen as auroras at the earth's poles
  - Impacts to radio, satellites, pipelines, power systems, and power transformers

Solar Flares

- ***Flares*** are short term brightenings that last for minutes or hours.
- They usually occur near active regions on the Sun where abrupt changes in magnetic field are taking place.
- When a flare begins, plasma is accelerated out from the Sun.
- This plasma usually returns in an arching fashion but in more eruptive flares, plasma is thrown completely away from the Sun.

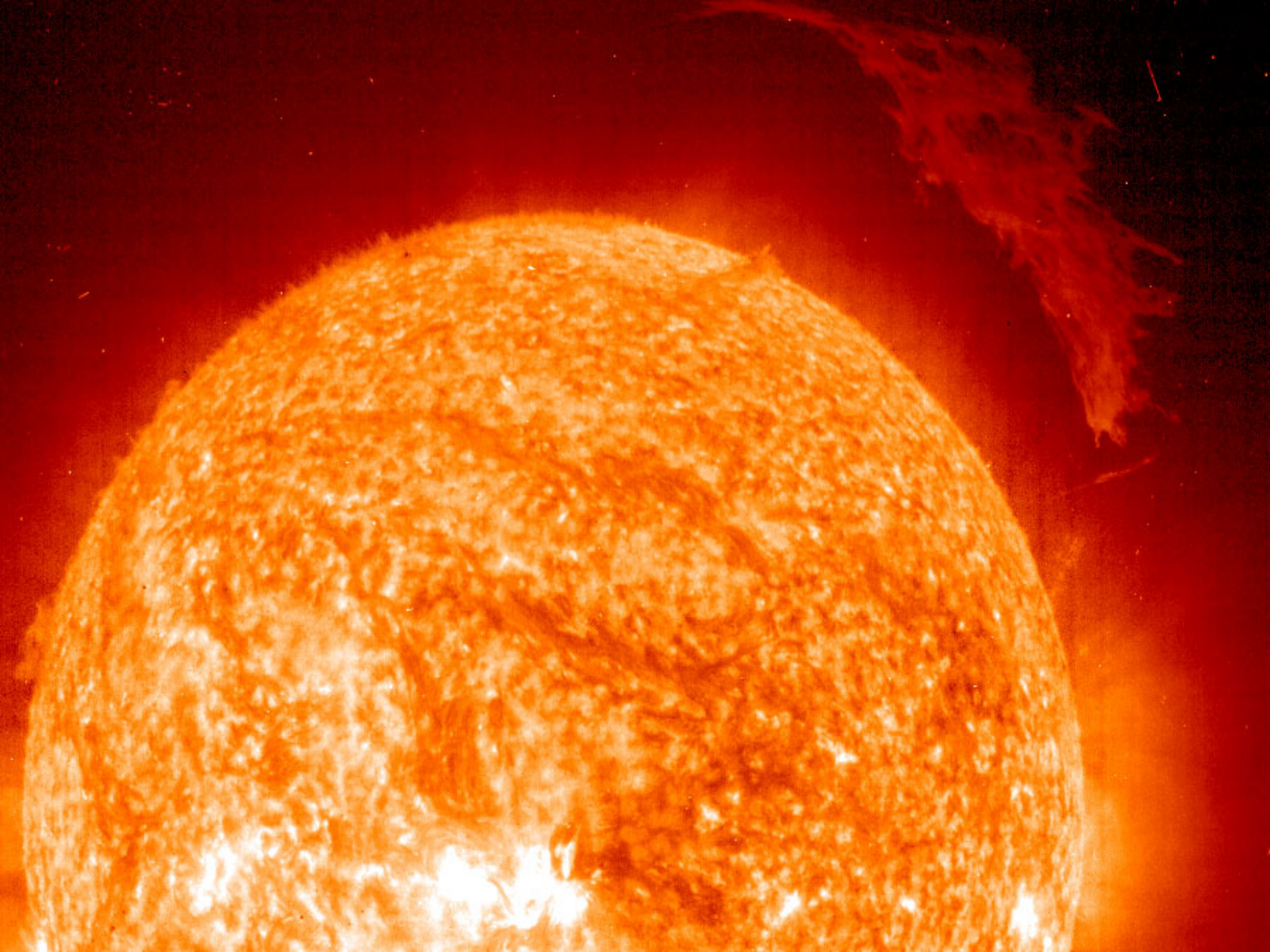



2001/09/29 21:42


GOES Xray Flux (5 minute data)
Begin: 2011 Sep 5 0000 UTC
M5.1
X2.1
Watts m-2
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
X
M
C
B
A
GOES15 1.0–8.0 A
GOES15 0.5–4.0 A
Sep 5
Sep 6
Sep 7
Sep 8
Universal Time
Updated 2011 Sep 7 14:20:11 UTC
NOAA/SWPC Boulder, CO USA

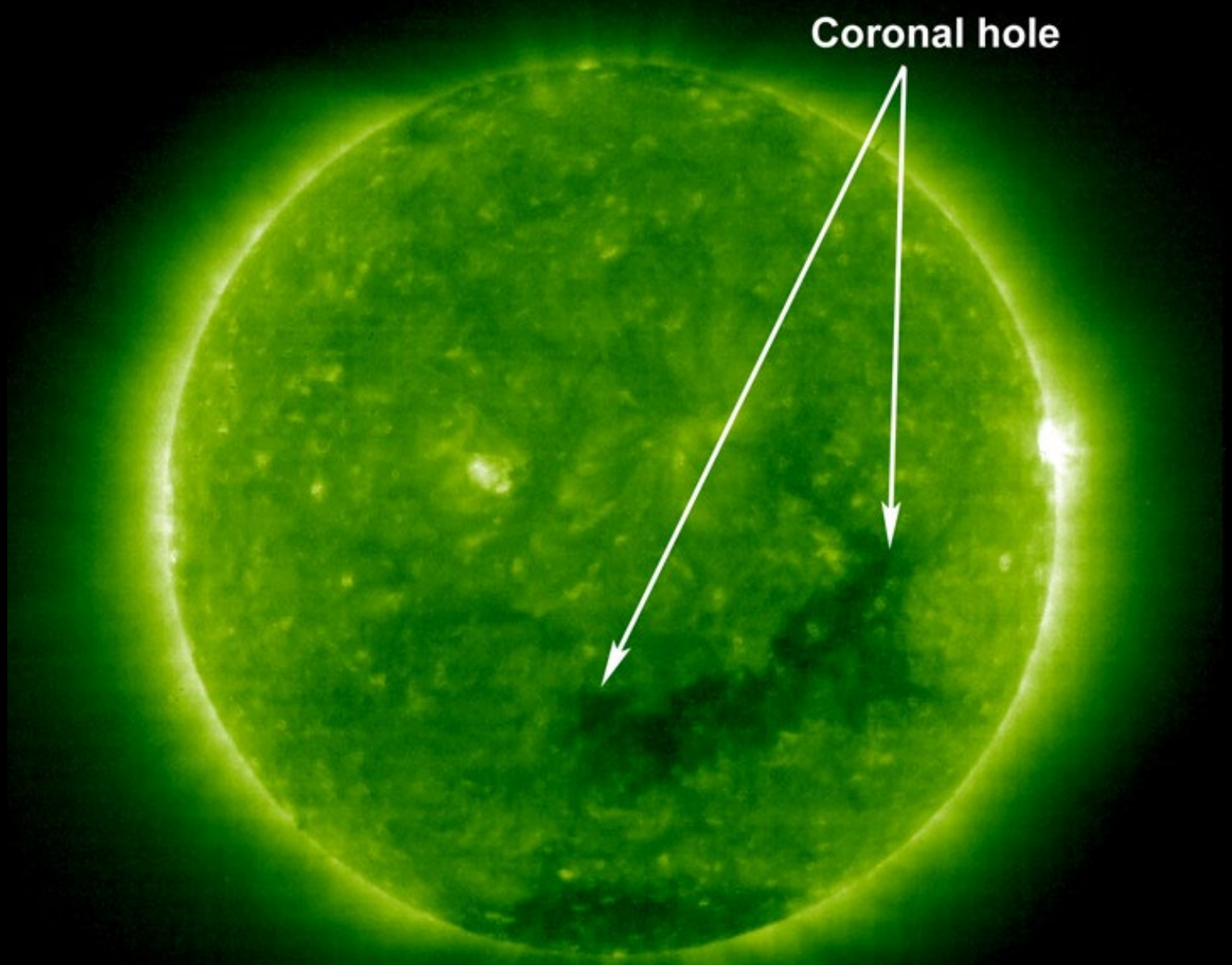
Filaments

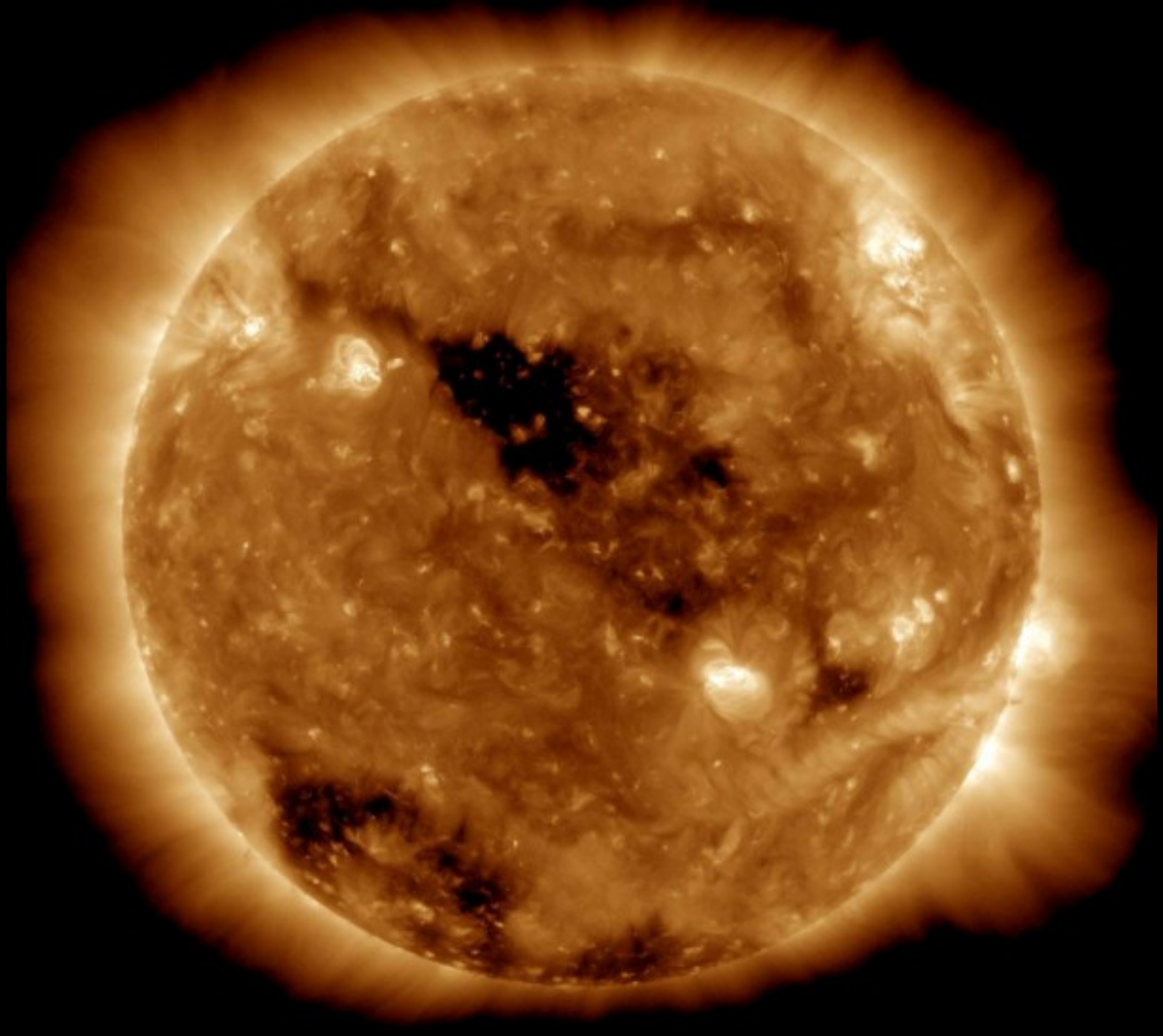
- Filaments are the long, string-like features which appear prominently in photos of the Sun.
- They hang like clouds for days or weeks then disappear, in most cases by dissipating, much like Earth clouds “burn off.”
- In other cases, though, filaments disappear by rising up, away from the Sun



Coronal Hole

- The third source of mass traveling out from the Sun is the ***coronal hole***, easily seen as a dark region in an x-ray photo of the Sun.
- Coronal holes reside permanently near the poles of the Sun, and the solar wind streaming out from these generally does not reach the Earth.
- But during some rotations of the Sun, coronal holes form at lower latitudes, facing the Earth, and these act like a broadly focused fire hose spraying the Earth with a high intensity of charged particles.


Coronal hole



Plasma: From the Sun to Earth

- Speed of plasma: 400 km/s - 1500 km/s
- Time to hit earth atmosphere: 28 – 100 hours (150,000,000 kilometers)
- Time for an alarm from satellites located around the first Lagrange point: 17 minutes – 1 hour (1,500,000 kilometers)

Geomagnetic Storm

- When an intense surge of solar wind reaches Earth, there are many changes which occur in the magnetosphere.
- The day side of the magnetosphere is compressed closer to the surface of Earth and the geomagnetic field fluctuates wildly.
- This type of event is generally called a ***geomagnetic storm***

Geomagnetic Induced Current

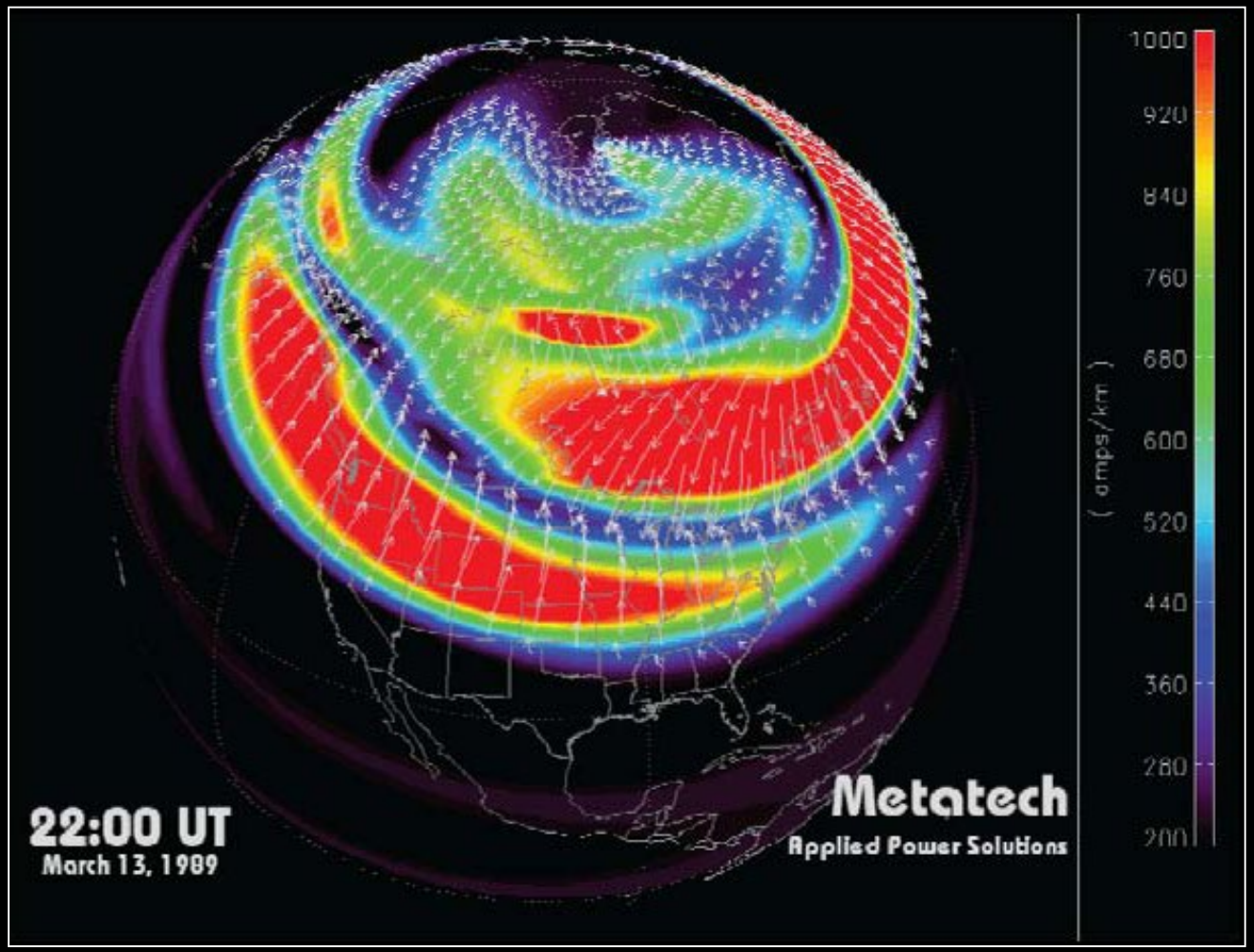
- Geomagnetic induced currents often flow through the ground unnoticed by humans.
- But when good conductors are present, like pipelines and electrical power transmission lines, the currents travel through these as well.
- Voltages as high as 10 volts per mile have been measured.

The HydroQuebec Blackout of March 1989

- On March 13, 1989, at 2:44 am, a transformer failure on one of the main power transmission lines in the HydroQuebec system precipitated a catastrophic collapse of the entire power grid. The string of events that produced the collapse took only 92 seconds from start to finish. 6 million people lost electrical power for 9 or more hours.

The HydroQuebec Blackout of March 1989

The HydroQuebec Blackout of March 1989

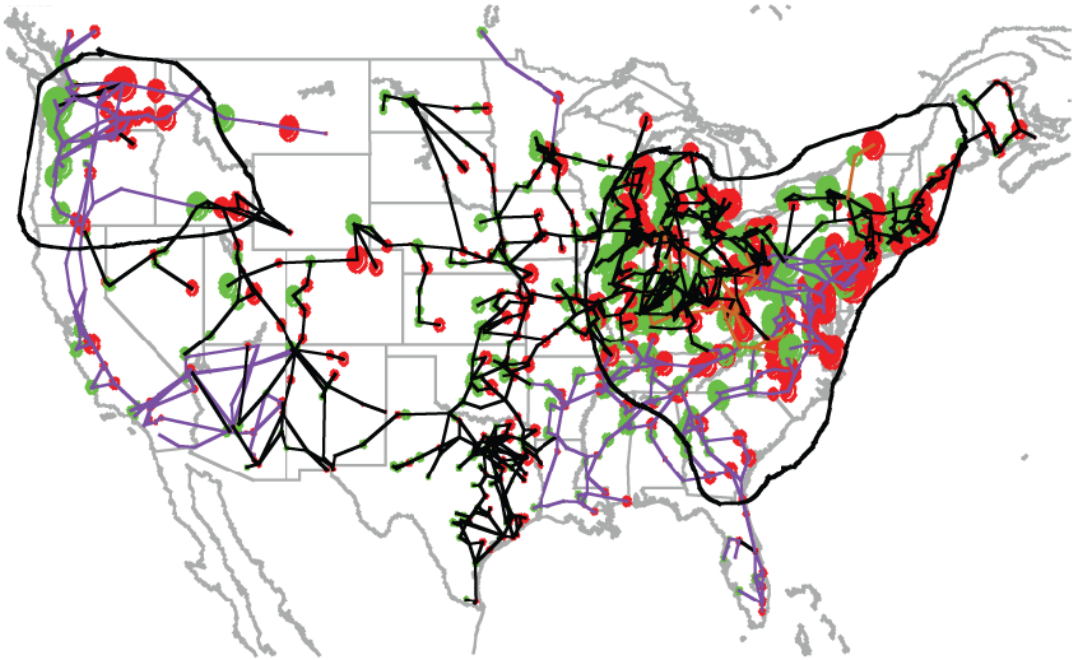


The HydroQuebec Blackout of March 1989

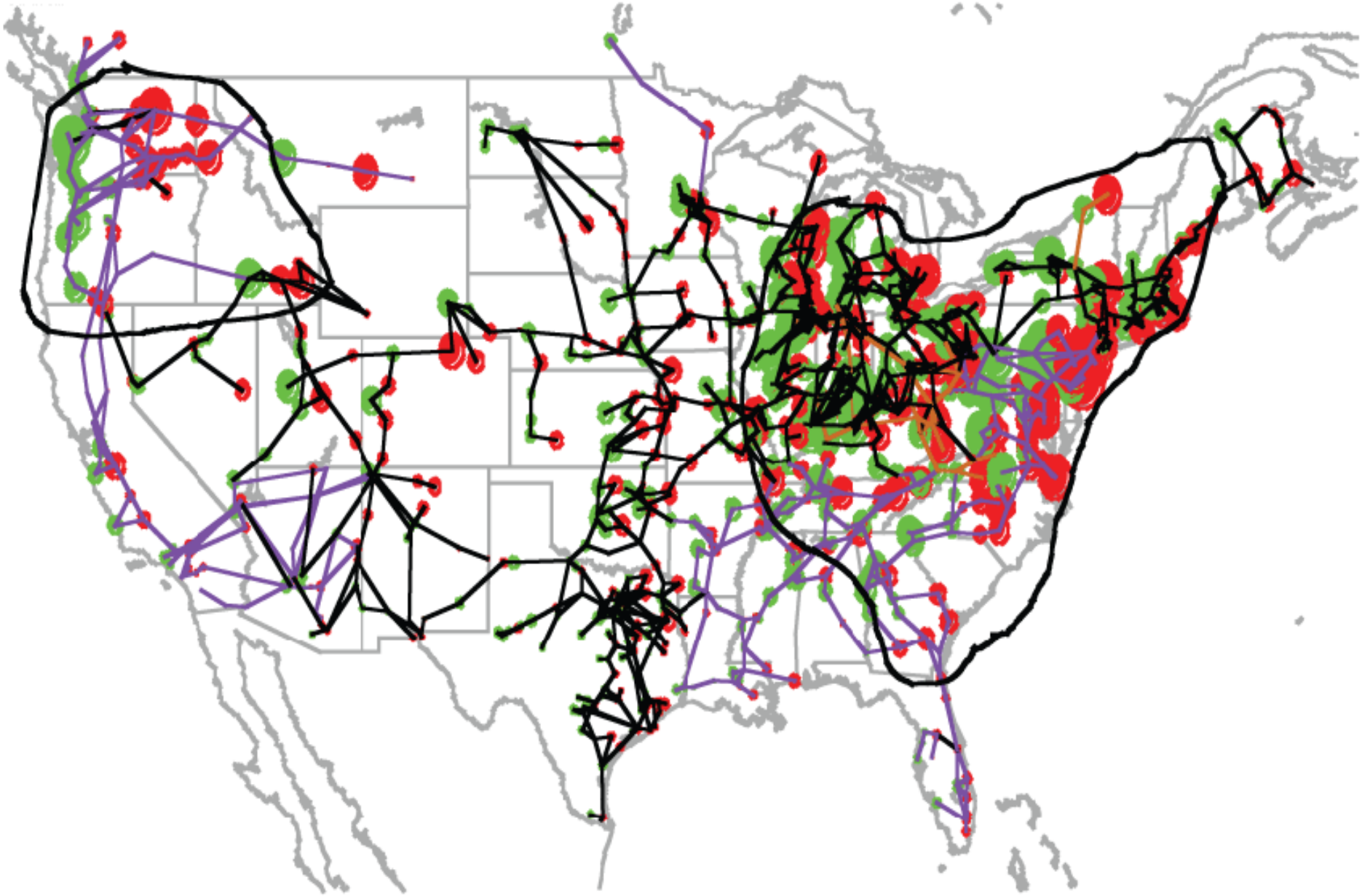
The HydroQuebec Blackout of March 1989

May 1921 Super Storm

Produced ground currents as much as ten times stronger than the 1989 Quebec storm



100 Year Geomagnetic Storm Ğ50 Degree Geomagnetic Disturbance Scenario

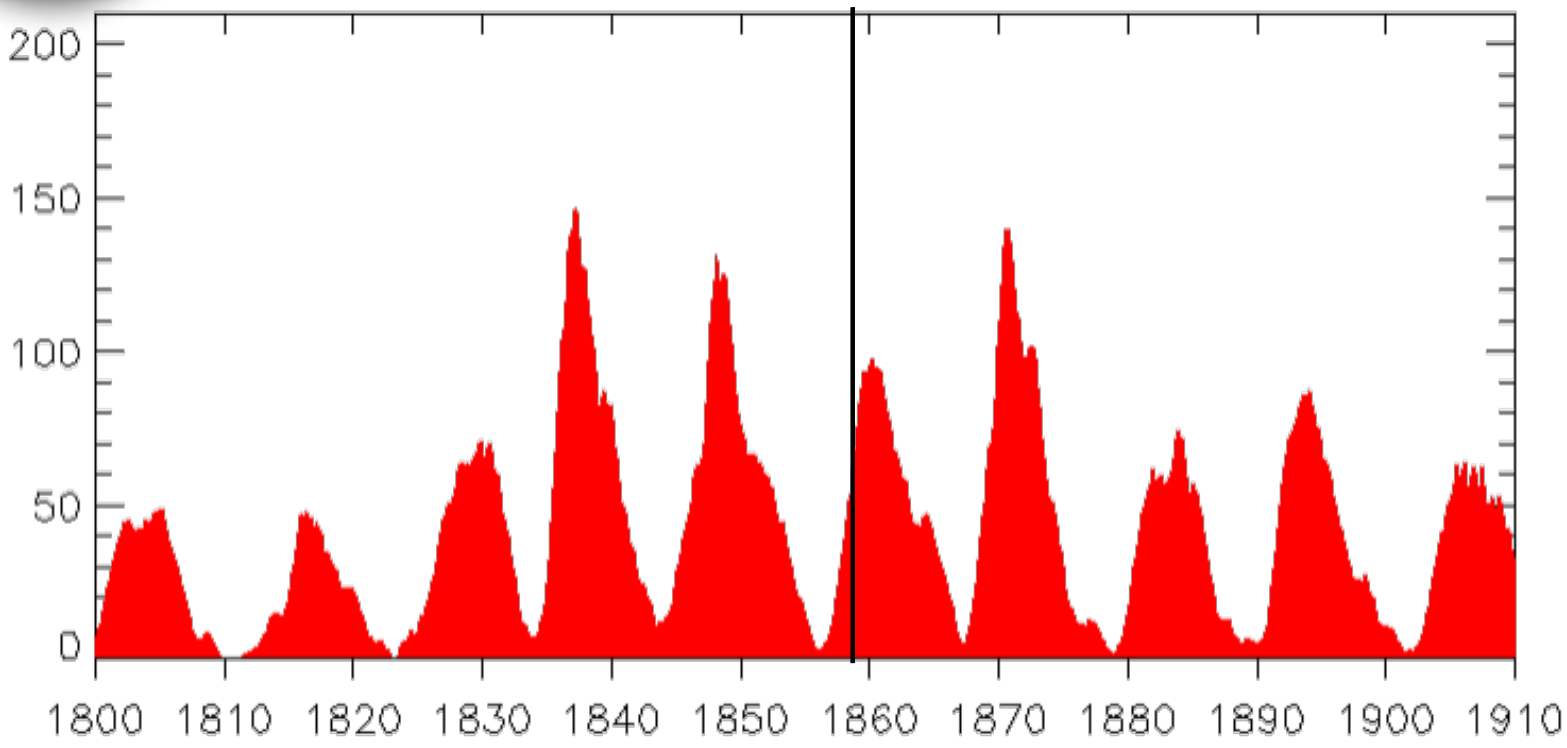


100 Year Geomagnetic Storm Ğ50 Degree Geomagnetic Disturbance Scenario

1859 Carrington Event

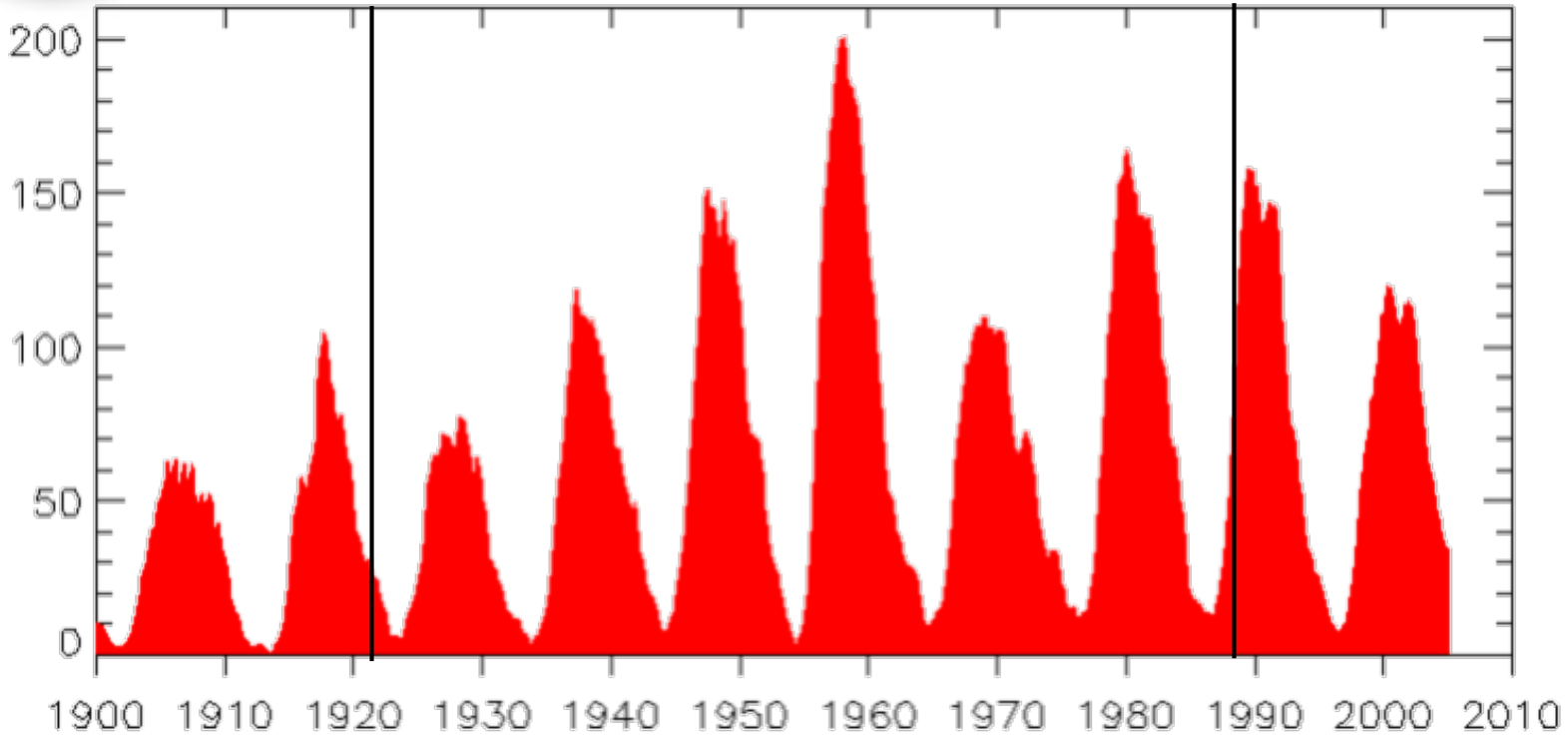
- On September 1–2, 1859, the largest recorded geomagnetic storm occurred. Aurora were seen around the world, most notably over the Caribbean.
- Telegraph systems all over Europe and North America failed.

Recorded Solar Cycles



1859

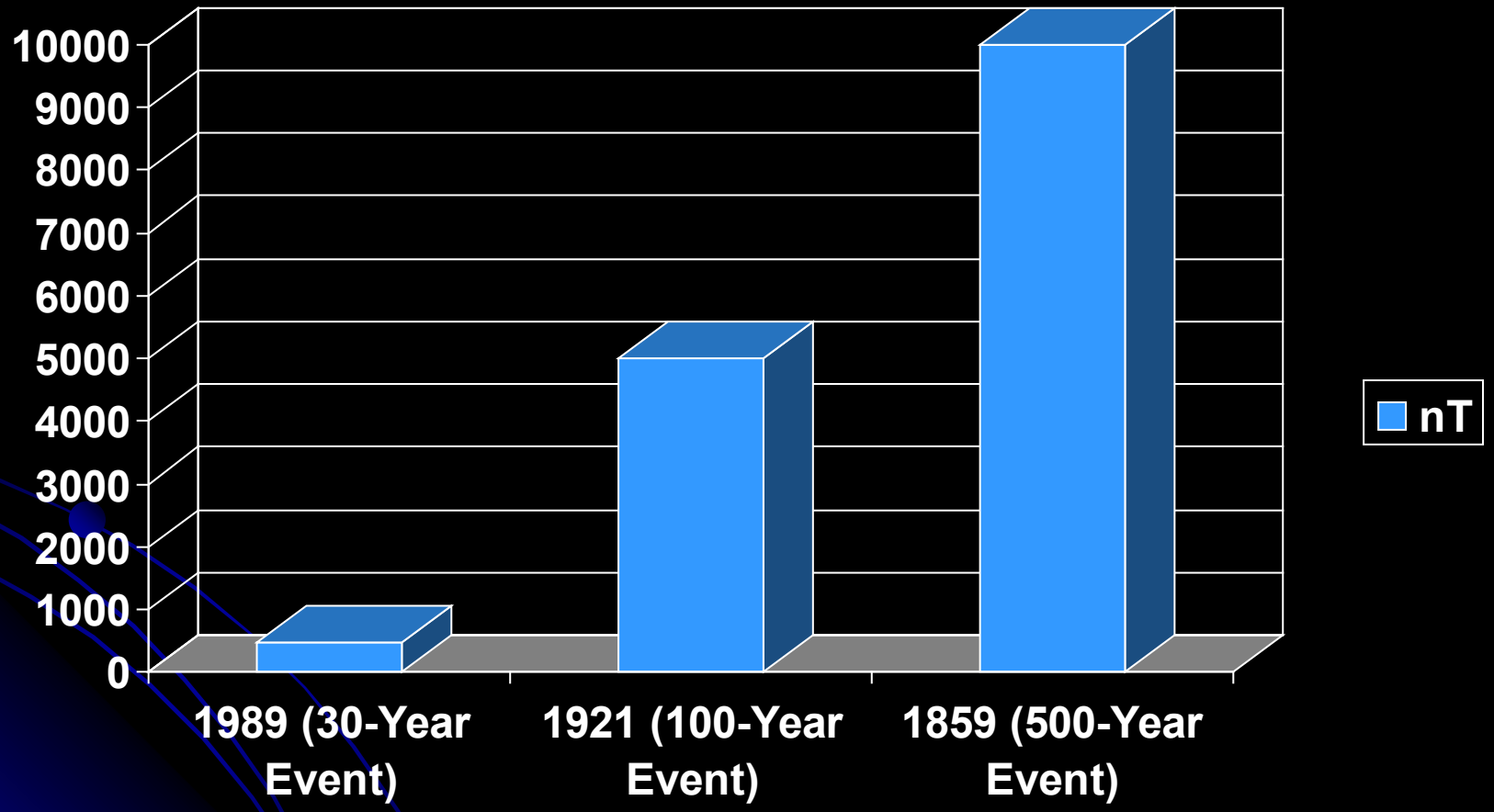
Recorded Solar Cycles



1921

1989

Comparison


10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1989 (30-Year Event)
1921 (100-Year Event)
1859 (500-Year Event)
nT

NOAA Scales Activity

- Geomagnetic Storms
  - Power Systems
  - Spacecraft Operations
  - Others (pipelines, radio, satellites, auroras)
- Solar Radiation Storms
  - Biological
  - Satellite Operations
  - HF Radio
- Radio Blackouts
  - HF Radio
  - Navigation

K Index Hourly Range in Nanoteslas (nT)

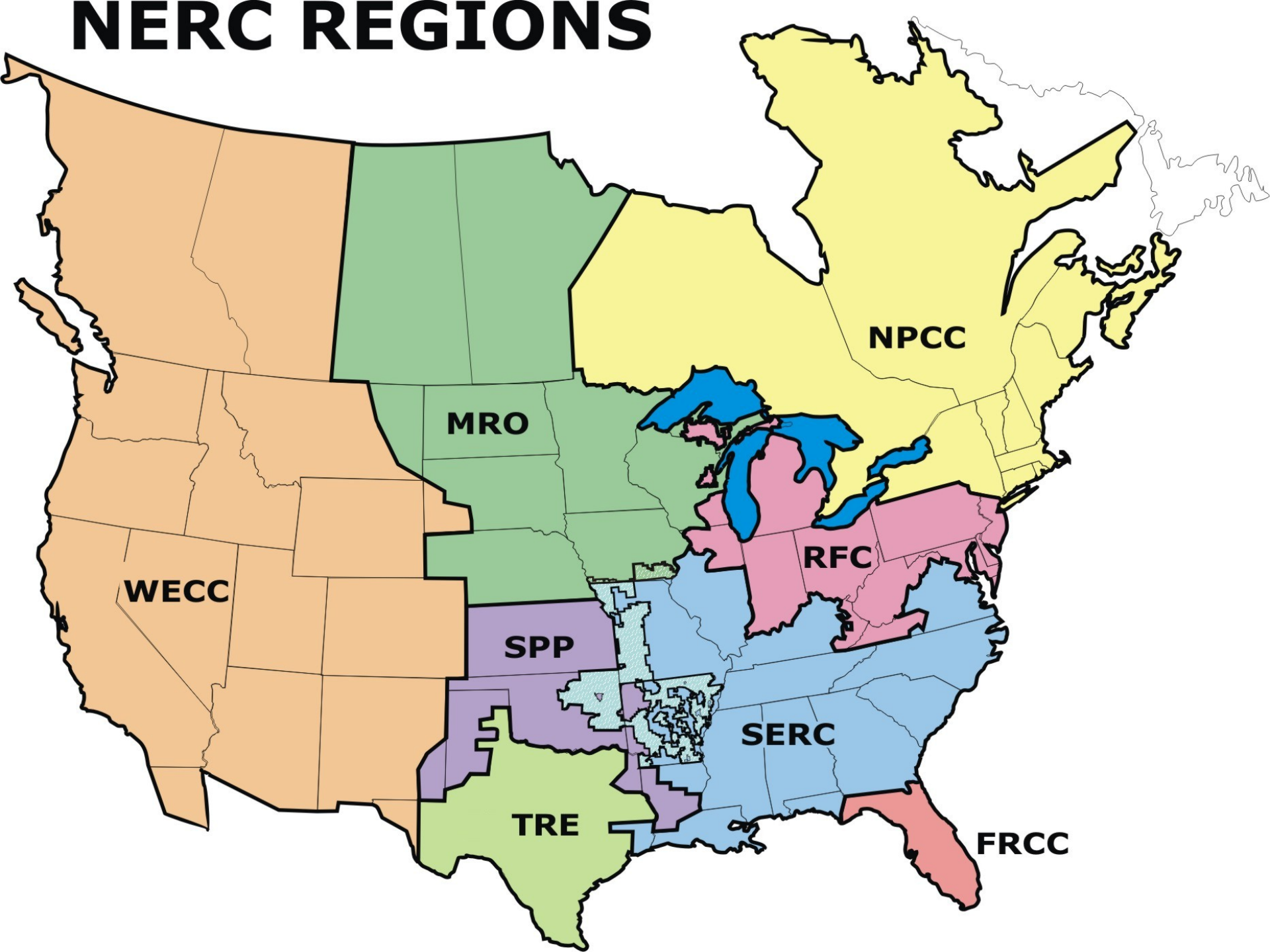
K	G	nT	
9	G 5	750+	Extreme
8	G 4	500-749	Severe
7	G 3	300-499	Strong
6	G 2	180-299	Moderate
5	G 1	105-179	Minor
4		60-104	Active
3		30-59	Unsettled
2		15-29	Quiet
1		8-14	Quiet
0		0-7	Quiet

Electrical Grid

- North America's bulk power system is one of our most critical infrastructures; it underpins our government, economy and society in many important ways.

- Comprised of over 200,000 miles of transmission lines and thousands of generating plants.

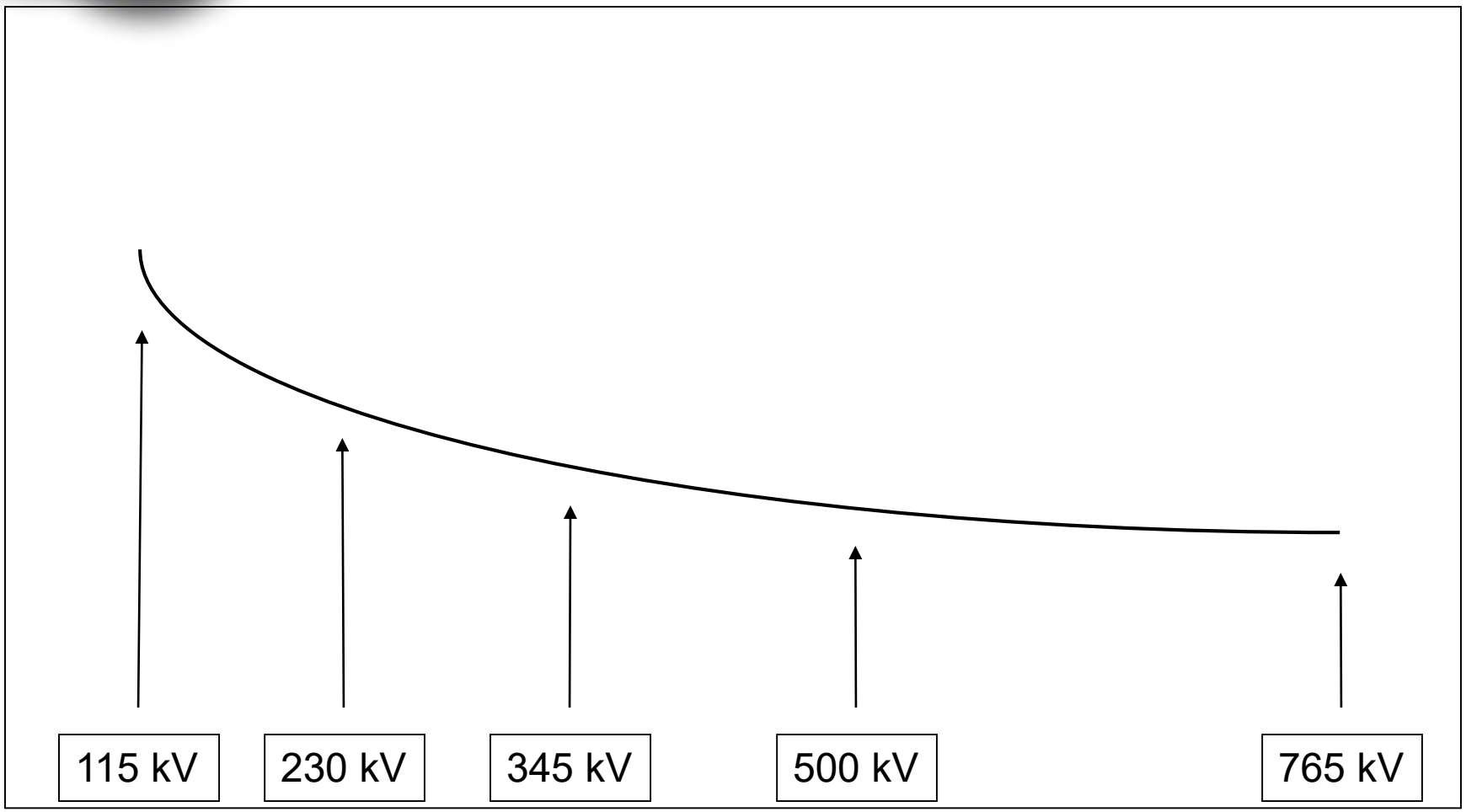
NERC REGIONS

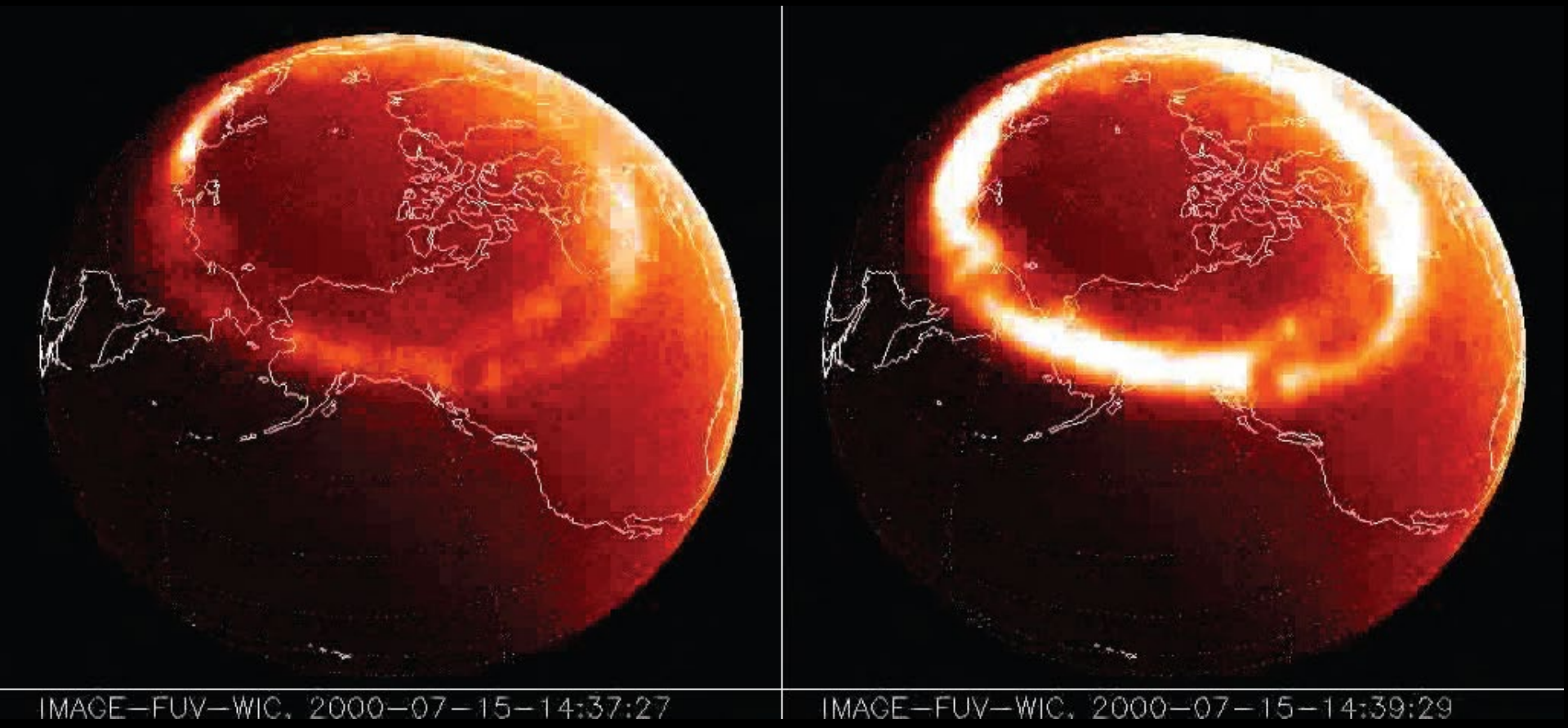


Vulnerability Factors

- Electrical line voltage
- High magnetic latitudes
- Direct current
- Soil type

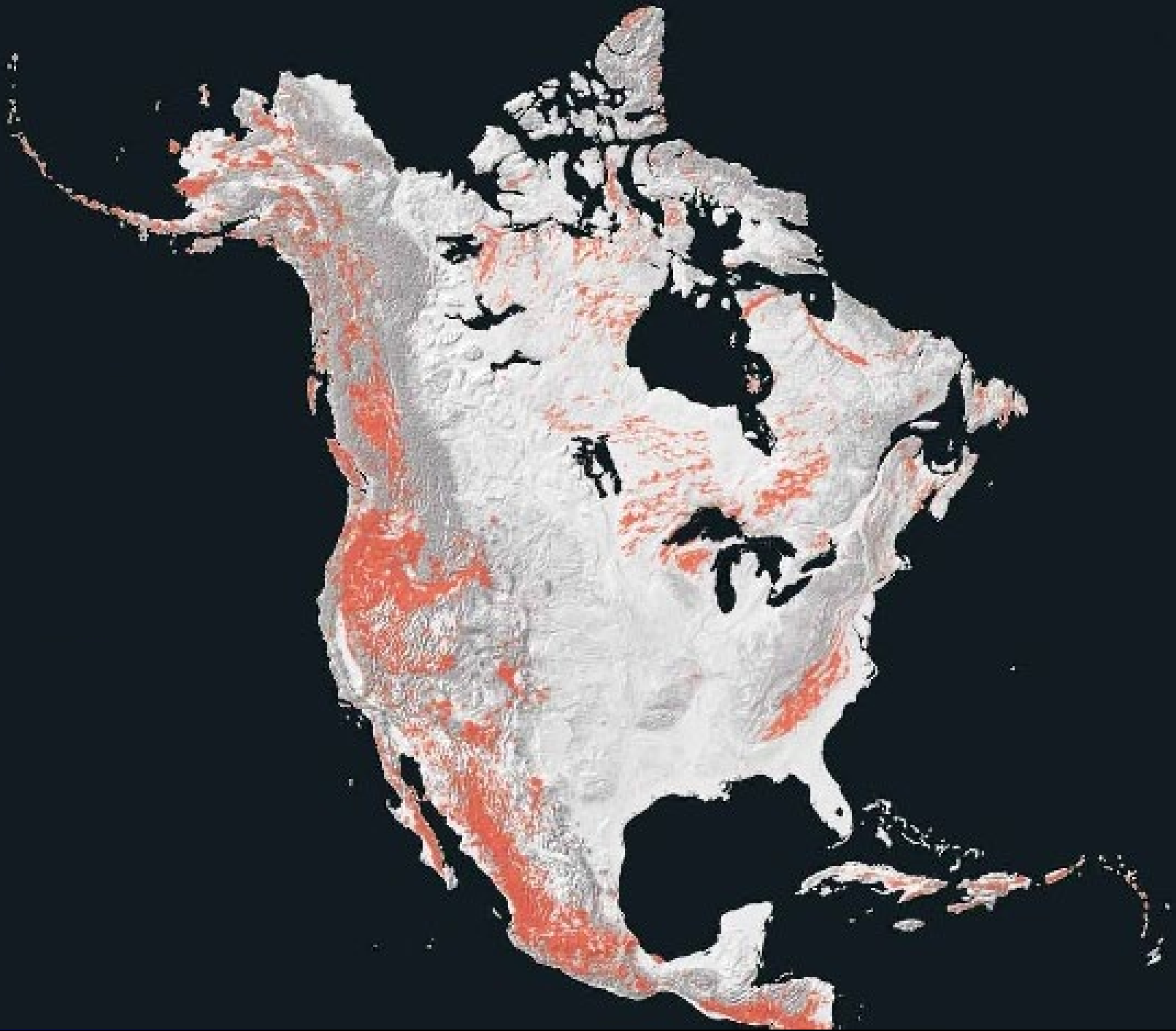
Transmission Line Resistance




IMAGE–FUV–WIC, 2000–07–15–14:37:27
IMAGE–FUV–WIC, 2000–07–15–14:39:29

Igneous Rock

Because igneous rock has a low conductivity, the induced currents tend to take a path through man-made conductors



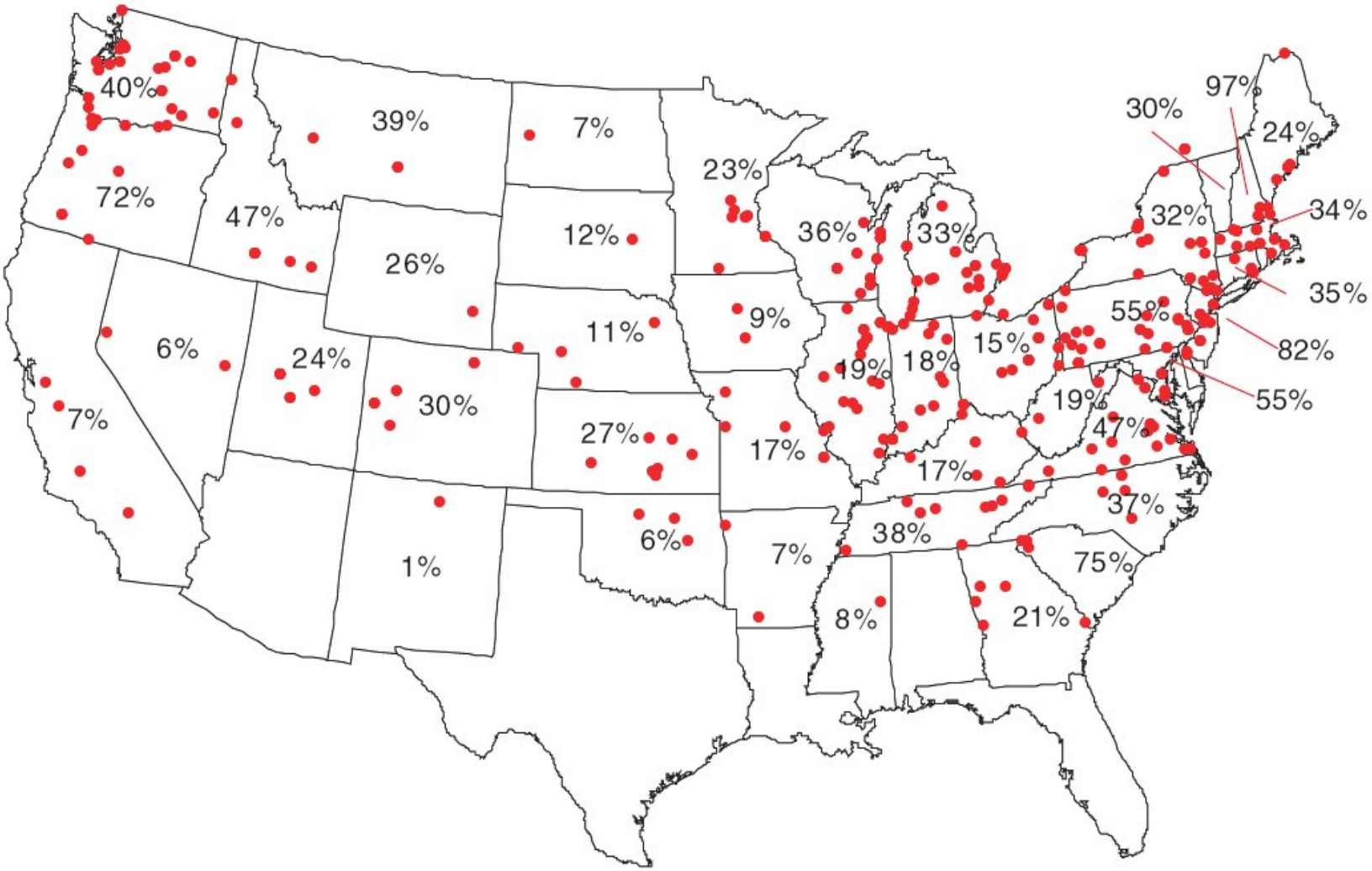


FIGURE 7.2 A map showing the at-risk EHV transformer capacity (estimated at ~365 large transformers) by state for a 4800 nT/min geomagnetic field disturbance at 50° geomagnetic latitude. Regions with high percentages of at-risk capacity could experience long-duration outages that could extend multiple years. SOURCE: J. Kappenman, Metatech Corp., "The Future: Solutions or Vulnerabilities?," presentation to the space weather workshop, May 23, 2008.

Protective Measures

GIC risk can, to some extent, be reduced by capacitor blocking systems, maintenance schedule changes, additional on-demand generating capacity, and ultimately, load shedding.

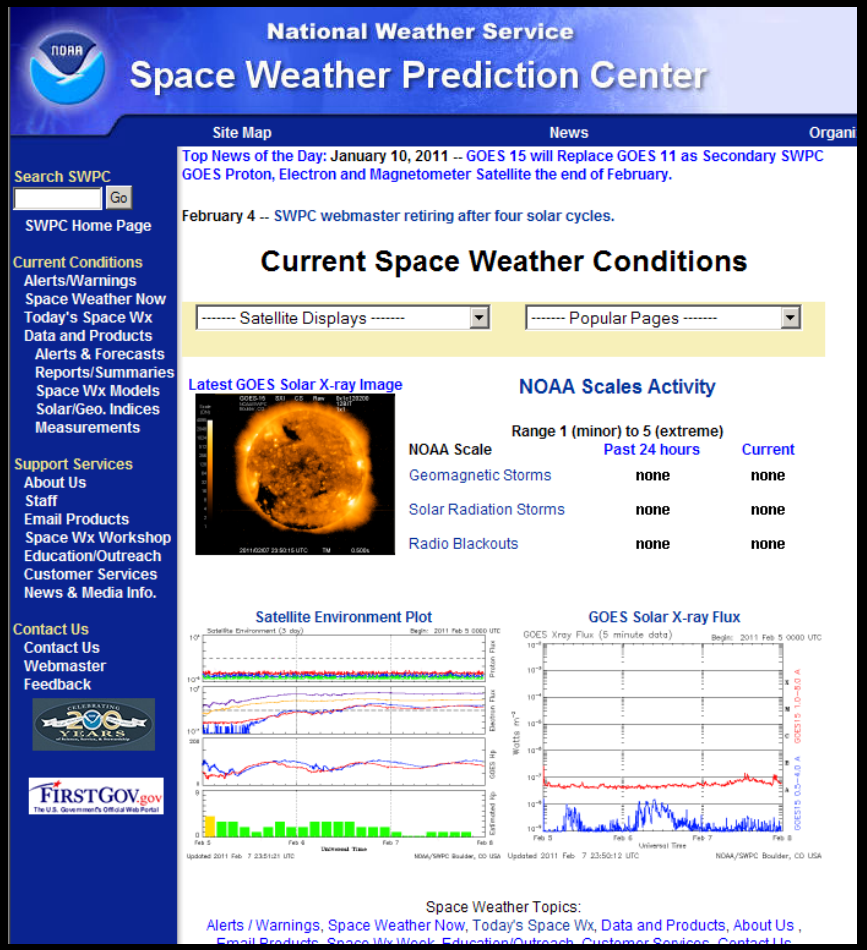
These options are expensive and sometimes impractical.

Seattle City Light

- ~30% of power comes directly to Seattle from the Skagit Project.
- All of the rest, including Boundary Dam, comes through BPA transmission lines.
- All of Seattle City Light's equipment is 230 kV or less.

Monitoring

- Space Weather Prediction Center
- www.swpc.noaa.gov/

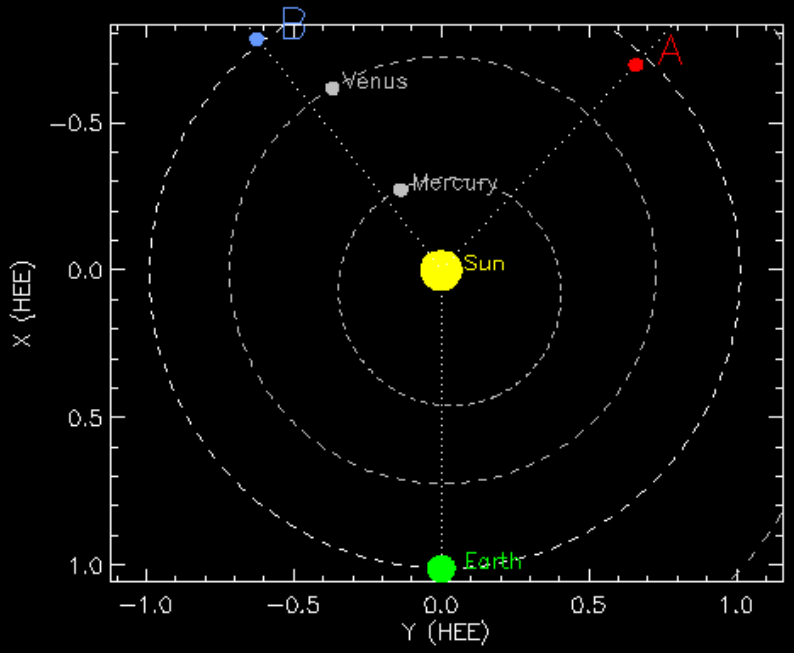


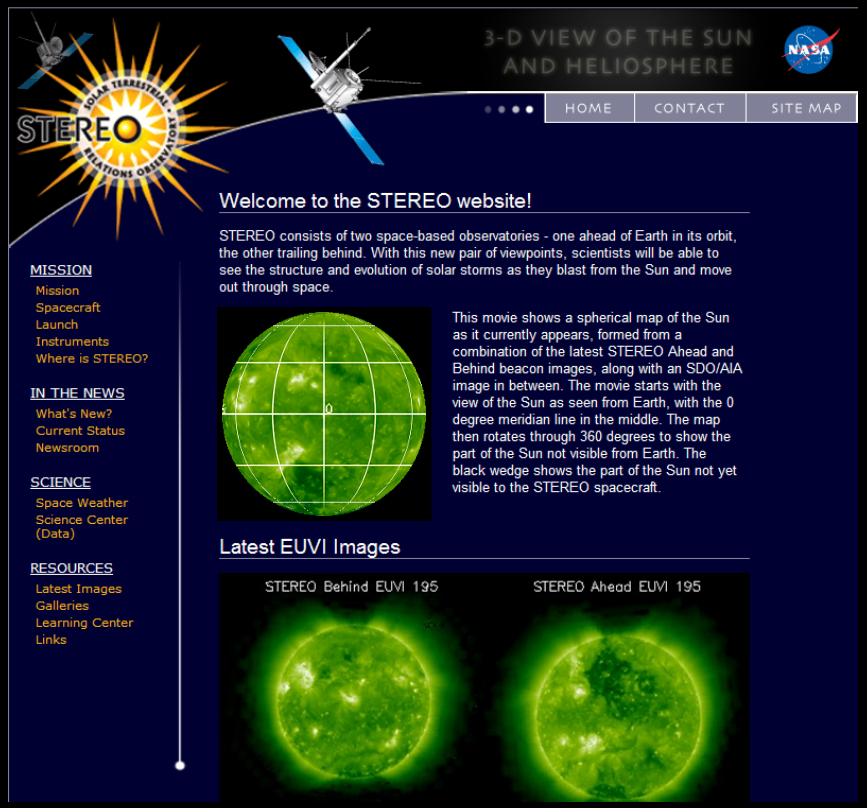
Monitoring

- Space Weather Canada
- www.spaceweather.gc.ca

Monitoring

- STEREO – Solar Terrestrial Relations Observatory
- www.stereo.gsfc.nasa.gov/






Questions?