Space Weather

Indiana Space Day, March 28, 2009

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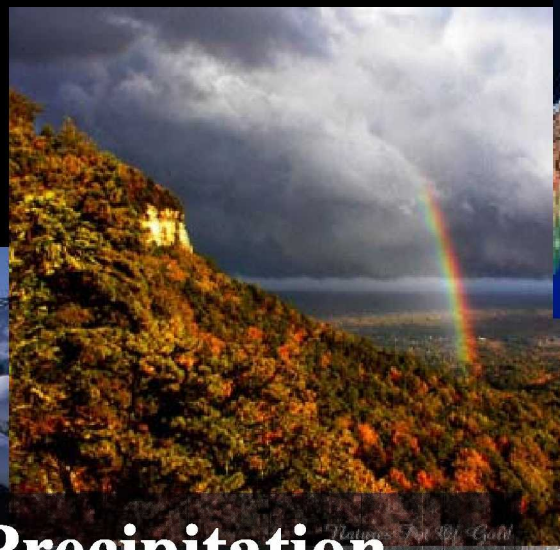
Weather on Earth



- Precipitation
- Light Displays
- Power of Nature
- Societal Danger

Weather in Space?

- Precipitation
- Light Displays
- Power of Nature
- Societal Danger

Shock and Awe?

Roadmap

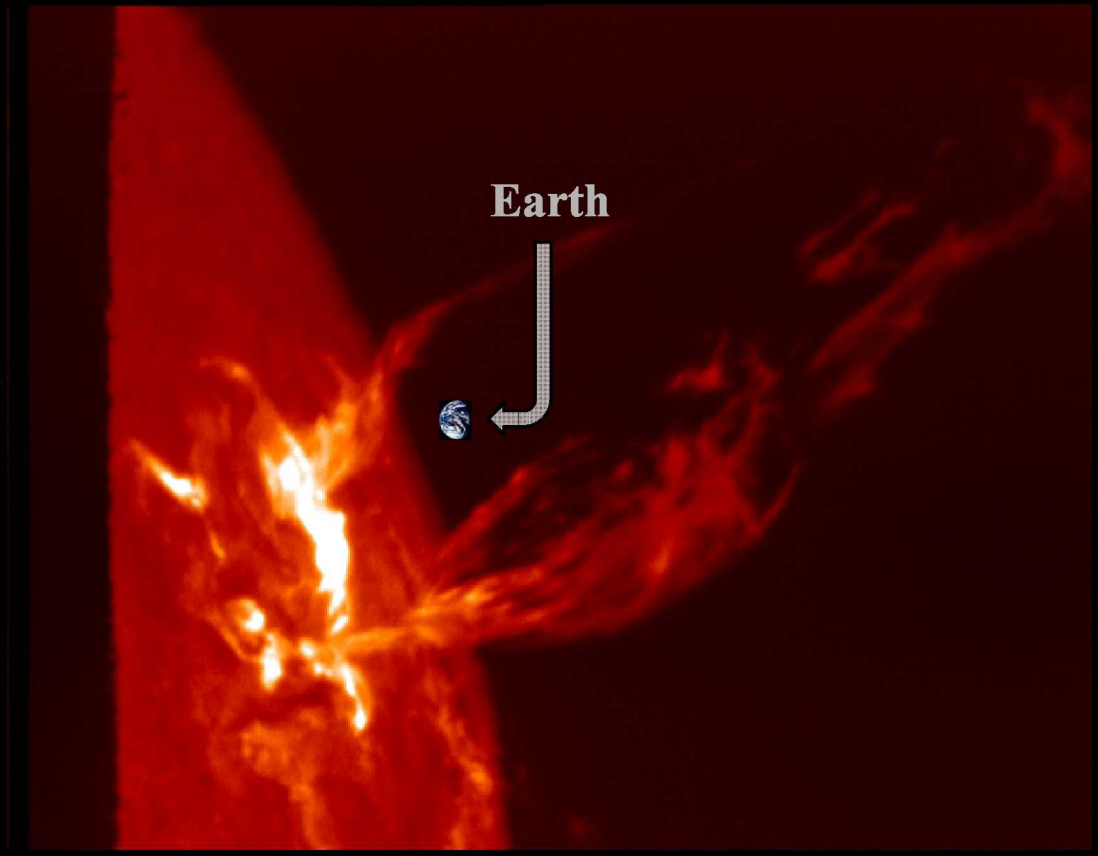
- Hazards and effects to humans and manmade systems?
  - In space
  - In the air
  - On the ground

Start at the Sun

Flare or Coronal Mass Ejection:

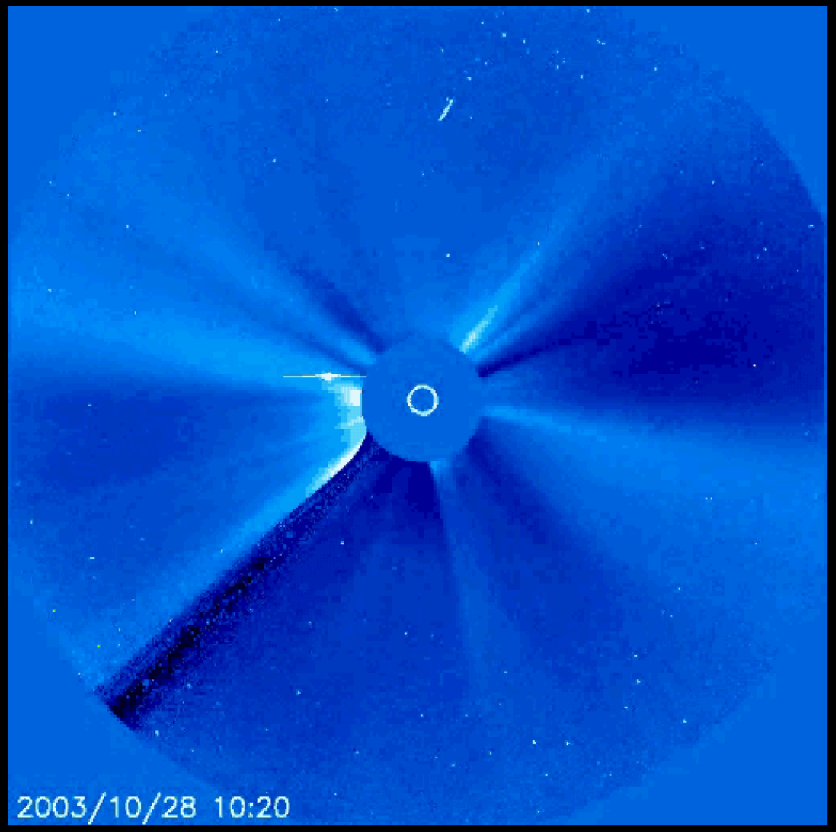
Violent release of as much a billion tons of matter.

Can be equivalent of 40 billion Hiroshima-sized atomic bombs.

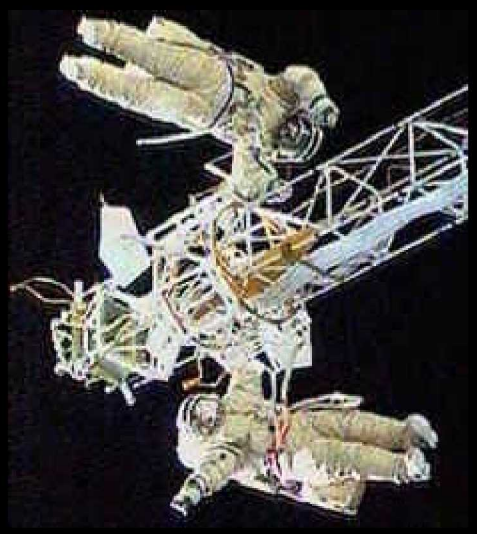


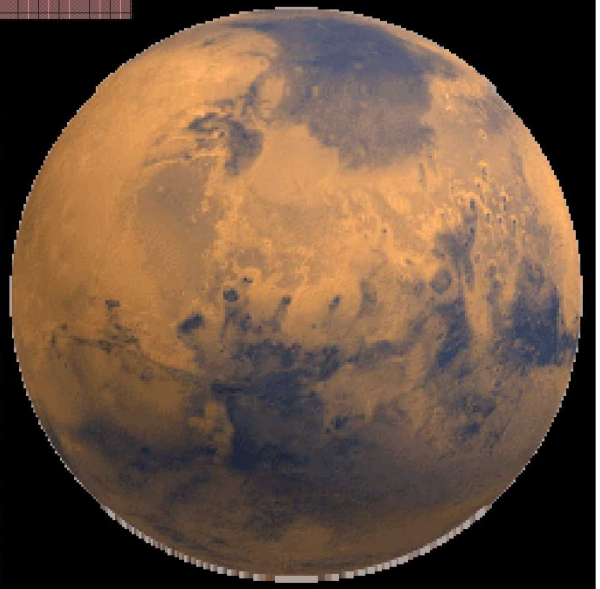
Weather at the Sun or Elsewhere Means There are Events

- What do you see?
- Near the Sun?
- Far from the Sun?

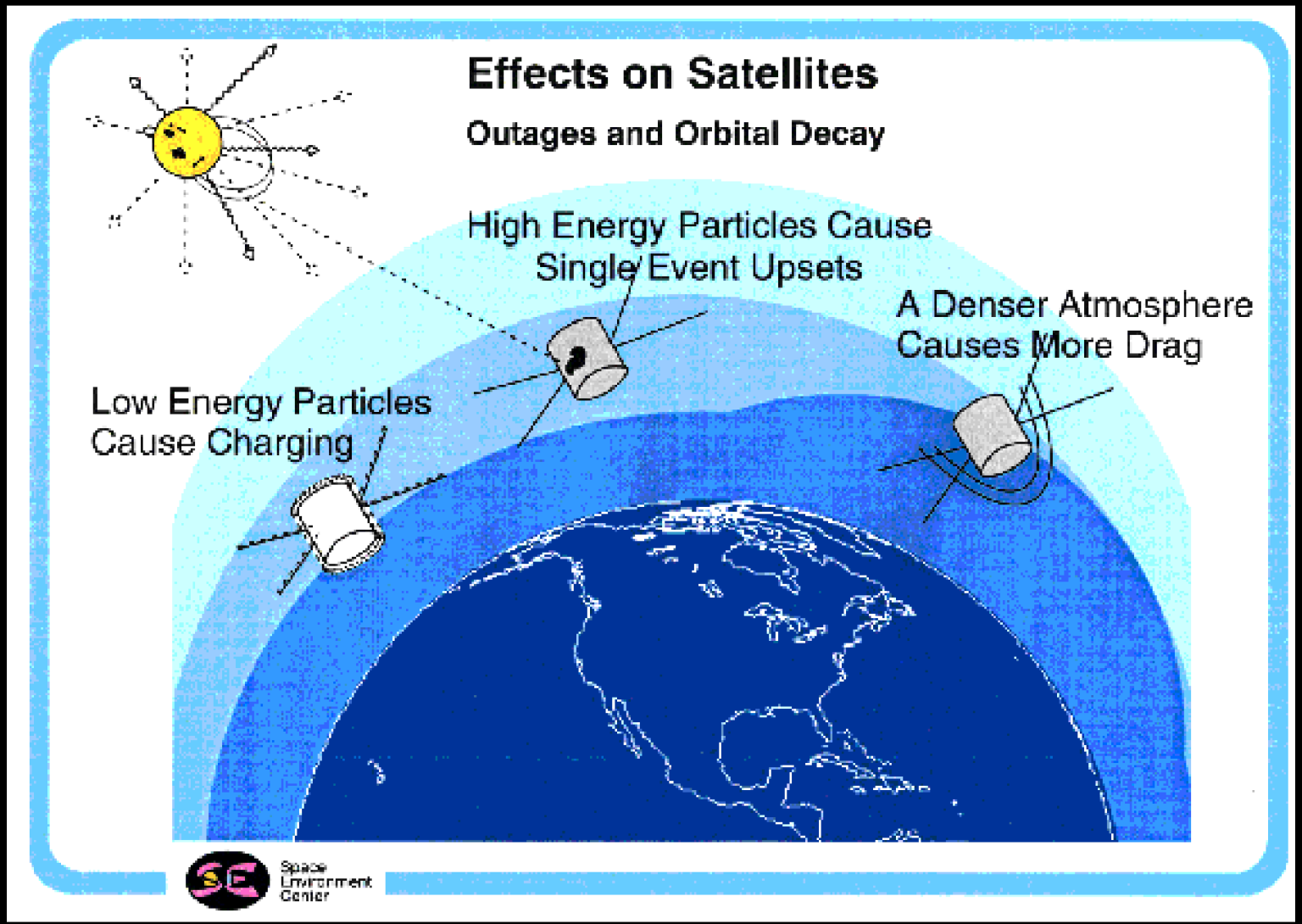


Hazards to Humans in Space





Satellite Hazards



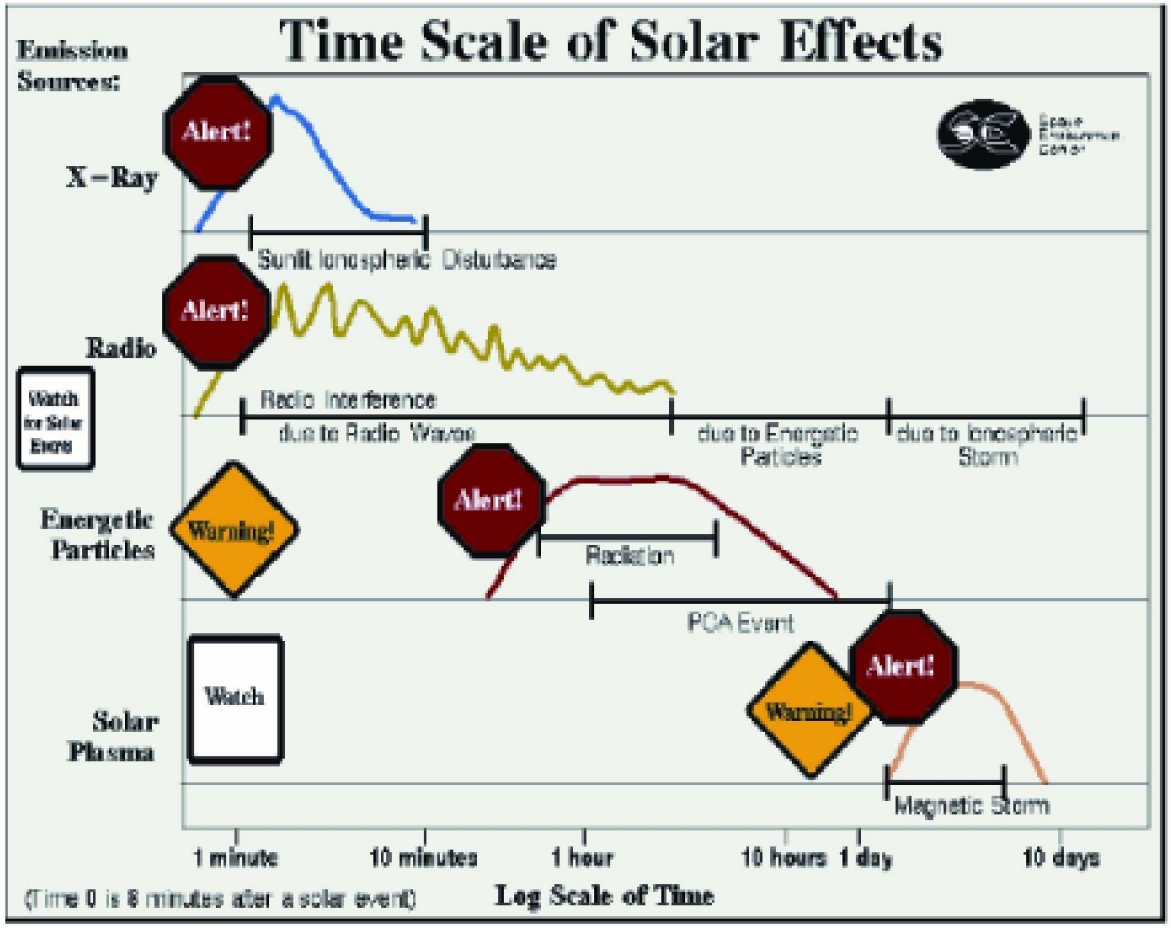


Figure 2. The time scales of solar effects (source: NOAA SEC). Eight minutes after a flare and/or a CME erupts from the Sun, the first blast of Extreme Ultraviolet (EUV) and X-ray light increases the ionospheric density, which can impact HF communication loss. 10 minutes to several hours later, energetic particles arrive. One to four days later, the CME passes and energizes the magnetosphere and ionosphere, affecting navigation systems and radio communications.

From the American Meteorological Society & SolarMetrics Policy Workshop Report March 2007

Risks for Electronics

- In space single event upsets (SEU) cause satellite control errors, risking damage or loss
- In aircraft SEU's cause upsets of about 1 per 200 hours of operation measured on a Boeing 777 autopilot: (designed for 1:1 million); pacemakers have been used to measure SEU's in commercial aircraft
- On the ground SEU's are thought to have caused power loses in German high-speed trains in the 1990's from cosmic radiation.

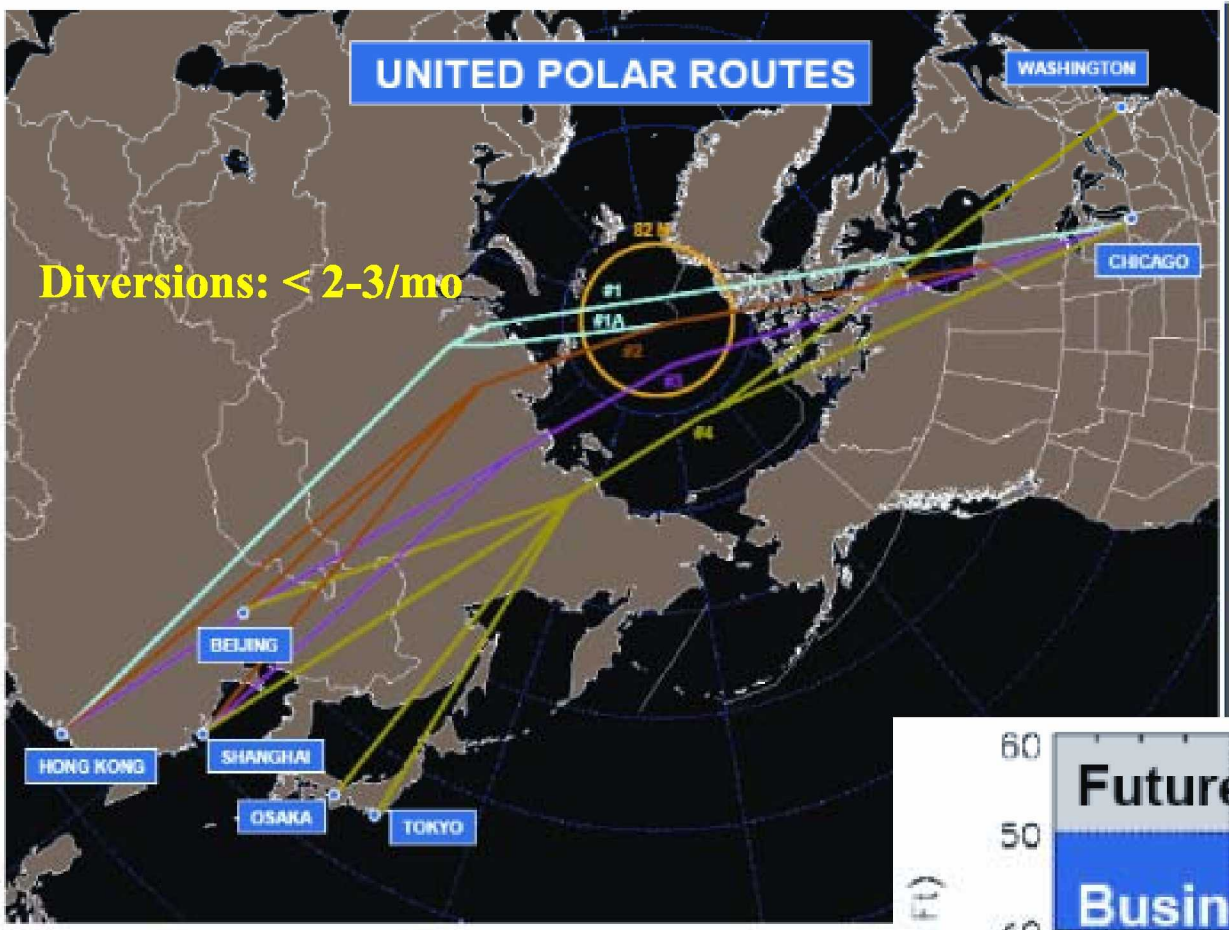
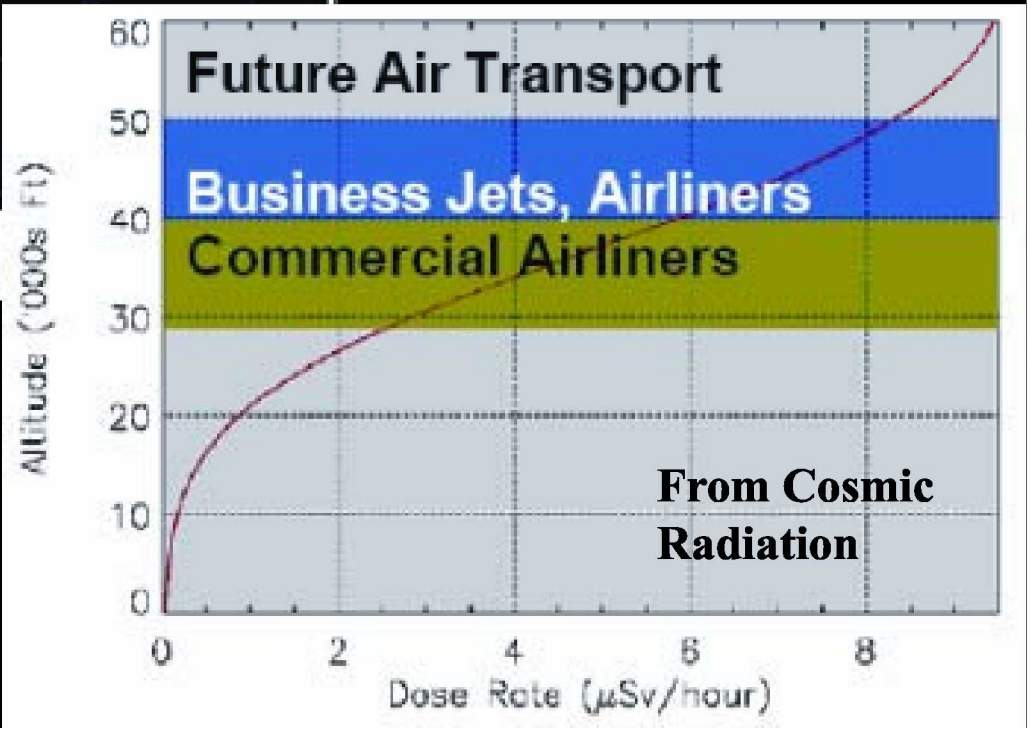


Figure 1. Polar Routes used by United Airlines (source:

Transpolar Flights and cosmic radiation risks are increasing



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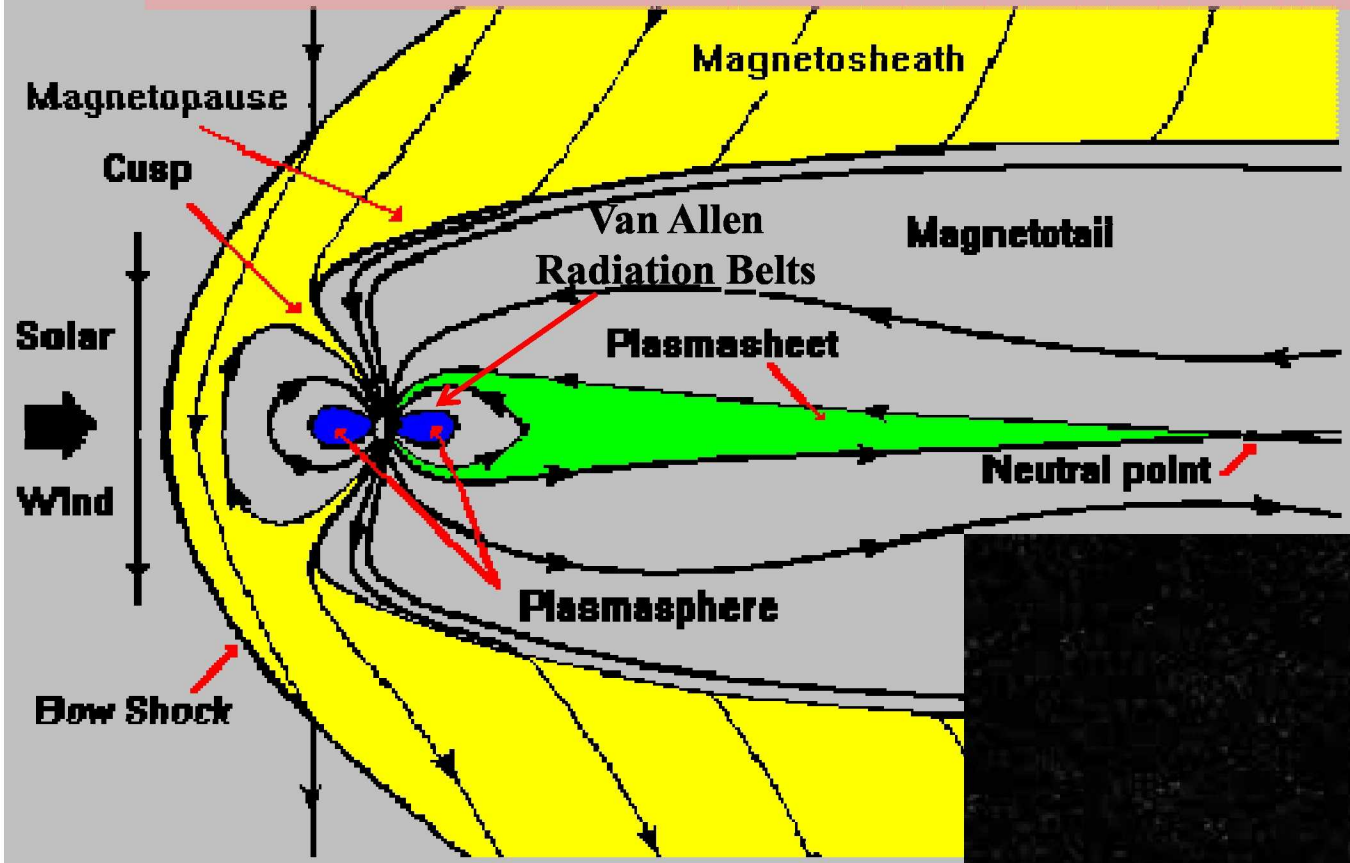
Max permissible mean dose rate limit: 7.5 mSv/hour


Fairbanks, Alaska

Earth's Magnetic Environment



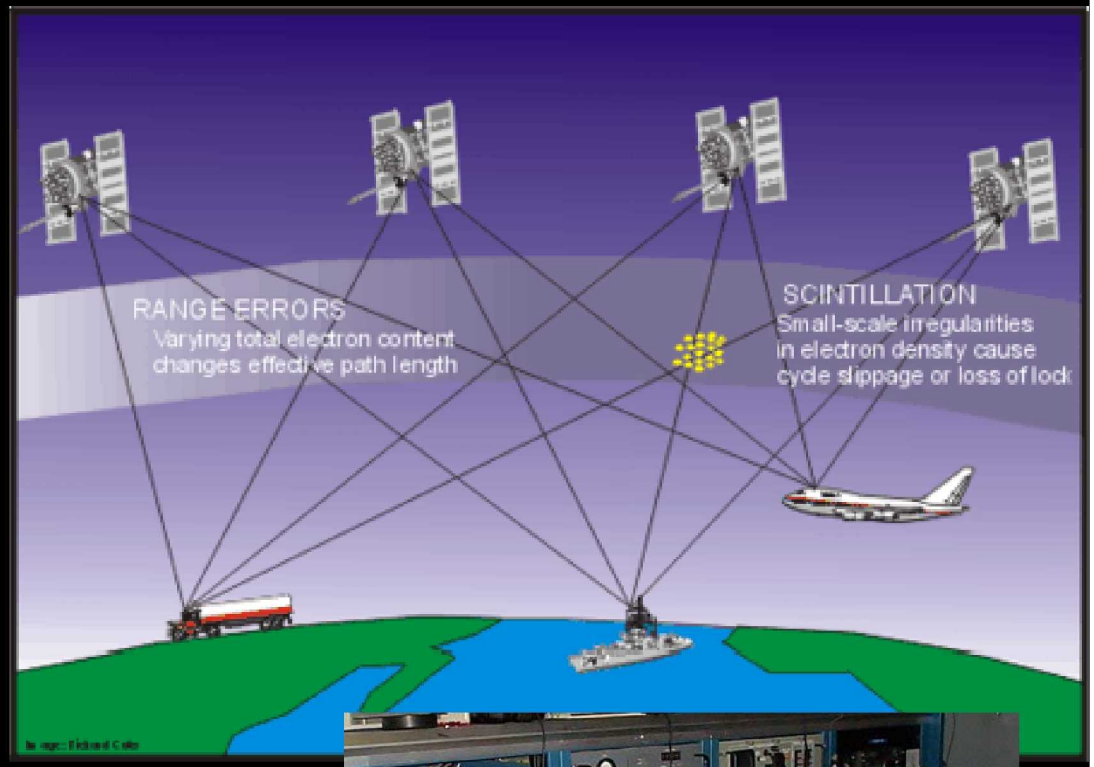
Precipitation
Electric Currents
Ionospheric scintillation
10MW radio emission
Radiation

The Magnetosphere

Disruption of:

HF Communication

Navigation



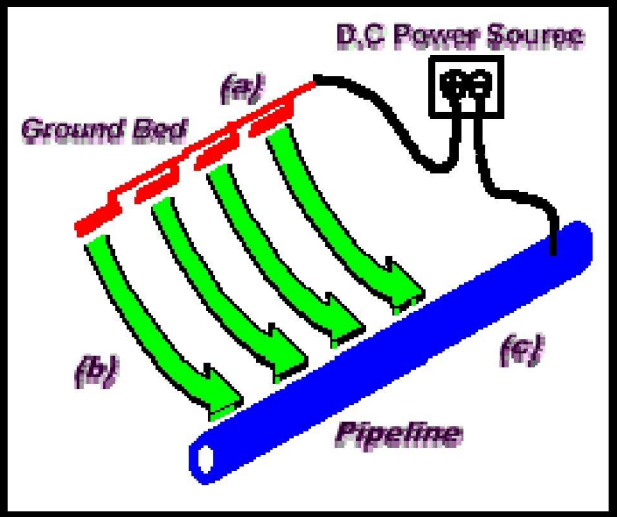
Ground Induced Currents (GIC)

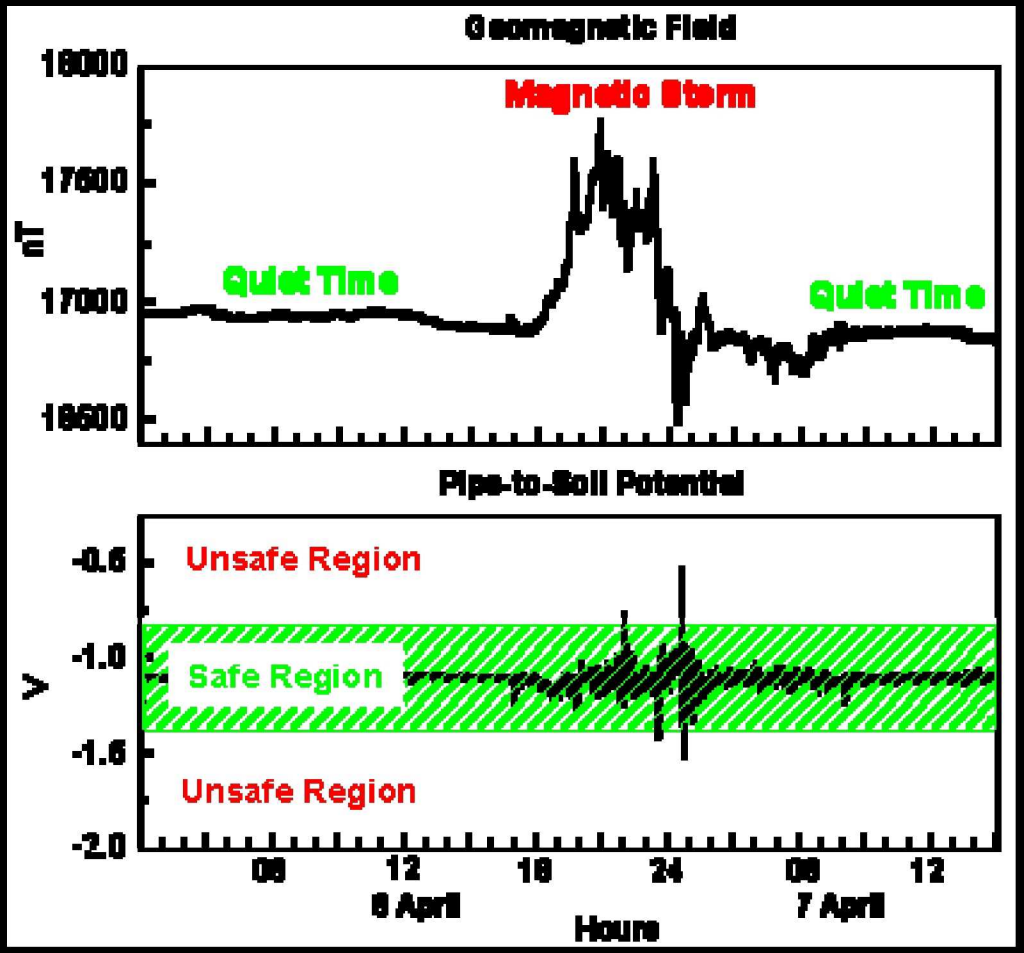
- GIC's hamper rail traffic by disturbing signaling systems. In Sweden in 1982, railway signals failed to switch correctly; induced voltage may cause such a malfunction; 19 lives were lost in Norway in January 2000 due to flawed "track clear" signal during heightened solar activity, although not proven.

- GIC's are thought to generate hundreds or even thousands of volts on deep sea communication cables during geomagnetic storms; even fiber optic cables are metal clad and there are cables to carry current to the amplifiers

Pipeline-Soil Potentials Advance Corrosion

Telluric currents disrupt cathodic protection

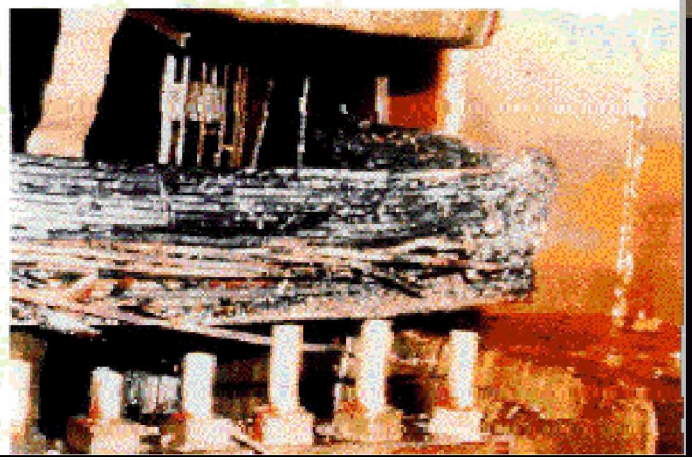


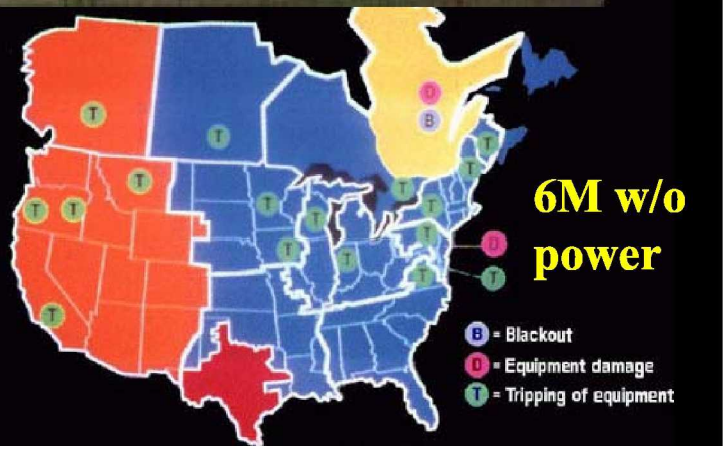


Electrical Power Disruption Due to Induced Electric Currents

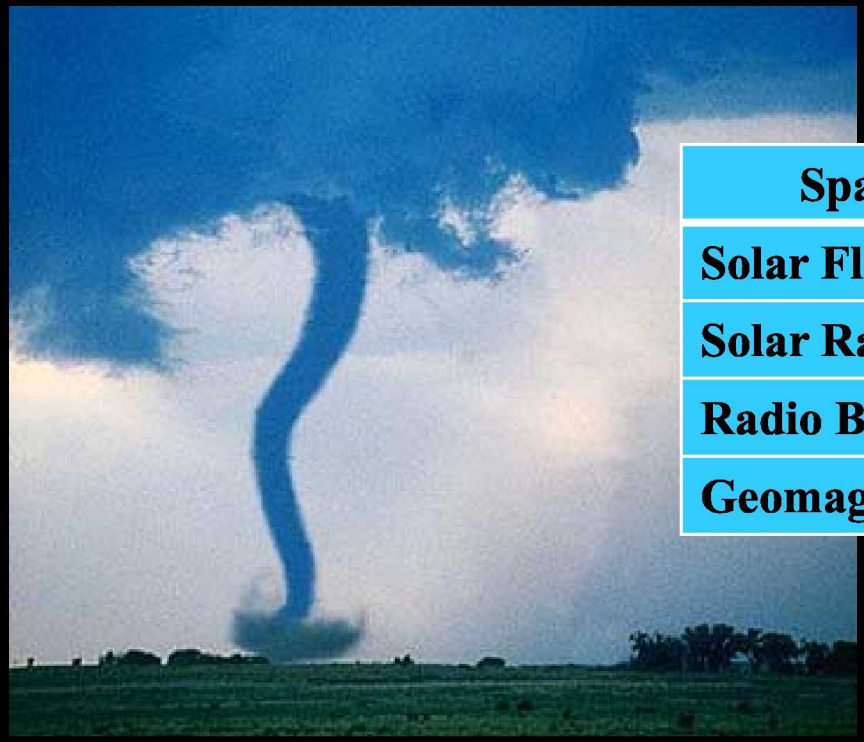
PJM Public Service
Step Up Transformer

Severe internal damage caused by the space storm of 13 March, 1989.





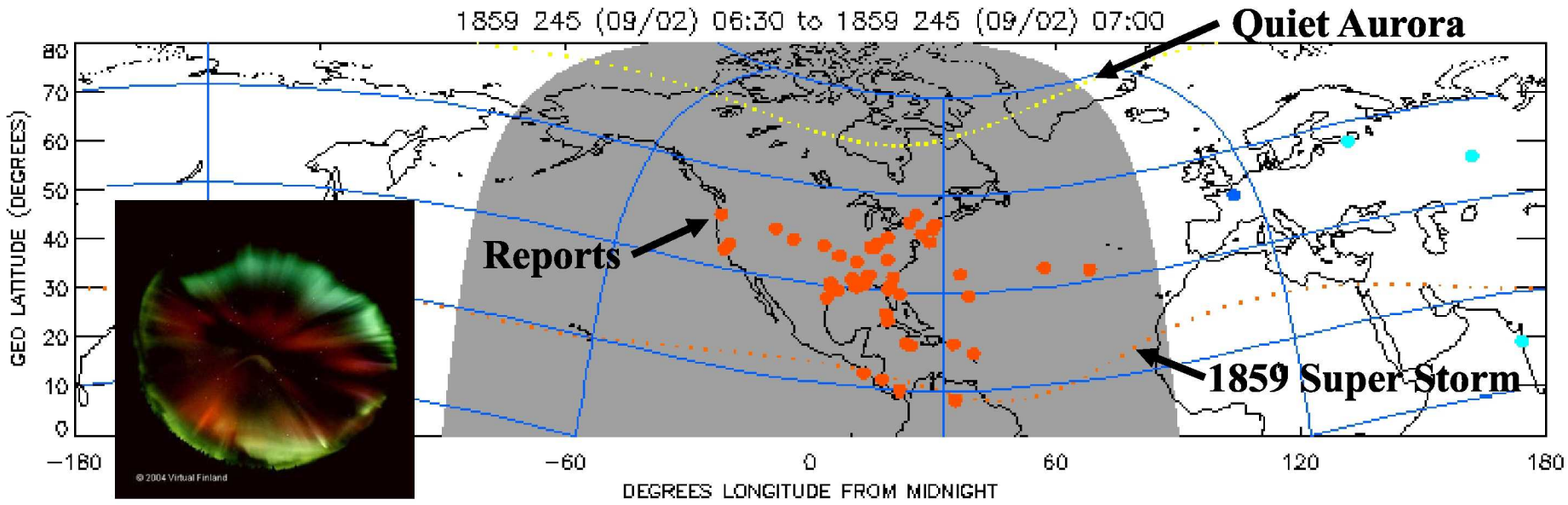
Atmospheric storms have categories. Don't space storms too?



Space Storm	Minor → Extreme
Solar Flares	B → C → M → X
Solar Radiation	S1 → S5
Radio Blackouts	R1 → R5
Geomagnetic Storms	G1 → G5

September 2, 1859 Event

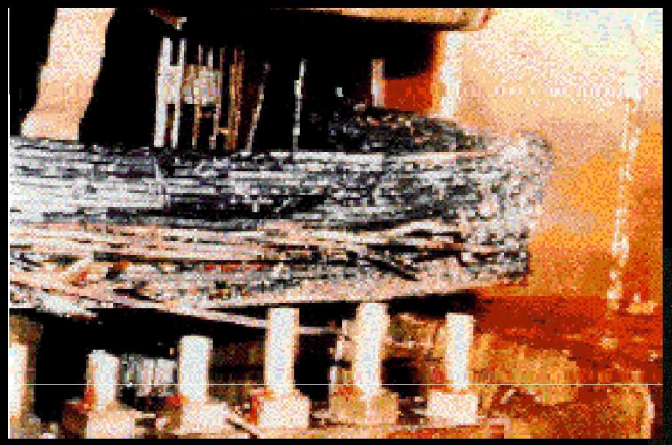
3X recent storm strength / 1/3 strongest ever



- Messenger (deck log: Lat. 49°) "we witnessed the most magnificent display of the aurora boreales (sic) imaginable … the whole firmament was a blaze of Crimson shooting up from all points of the compass but the most splendid from the South W. I have not the language to describe it"

Courtesy James L. Green, NASA/GSFC

Weather in Space



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Shock and Awe