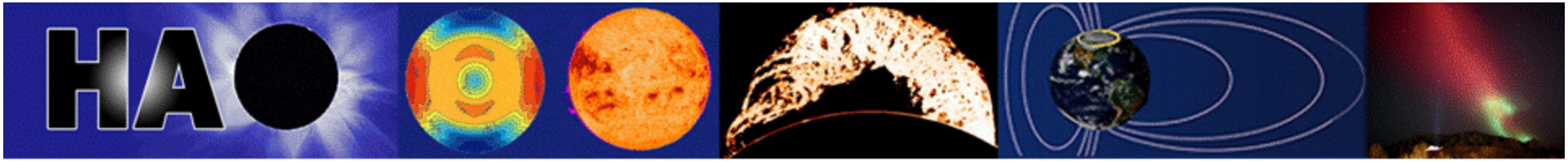


An Introduction to Space Weather

J. Burkepile
High Altitude Observatory / NCAR

Tornado in Union City, Oklahoma, May 1973

Credit: NOAA Photo Library, NOAA Central Library; OAR/ERL/National Severe Storms Laboratory (NSSL)

Power and telephone lines sagging after heavy ice storm

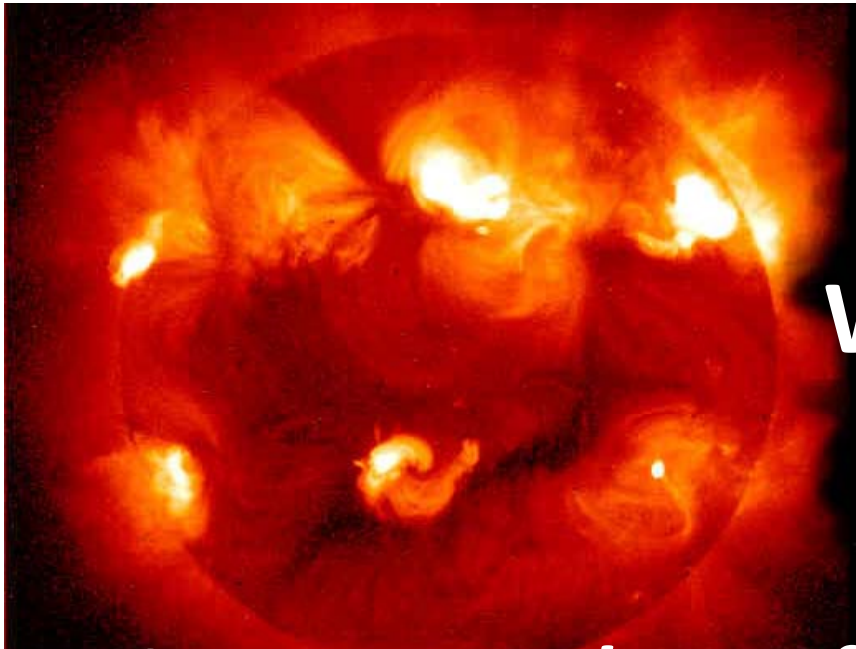
Historic NWS Collection

A computer-generated image of Hurricane Fran using data from the GOES weather satellites

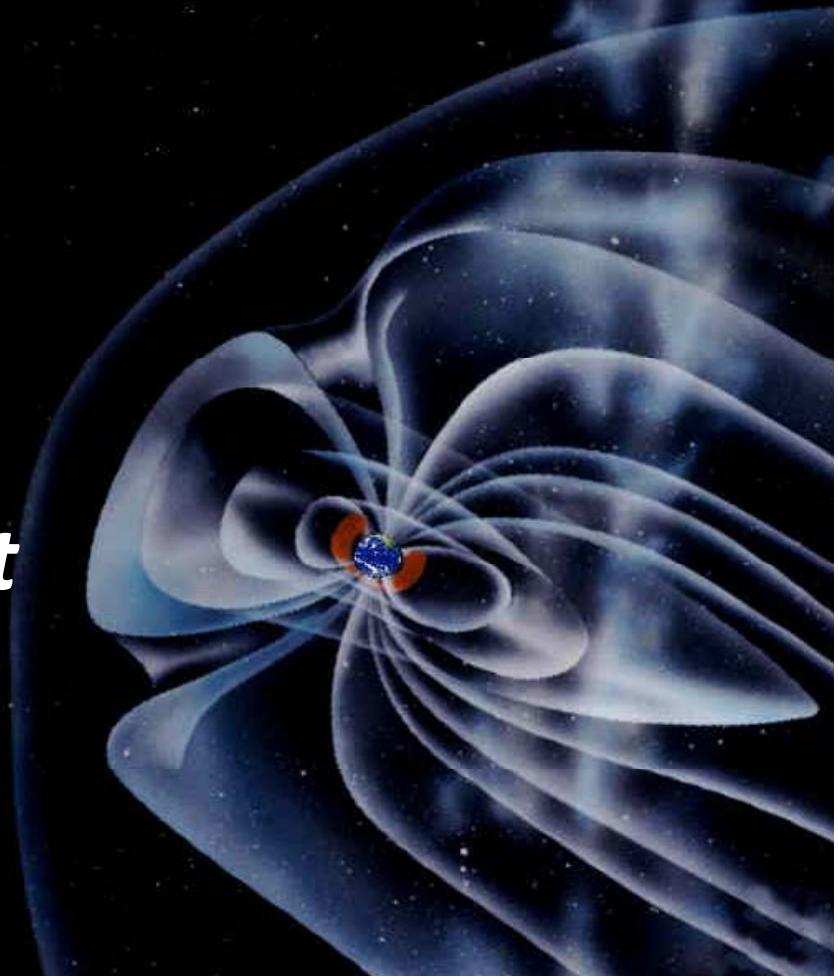
Multiple cloud-to-ground and cloud-to-cloud lightning strokes during a thunderstorm

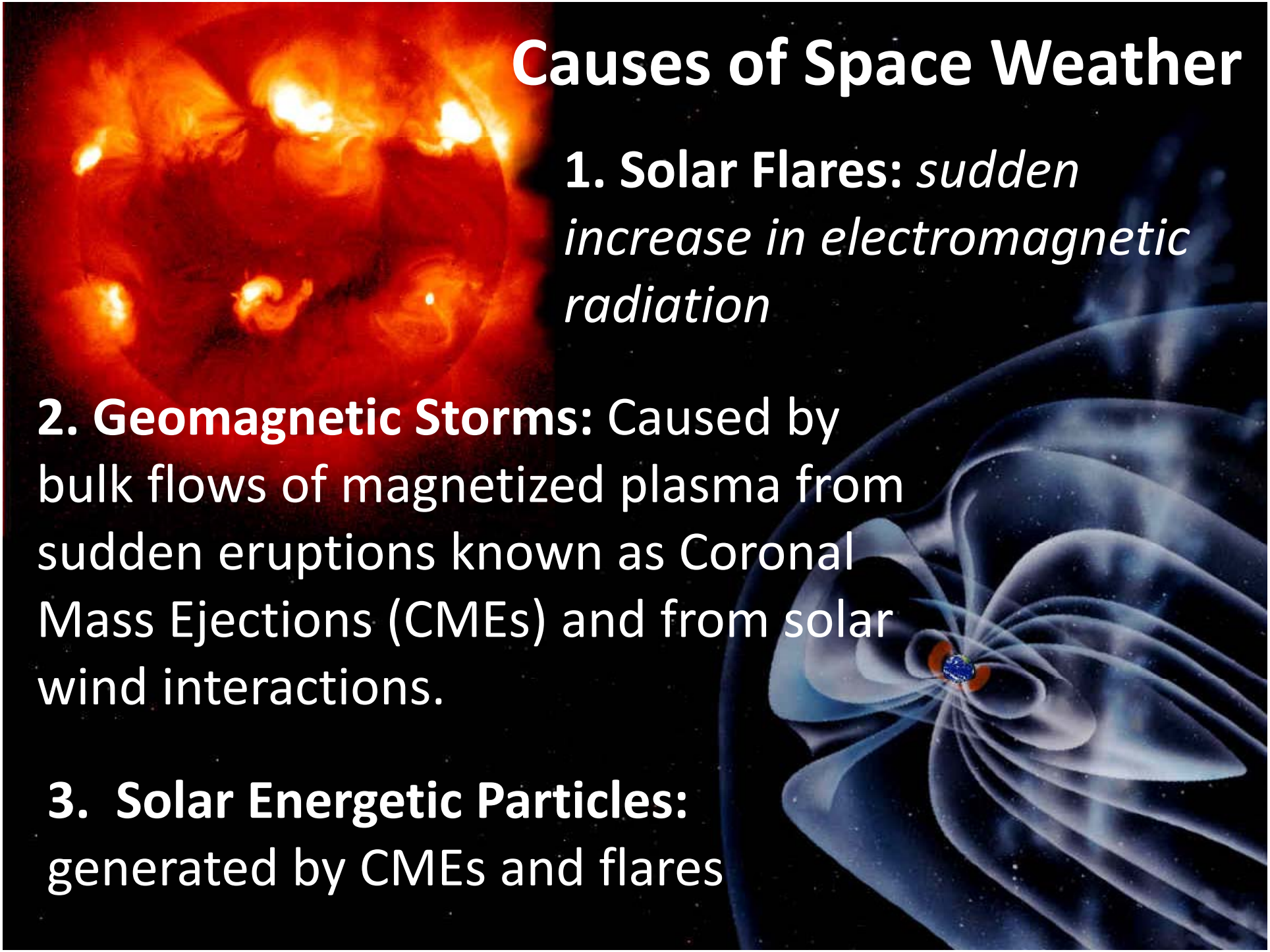
Photographer: C. Clark Credit: NOAA Photo Library, NOAA Central Library; OAR/ERL/National Severe Storms Laboratory (NSSL)

What is Space Weather?



Space Weather refers to conditions in interplanetary space, produced by the Sun, that can disrupt modern technologies and affect human life or health.





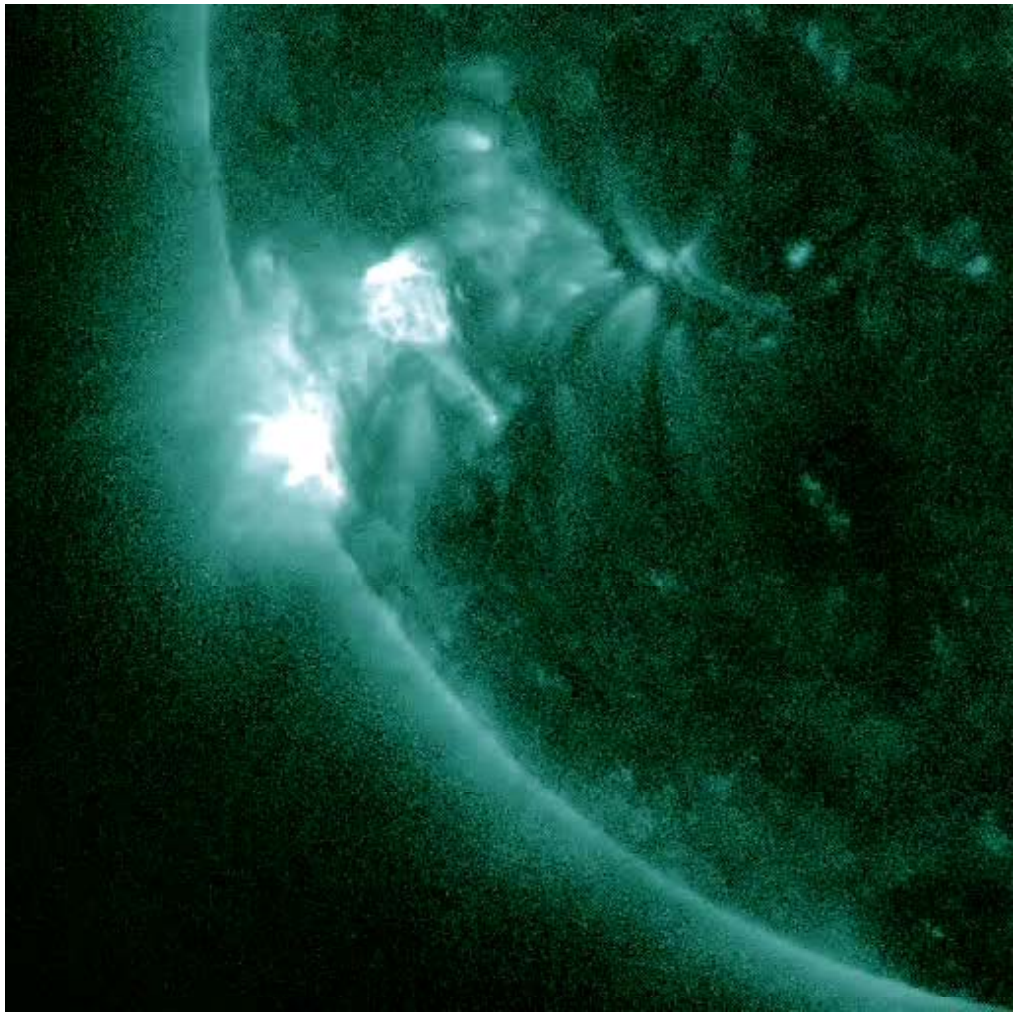
Causes of Space Weather

1. Solar Flares: *sudden increase in electromagnetic radiation*

2. Geomagnetic Storms: Caused by bulk flows of magnetized plasma from sudden eruptions known as Coronal Mass Ejections (CMEs) and from solar wind interactions.

3. Solar Energetic Particles: generated by CMEs and flares

Solar Flares

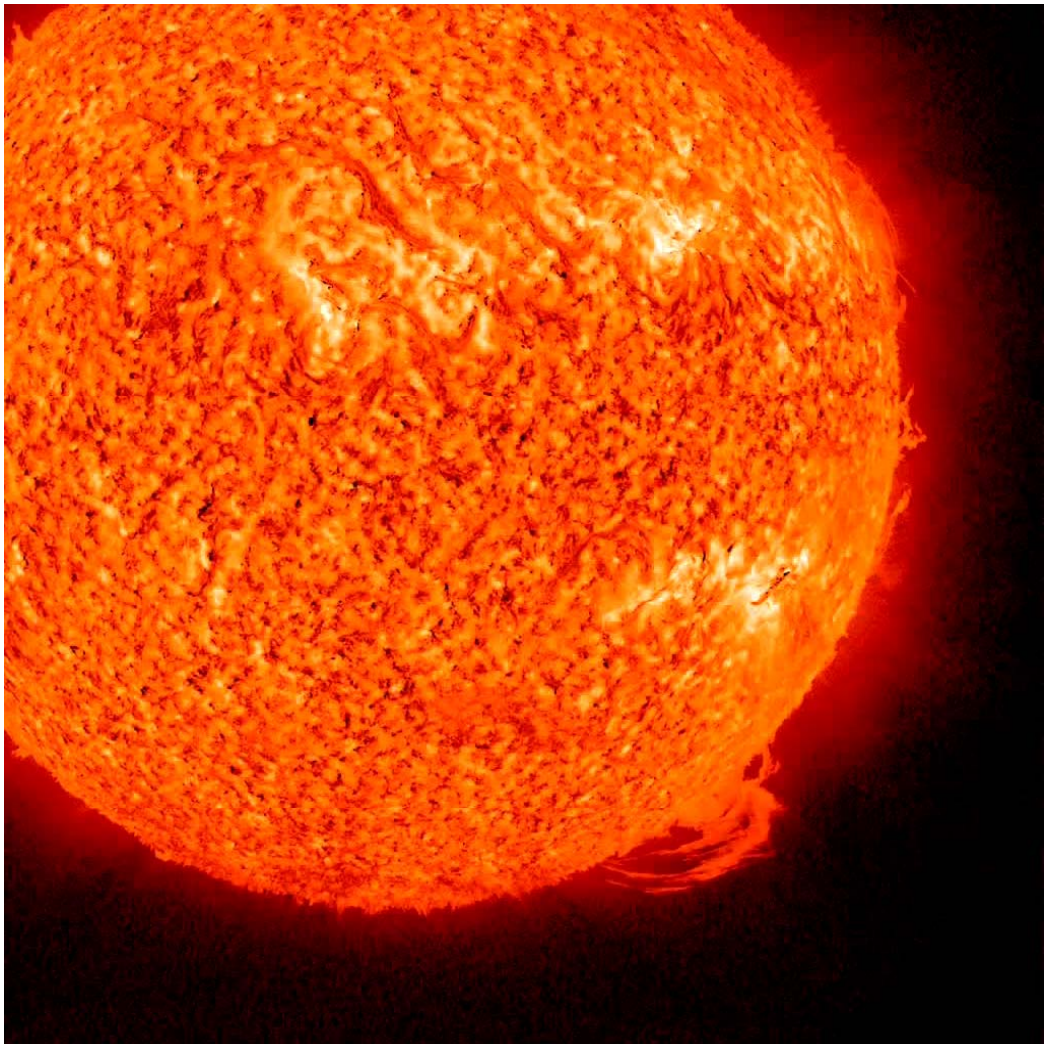


April 21-23, 2011 from Solar Dynamics Observatory, Courtesy NASA

Flares are sudden brightenings in nearly all wavelengths from radio to infrared to visible to X-rays. Light arrives at Earth in 8 minutes.

Short wavelengths (e.g. X-rays) have the greatest energy, modifying Earth's upper atmosphere, which can cause communication disruptions

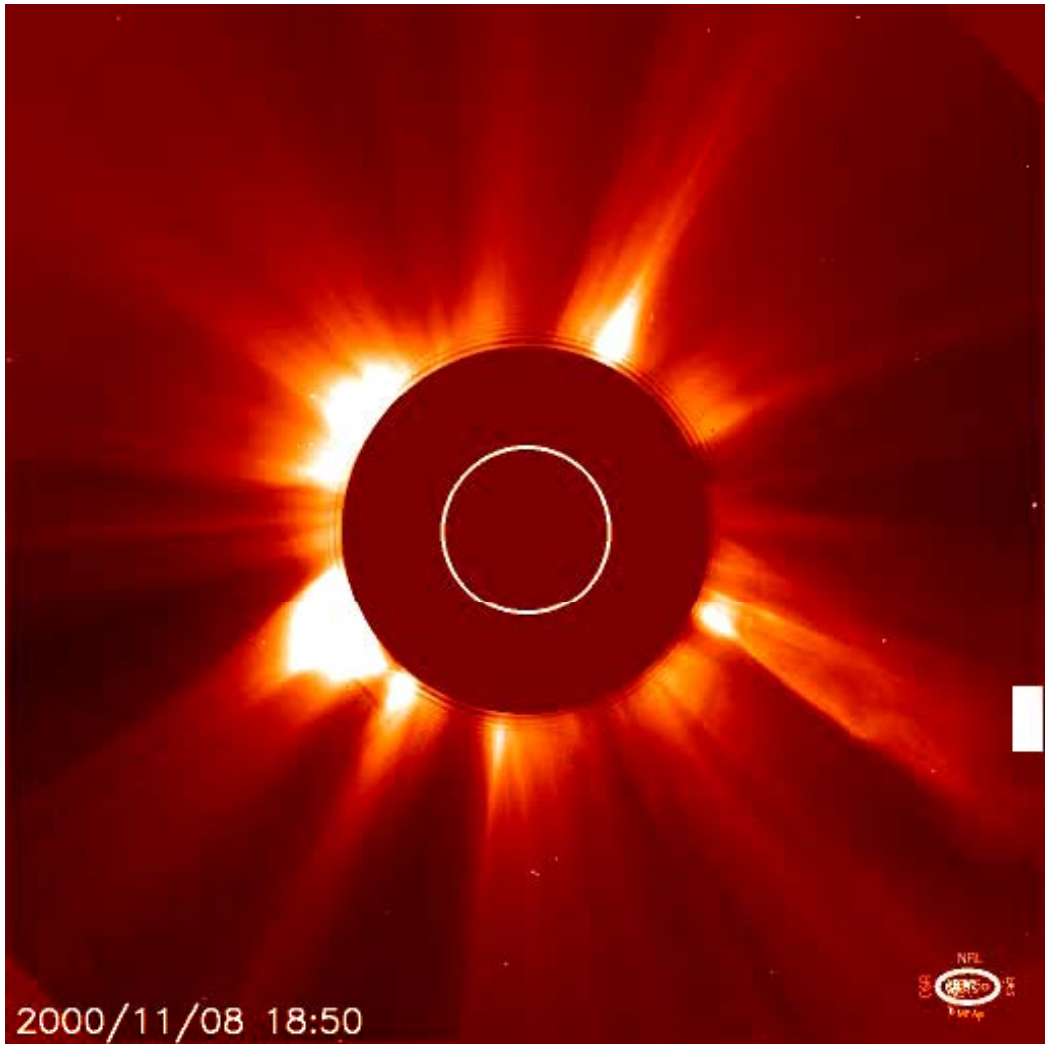
Coronal Mass Ejections (CMEs)



June 7, 2011 from Solar Dynamics Observatory, Courtesy NASA

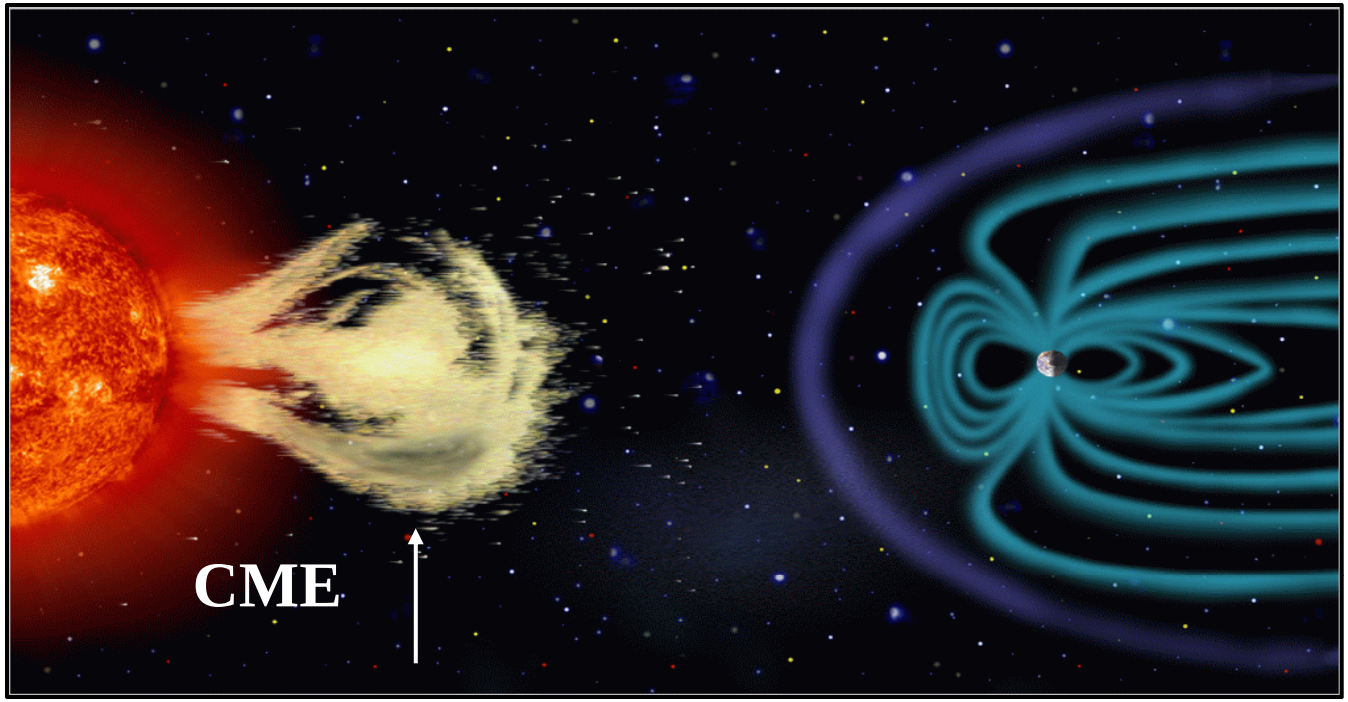
CMEs are regions of the Sun's outer atmosphere that are explosively released into interplanetary space. They arrive at Earth in 1 to 4 days. They are organized magnetic structures that transfer their energy to Earth's magnetic field.

Solar Energetic Particles



November 8, 2000 from Solar Heliospheric Observatory (SOHO), Courtesy NASA

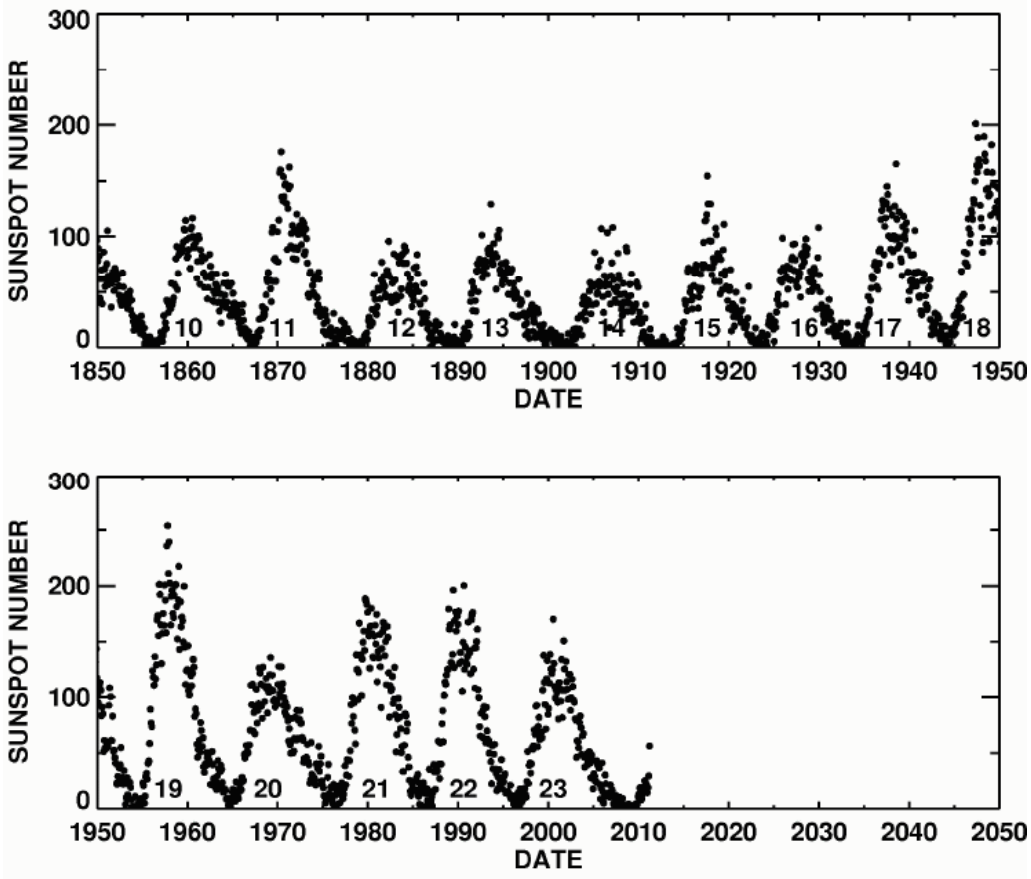
Particles are accelerated to relativistic speeds at shocks produced by CMEs and by flares. They arrive at Earth between 20 minutes and ~24 hours. They can cause communication outages, damage or 'kill' satellites and endanger astronauts.

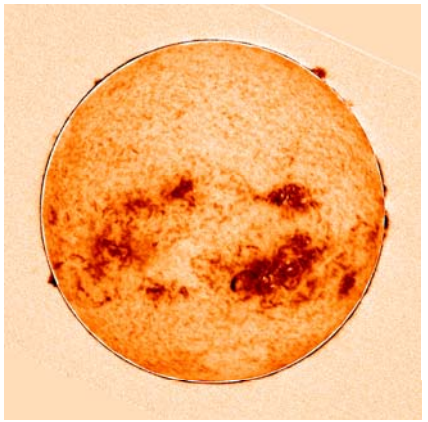


Space weather is driven by solar activity which is caused by the release of magnetic energy in the Sun's atmosphere. Major geomagnetic storms are triggered by southward-pointing magnetic fields in CMEs and the solar wind.

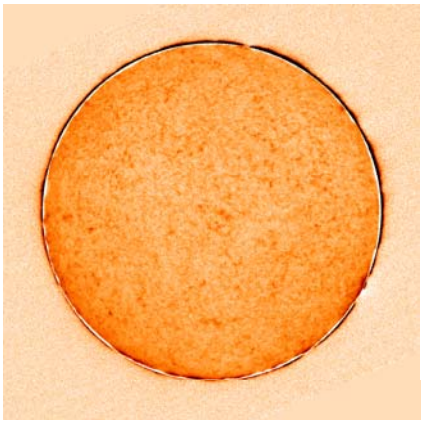
Need to track changes in Sun's magnetic field.

11-year sunspot cycle changes

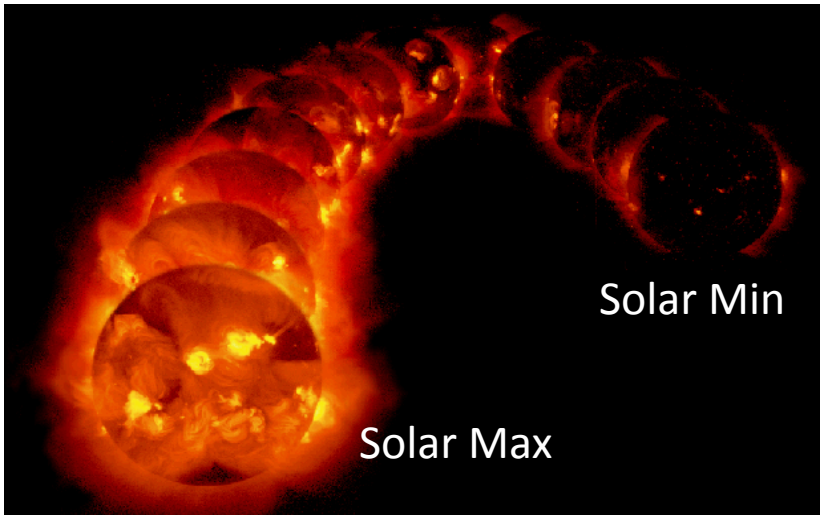




Solar Max – 2003



Solar Min - 2009



The number of sunspots reaches a peak approximately every 11 years. We are currently in the rise phase with solar maximum activity expected in about 2 years (~2013).

Frequency of Large Events

Severe Storm Rates:

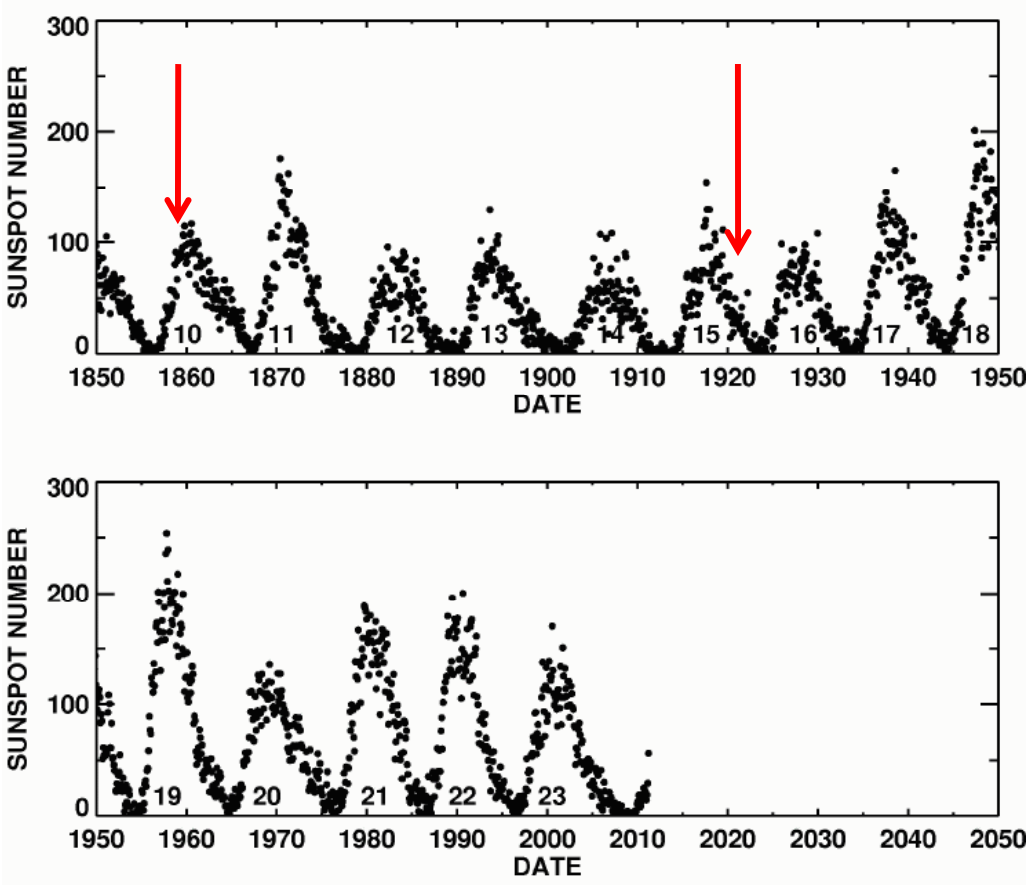
Activity maximum ~ 4 per year Activity minimum ~ 0.2 per year

Frequency of Super Storms

1989: This severe storm interfered with short wave radio all across Europe and tripped circuit breakers which knocked out Quebec's power grid. Aurora were seen as far south as Texas.

1921: 10 times stronger than 1989 event. The storm knocked out the entire signal and switching system of the NY central railroad in Manhattan. The storm interfered with telephone and cable traffic over most of Europe and burned out one station igniting a fire. Ice core samples record levels of high-energy particle radiation and reveal that over the past 450 years ***several (2-3) storms of this magnitude have occurred each century.***

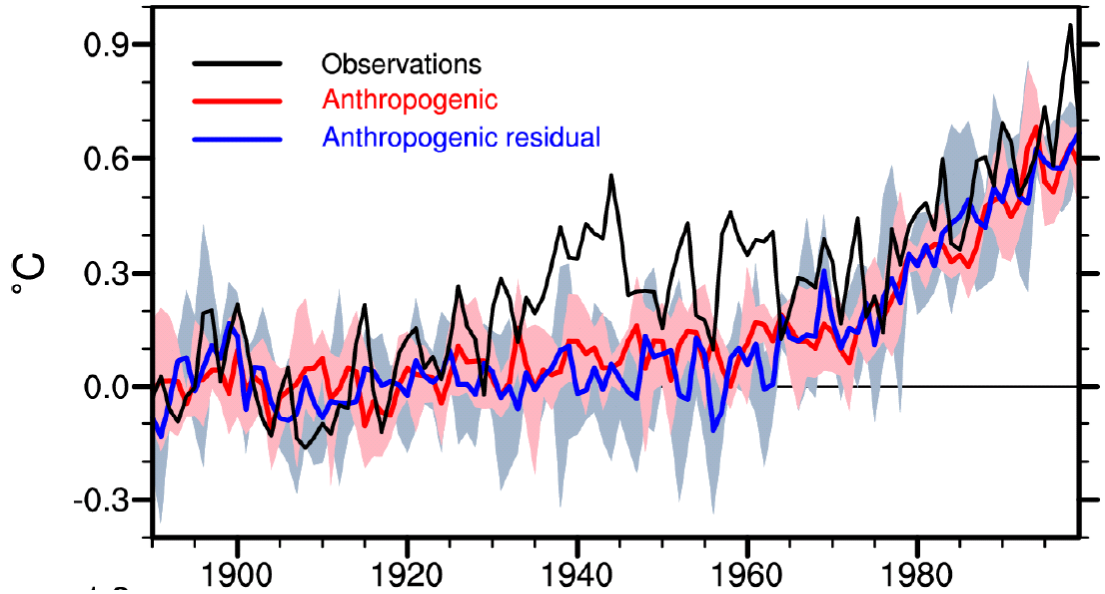
1859: At least twice as strong as 1921 event. The 'Carrington Superstorm' was the largest solar storm in recorded history and the first Space Weather event. ***Solar super storms occur once about every 500 years.*** The storm produced aurora worldwide and were so bright they woke people from their sleep. Telegraph systems failed all over Europe and North America, and electrically shocked some telegraph operators. Some telegraph pylons caught fire.



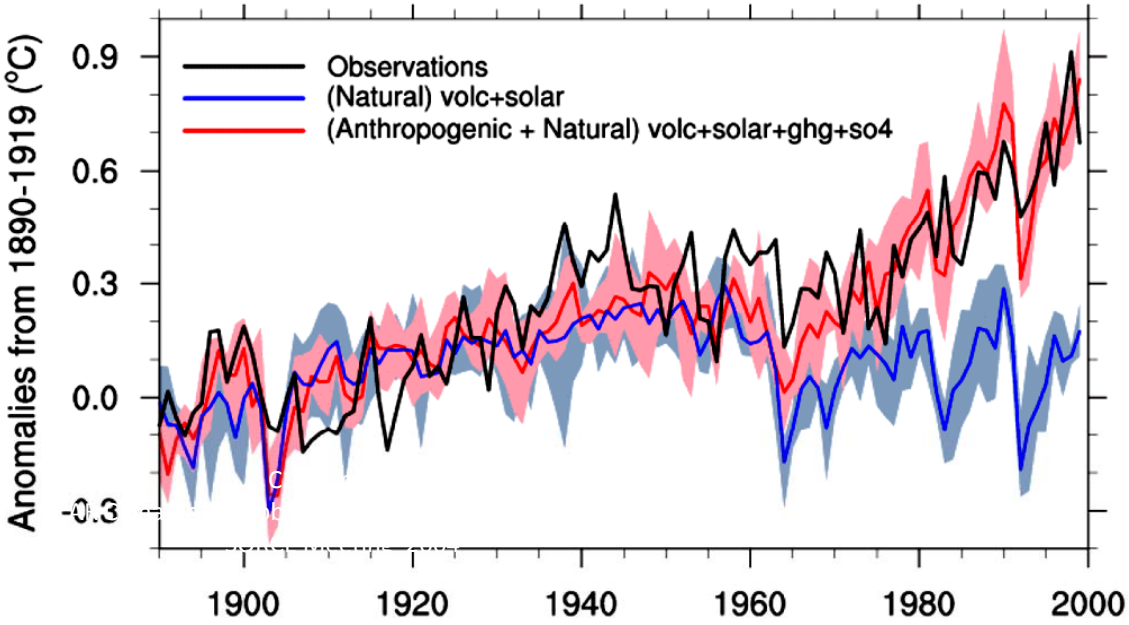
Super storms can occur during modest sunspot cycles

- Need to study details as well as trends: wide variety of observations: EUV, Coronagraphs, magnetic field measurements, Solar Irradiance, Solar wind monitors (e.g. ACE)
- Technologies are vulnerable: mitigate impacts

Solar Forcing in NCAR Climate Model



Without Solar



With Solar