What is a Carrington Event?

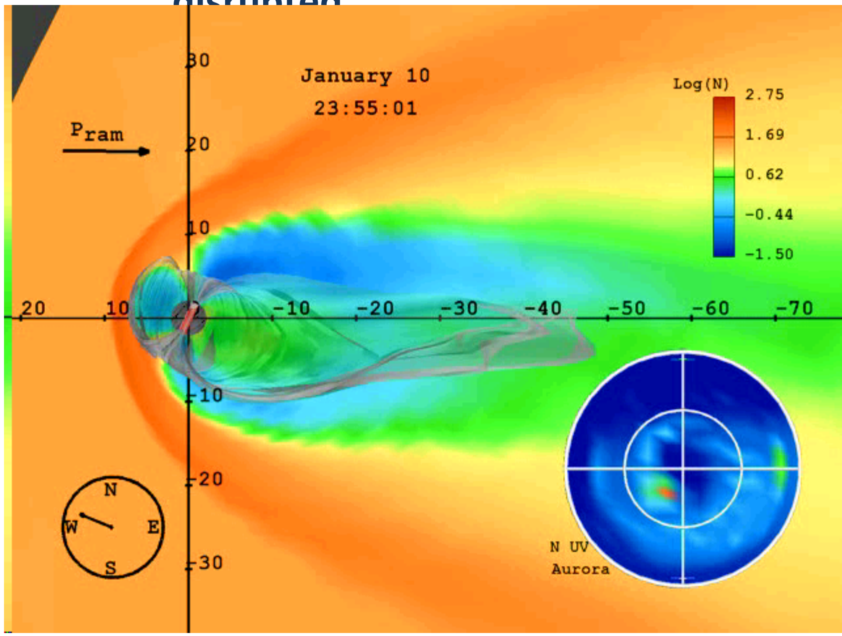
AMS Panel on "Space Weather Mitigation: Recovering from a Carrington Event"

Madhulika Guhathakurta
Lead Program Scientist, LWS
NASA Headquarters

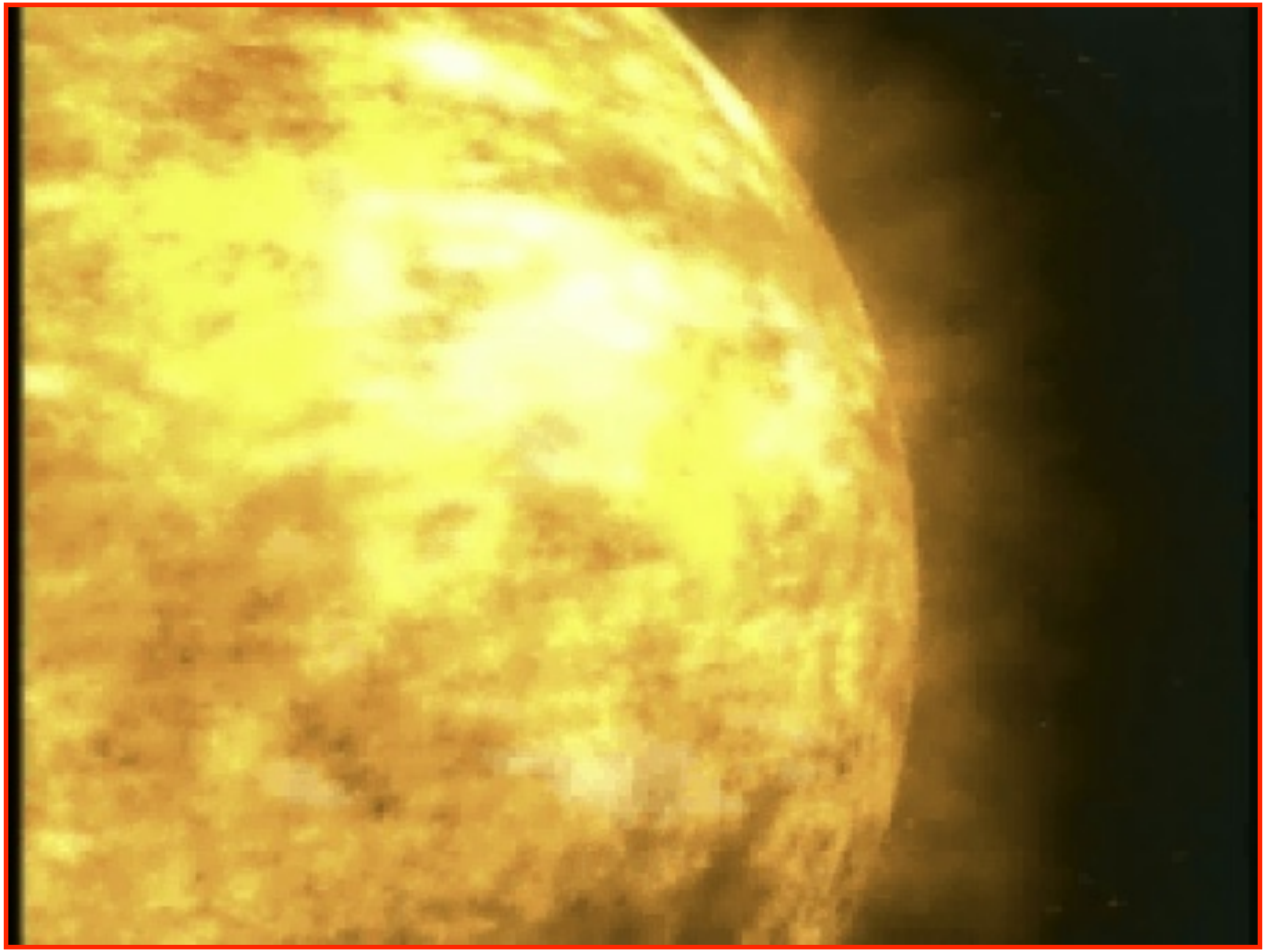
April 2nd , 2014, DC

What is Space Weather?

- **SPACE WEATHER refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space born and ground-based technological systems and that can affect human life or health.**
- **"Space Weather" effects on installations on Earth not a new phenomena**
  - **17 November 1848: Telegraph wire between Pisa and Florence Interrupted**
  - **September 1851: Telegraph wire in New England disrupted**
  - **Induced currents made it possible to run the telegraph lines without batteries. The following is a transcript between Portland and Boston (1859):**
    - **Portland: "Please cut off your battery, let us see if we can work with the alone"**
    - **Boston: "I have already done so! How do you**
    - **Portland: "Very well indeed - much better**



What is Space Weather?



Impact of an Earth directed CME

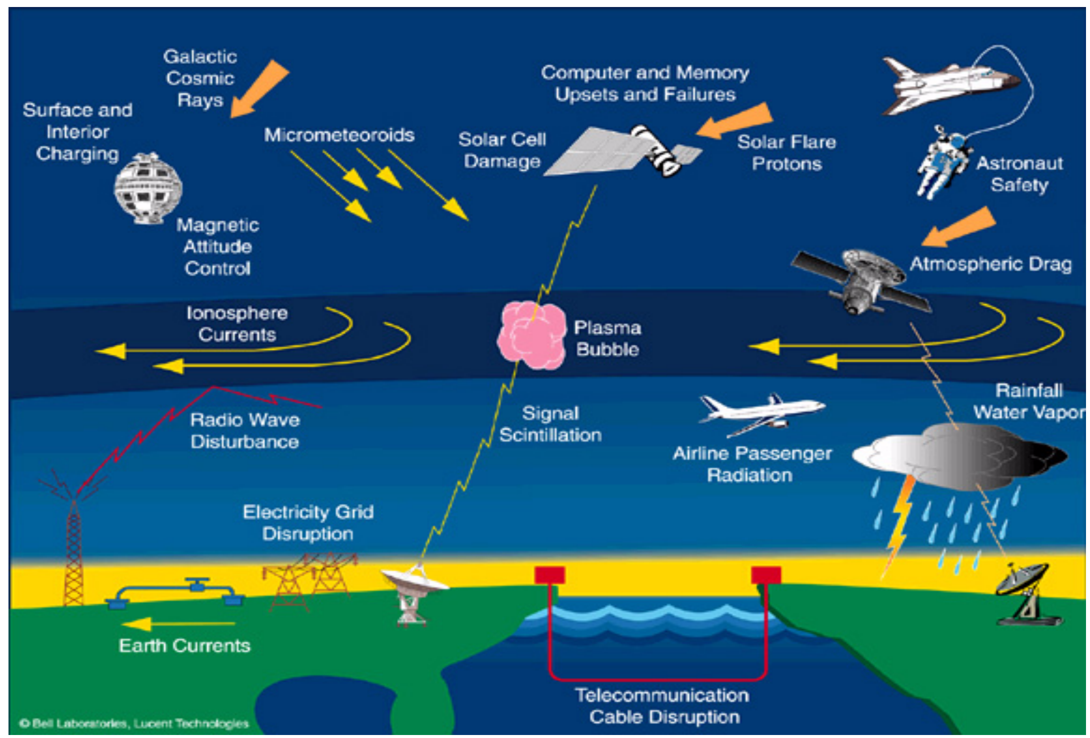
Space Weather: Why should we care?

- **Our society is much more dependant on technology today compared to in 1989**

- **The most rapidly growing sector of the communication market is satellite based**
  - Broadcast TV/Radio,
  - Long-distance telephone service, Cell phones, Pagers
  - Internet, finance transactions
  - Hundreds of millions of users of GPS

- **Change in technology**
  - more sensitive payloads
  - high performance components
  - lightweight and low cost
- **Power Grids**

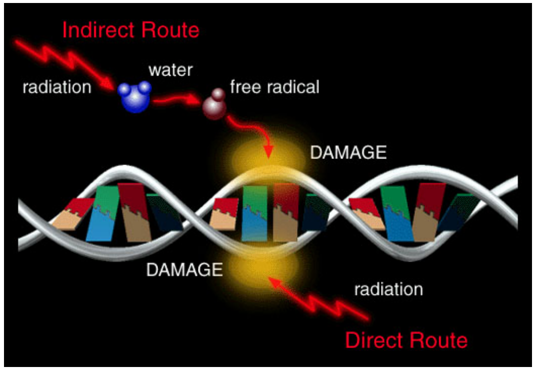
- **Humans in Space**
  - More and longer manned missions



Space Weather warning will be very important for our society in the future.

Damages: estimated to 200 M$ per year
- 100 M$ - satellites
- 100 M$ - powergrids
- 10 M$ - communication

Space Weather: Why should we care?



- **Humans in space**
  - Space Shuttle, International Space Station, missions to Moon, Mars & Beyond

- **Crew/Passengers in high-flying jets and polar routes**
  - Concorde carries radiation detectors
  - Passengers may receive radiation doses equivalent to several chest X rays.

High Energy Particles: Hazards to Humans

Uniqueness of 1859 Storm

- **There are several storms of the past 150 years that sparked auroras in or near the tropics; Sept. 1909, Nov. 1960, March 1989, May 1921, Feb. 1872 and others.**
- **Storms within a factor of two of the Carrington Event happen, roughly, a couple of times a century. We could be due for one anytime now!**
- **The nightmare scenario outlined in the National Academy report on severe space weather in which 130+ million people lose electricity is based, not on the Carrington Event, but rather upon the lesser May 1921 storm. It doesn't take a Carrington Event to cripple modern technology.**
- **From probability standpoint another great geomagnetic storm will almost certainly occur in our lifetimes, and it won't have to be a Carrington Event to cause real trouble.**

So What Do We Mean by Extreme SWx?

The biggest geomagnetic storm occurred in March 1989.

The biggest solar particle event occurred in Sept. 1859.

The lowest latitude auroras were observed in Feb. 1872.

The fastest CME on record crossed the sun-Earth divide in only 14 hours in August 1972.

The most intense SID occurred during the Halloween storms of 2003.

From Cliver & Svaalgard (Solar Physics, 2004)

What do we mean by CR Event?

The Carrington Event has become a touchstone of heliophysics and space weather. Researchers refer to it often when discussing severe solar storms and their possible effects on modern society. However, if you listen carefully you will hear that "Carrington Event" has two different meanings:

1. Literally, the event itself: a series of solar flares and geomagnetic storms in Sept. 1959.

2. Operationally, a solar storm so severe that it can have widespread societal consequences.

Pinning down the literal Carrington Event is not easy. It happened in a day when modern space weather sensors and satellites did not exist. To define the actual Carrington Event, researchers must look into ice cores, primitive magnetometer records, and even newspaper reports from the 19th century.

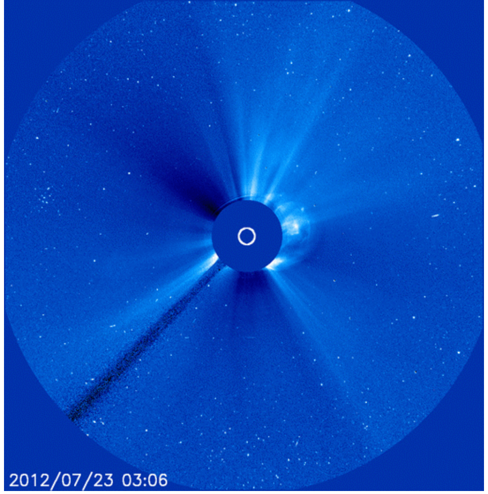
What kind of solar storm would it take to bring modern society to its knees?

The operational "Carrington Event" that we rightly worry about in 2014 is surely smaller than the literal Carrington Event of 1859. Our increasing dependence on sun-sensitive technologies such as smart power grids, GPS navigation and time transfer, and satellite communications is redefining downward the concept of a "crippling" solar storm. It's time to re-think what we mean by "Carrington Event" in the 21st century.

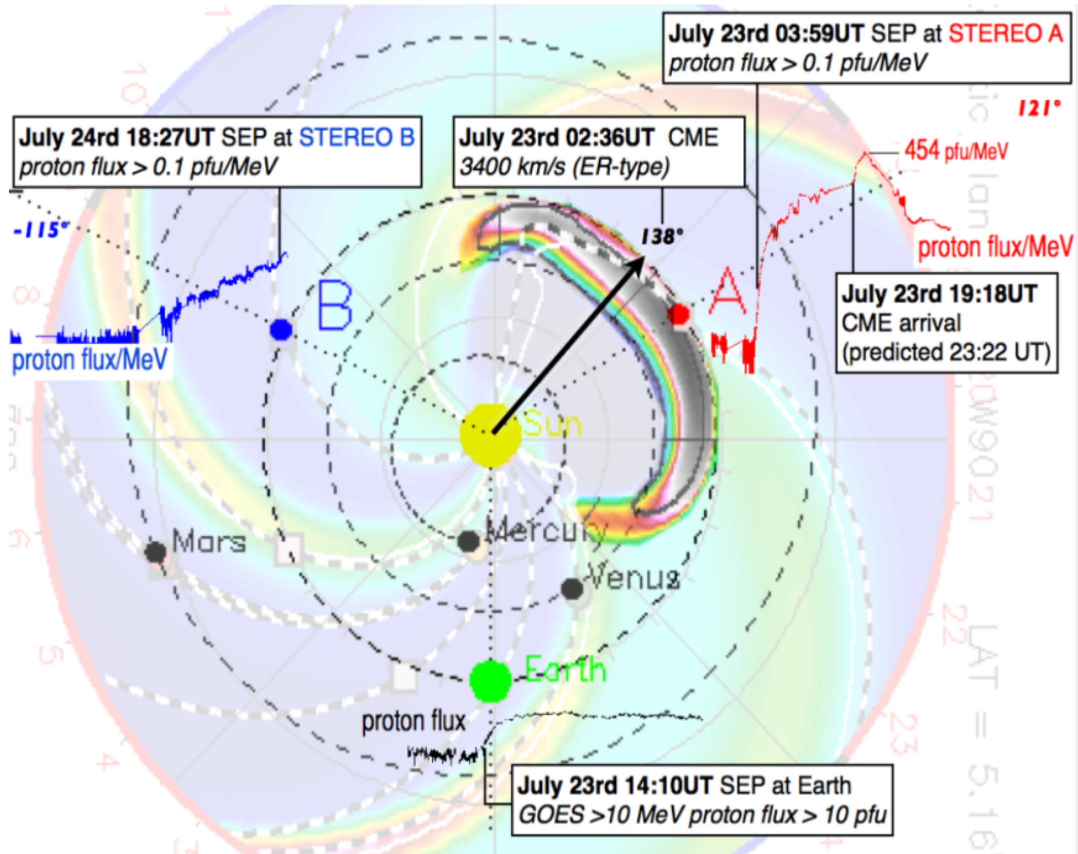
Instead of defining the storm and extrapolating the consequences from there, it might make more sense to start with a set of consequences and work backward to the storm.

For instance, suppose we define a modern Carrington Event to be any storm that
1. Can cause power blackouts and permanent transformer damage over a regional area at least the size of New England, and/or
2. Disturbs the ionosphere so badly that scintillation severely degrades GPS navigation and time transfer for at least two weeks, and/or
3. Permanently disables at east 25% of the geosynchronous tele-com satellite fleet.

These are just notional criteria intended to jump start the conversation. The idea would be to ask, for each criterion, "what kind of storm is required to cause this problem?" and by answering those questions work toward an operational definition of a 21st century Carrington Event.



July 23, 2012, one of the fastest CMEs of the Space Age rocketed away from the western limb of the sun travelling 3500 km/s.



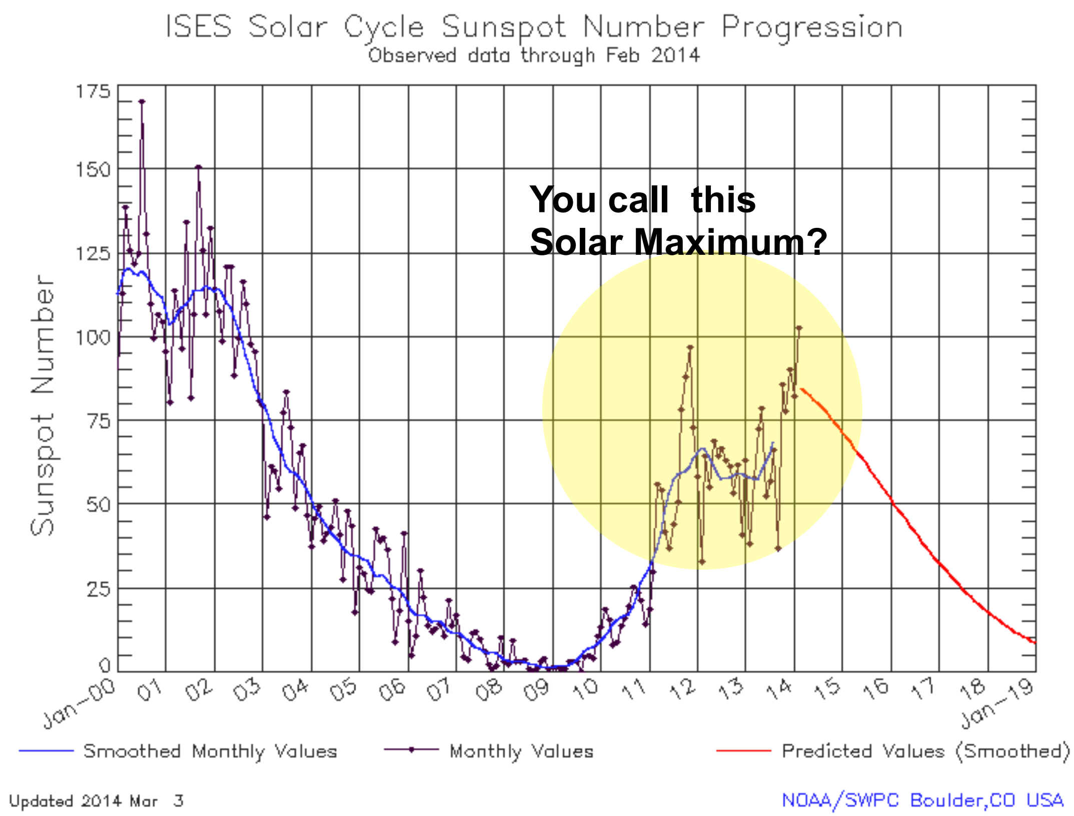
Surrounding the sun has allowed us to detect major storms that otherwise we might have missed.

What would this storm have done to our planet?

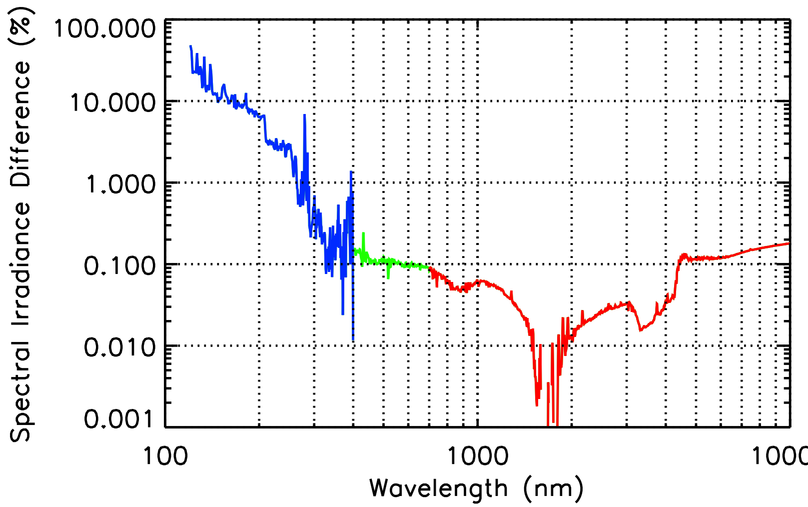
Develop this chart to discuss modern CR

STEREO-A was in the line of fire, and the spacecraft was hit by a severe solar radiation storm. It was stronger than any proton event observed since 1976. Without STEREO-A, this major event would have passed unnoticed

Look out! Solar activity is so low that Solar Max looks a lot like Solar Min.



Spectral Solar Irradiance (SSI): SMax vs. SMin



Small variations in the visible (0.1%), but big changes in the UV. ***(UV, EUV and X-ray spectral irradiances are drivers of space weather)***

As the solar cycle unfolds in an unexpected way, it is important to remember that

Space Weather Swings Between Extreme Effects

Solar La Niña
(low sunspot number)

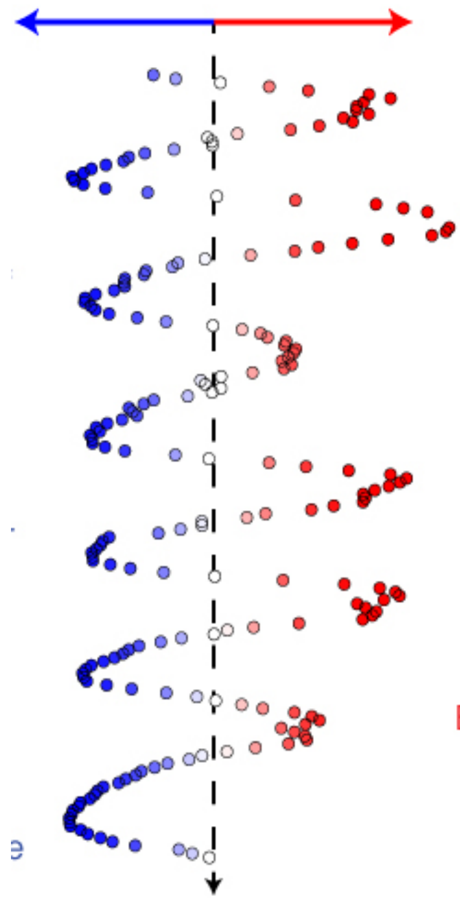
extreme galactic cosmic rays

rapid accumulation of space junk

sharp contraction of the heliosphere

collapse of the upper atmosphere

total solar irradiance changes



Solar El Niño
(high sunspot number)

super solar flares

extreme solar "cosmic rays" (energetic particles)

radio blackouts

extreme geomagnetic storms

melted power grid transformers – power blackouts

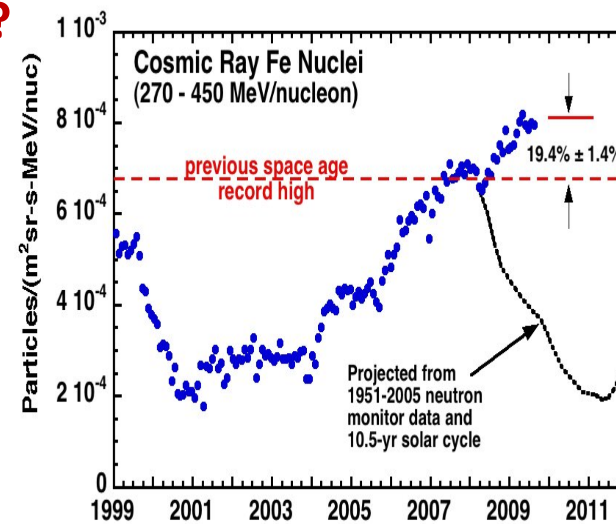
solar wind streams hit Earth

Illustration shows smoothed monthly sunspot counts from the past six solar cycles plotted horizontally instead of vertically. High sunspot numbers are in red and on the right, low sunspot numbers are in blue and on the left. Associated with each high and low sunspot numbers are different space weather impacts experienced at Earth (doi: 10.1002/swe.20039).

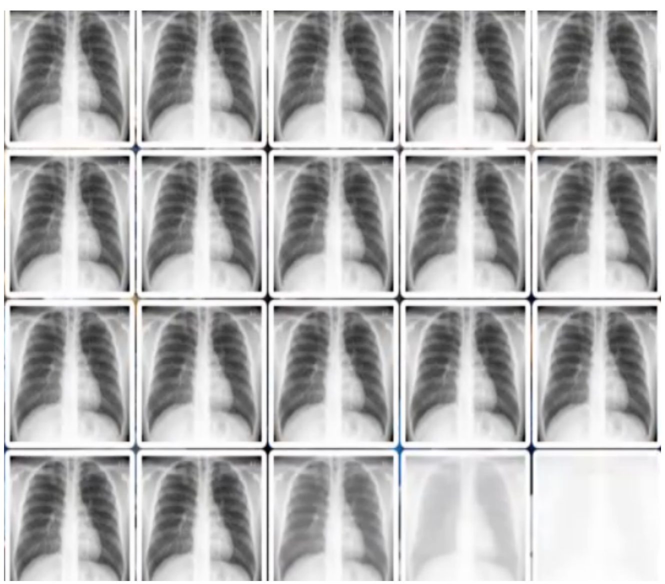
During periods of low solar activity, cosmic rays pose a threat not only to astronauts, but also to ordinary air travelers.

Who's Afraid of a Solar Flare? Cosmic rays are much scarier

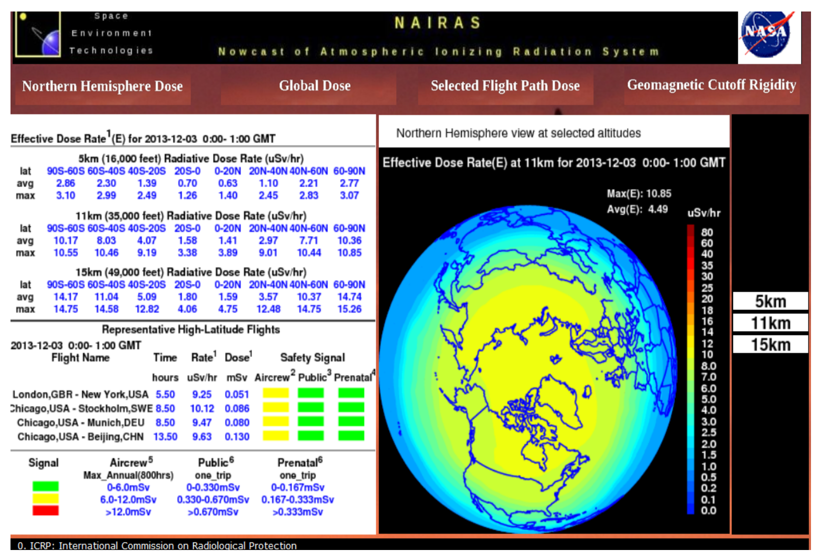
When solar activity is low, cosmic rays are able to invade the inner solar system. During the 2008-2009 solar minimum, cosmic rays surged to record-high levels.



A 100,000 mile frequent flyer receives a dose equivalent to 20 chest x-rays



NASA's experimental *Nowcast of Atmospheric Ionizing Radiation System* keeps track of the danger



But we are not Defenseless (1/3)

National Space Weather Program

The NSWP is a federal interagency initiative established in 1995 to improve our capability to make timely and reliable predictions of significant disturbances in space weather and to provide this information in ways that are tailored to the specific needs of those who are potentially affected by them.

GOAL:

I. Discover and understand the physical conditions that produce space weather and its effects.

I. Develop and sustain necessary observational capabilities.

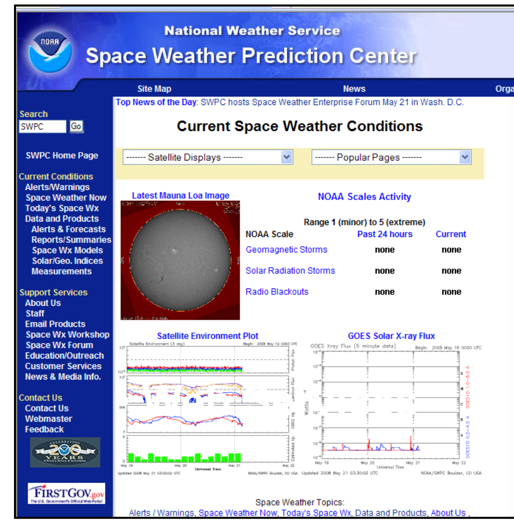
II. Provide tailored and accurate space weather information where and when it's needed.

III. Raise national awareness of the impacts of space weather.

IV. Foster communication among government, commercial, and academic organizations.

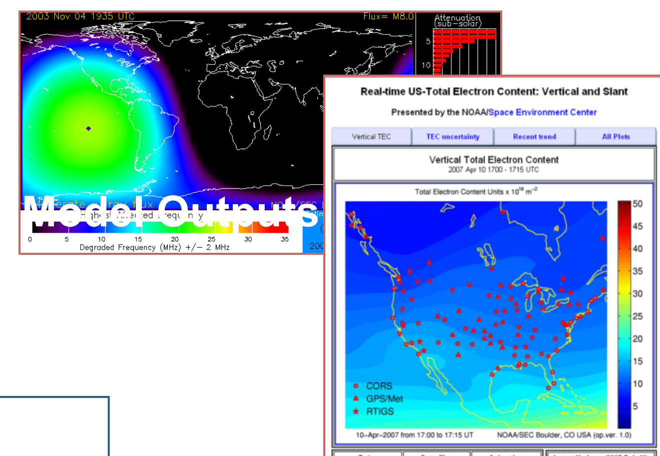
But we are not Defenseless (2/3)

NOAA SWPC



Space Weather Products and Services

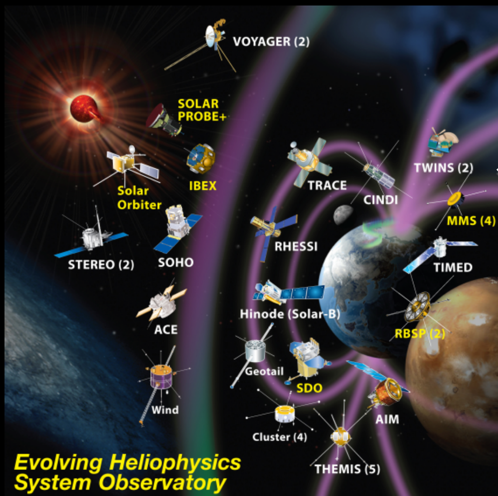
- **Watches:** The conditions are favorable for occurrence
- **Warnings:** disturbances that are imminent, expected in the near future with high probability
- **Alerts:** observed conditions meeting or exceeding thresholds
- **Forecasts and other routine products**



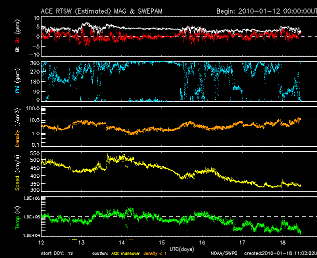
www.spaceweather.gov

But we are not Defenseless (3/3)

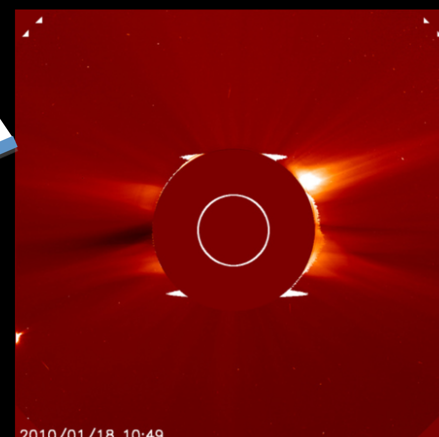
NASA Heliospheric System Observatory (HSO): SWx Today



HSO

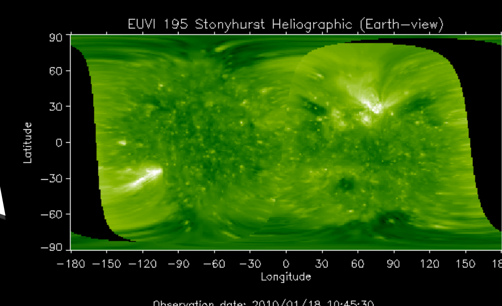


ACE



SOHO

STEREO



CCMC data
Models+Theory

SWx Users

Pressent Observational Assets

NASA STEREO (Ahead)

•Ground Sites
- –Magnetometers (NOAA/USGS)
- –Thule Riometer and Neutron monitor (USAF)
- –SOON Sites (USAF)
- –RSTN (USAF)
- –Telescopes and Magnetographs
- –Ionosondes (AF, ISES, …)
- –GPS (CORS)

•SDO (NASA)
- - Solar EUV Images
- - Emerging sunspots
- -- Spectral Irradiance

•SOHO (ESA/NASA)
- –Solar EUV Images
- –Solar Corona (CMEs)

ESA/NASA SOHO

•Van Aleen Probes (NASA)
- -energetic particles

L1

NASA ACE

•ACE (NASA)
- –Solar wind speed, density, temperature and energetic particles
- –Vector Magnetic field

NOAA GOES

NOAA POES

•STEREO (NASA)
- –Solar Corona
- –Solar EUV Images
- –Solar wind
- –Vector Magnetic field

NASA STEREO (Behind)

•GOES (NOAA)
- –Energetic Particles
- –Magnetic Field
- –Solar X-ray Flux
- –Solar EUV Flux
- –Solar X-Ray Images

•POES (NOAA)
- **–High Energy Particles**
- **–Total Energy Deposition**
- **–Solar UV Flux**

Steps Ahead

- Space weather is a threat to our critical infrastructures that needs to be addressed.

- The assessment of space-weather impact on critical infrastructures requires a multidisciplinary effort from all stakeholders (scientists, engineers, infrastructure operators, policy makers).

- Ageing satellites that monitor space weather need to be replaced.

- Continued support of basic and applied research on solar events and their geospace consequences

- A need for systems analysis of long term loss of power (assessment of quality of prediction that leads to mitigation)
  - Is there a "tipping point" leading to disaster?

- Formal "risk analysis" of a major storm and its impact

- While there is some preparedness for normal space weather in some infrastructure sectors, nobody is fully prepared for extreme events.

- International cooperation is required to cope with the problem as response capabilities may be beyond the capacity of individual countries.