

# Space Weather Types and Impacts

*Bill Murtagh*

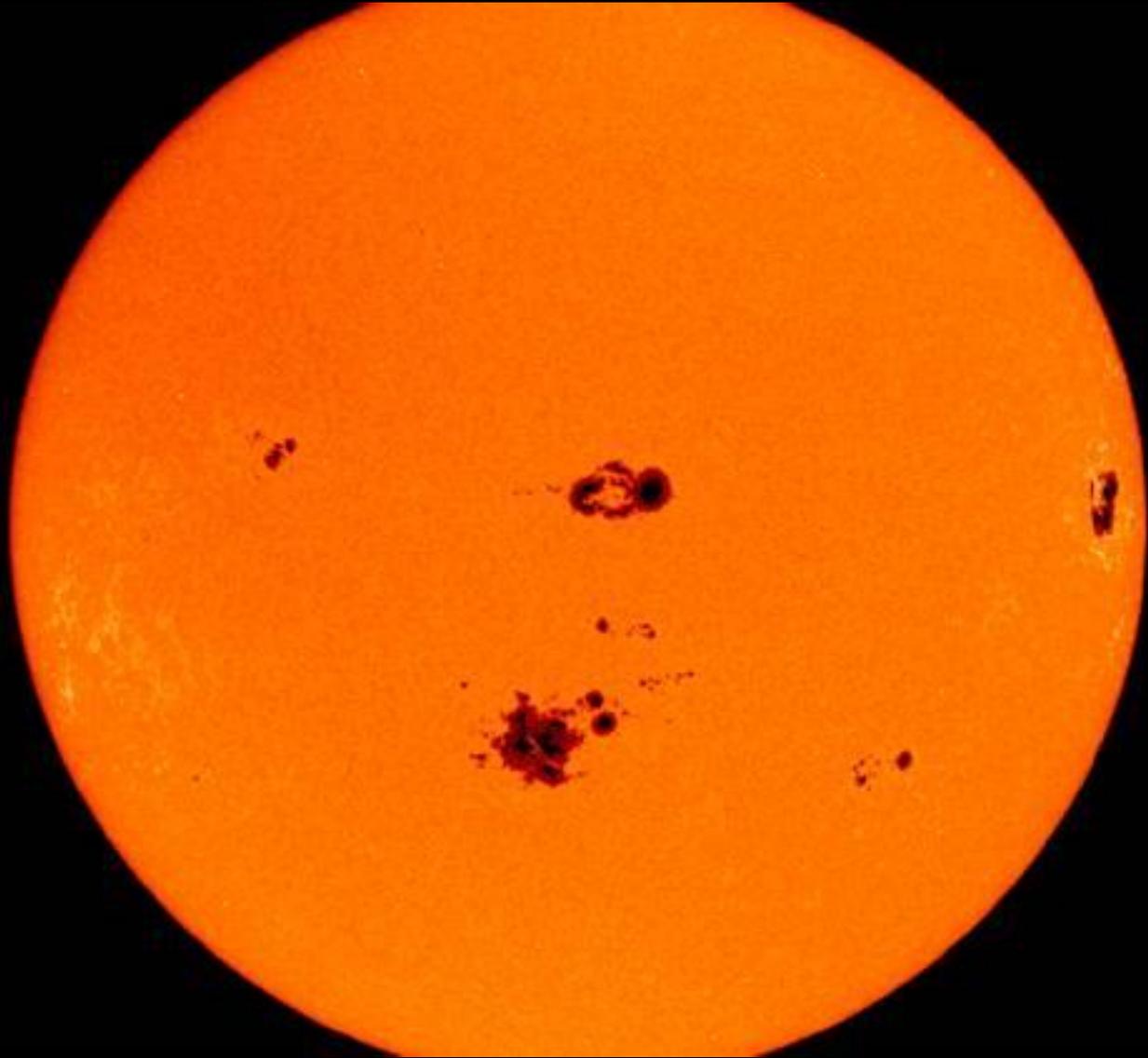
*Space Weather Enterprise Forum*

*20 October 2015*

*Hart Senate Office building*

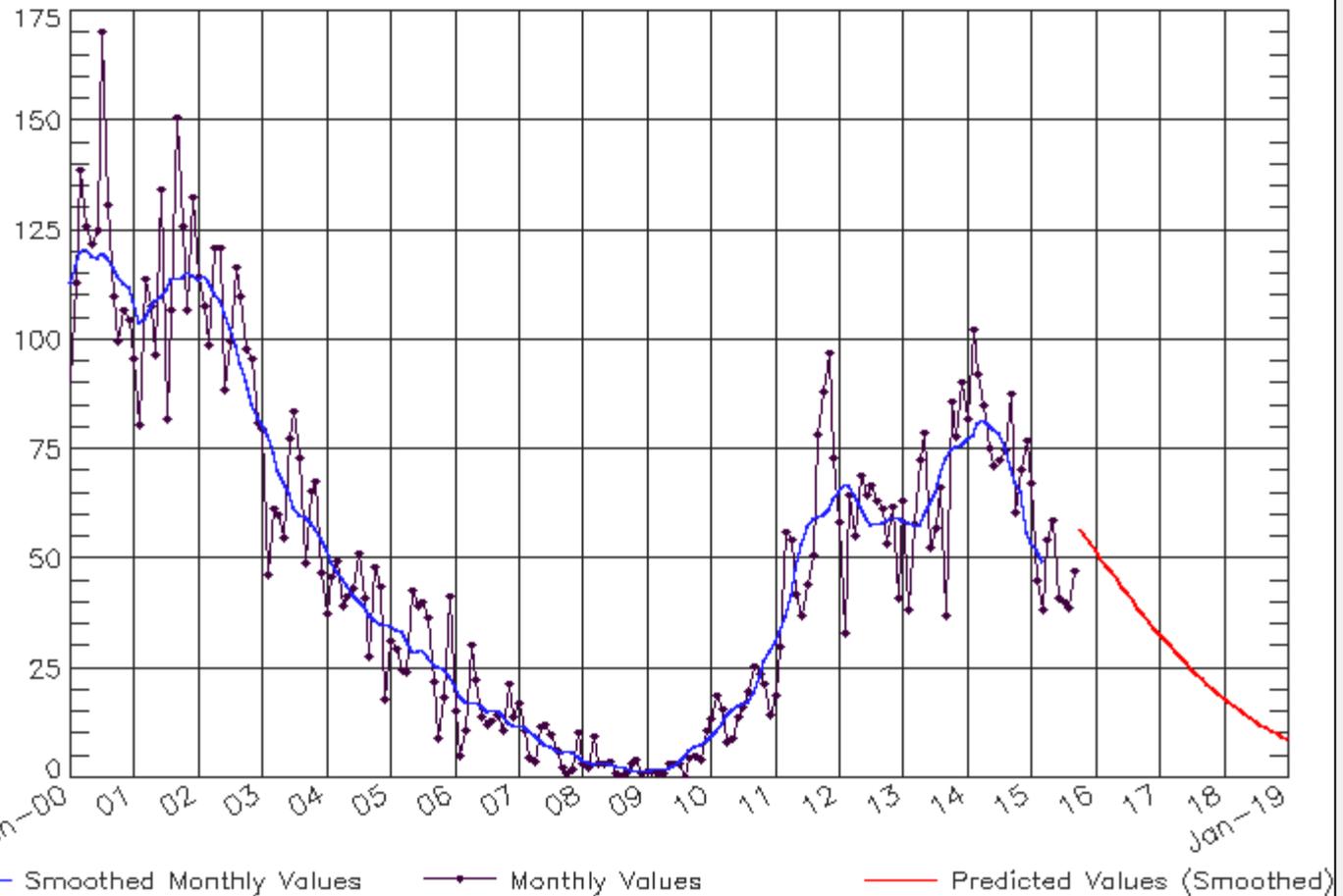
# Sunspots

Concentrations of magnetic fields – source of most major space weather storms



# Solar Cycle 24

ISES Solar Cycle Sunspot Number Progression  
Observed data through Sep 2015

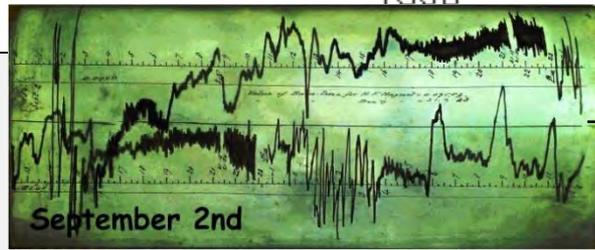
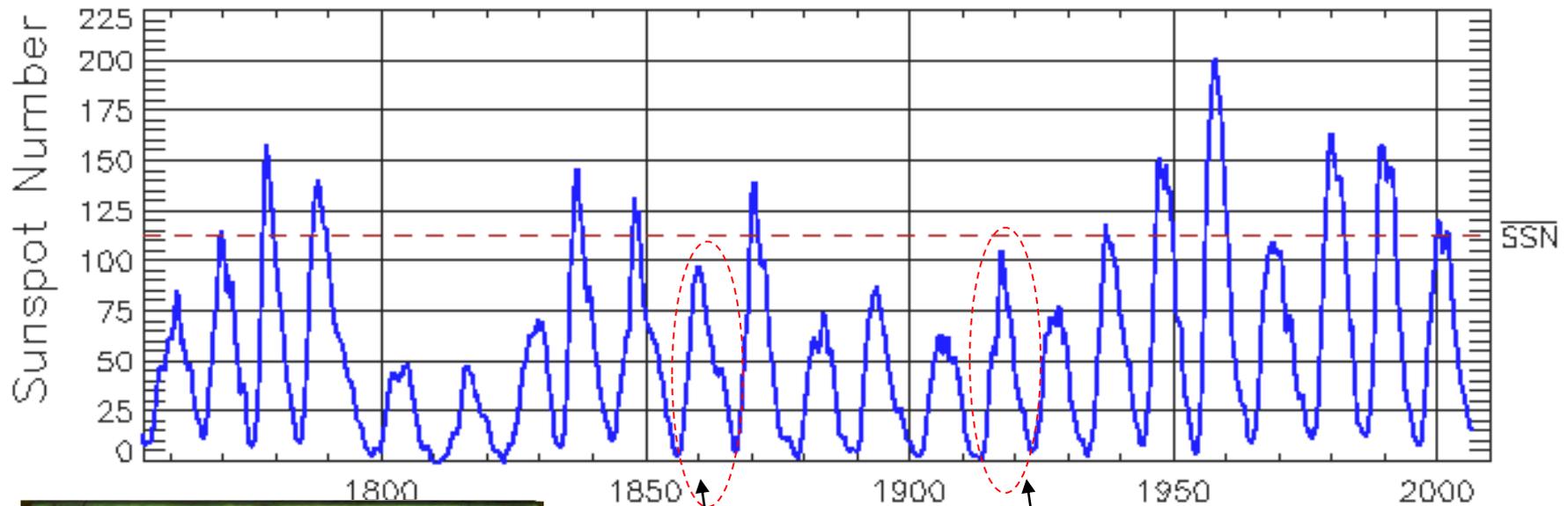


Updated 2015 Oct 5

NOAA/SWPC Boulder, CO USA

- Large geomagnetic storms can occur with smaller cycles
- The largest geomagnetic storms on record occurred during smaller than average cycles

The Solar Cycle in Sunspot Number



→ 1859 Storm

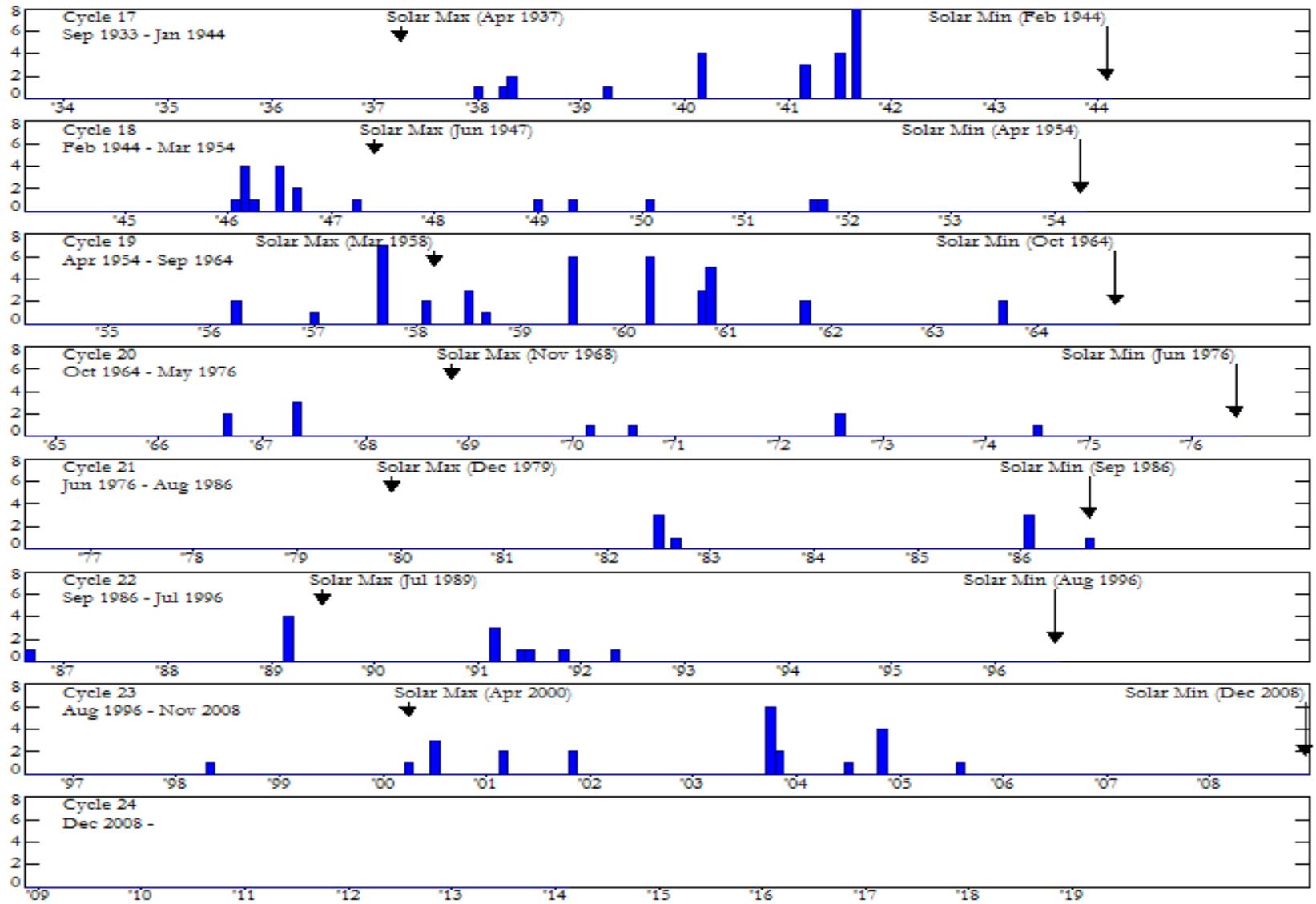
→ 1921 Storm

# Periods with $K_p \geq 9$

February 2014

(Month 63)

Number of  $K_p \geq 9$  per month



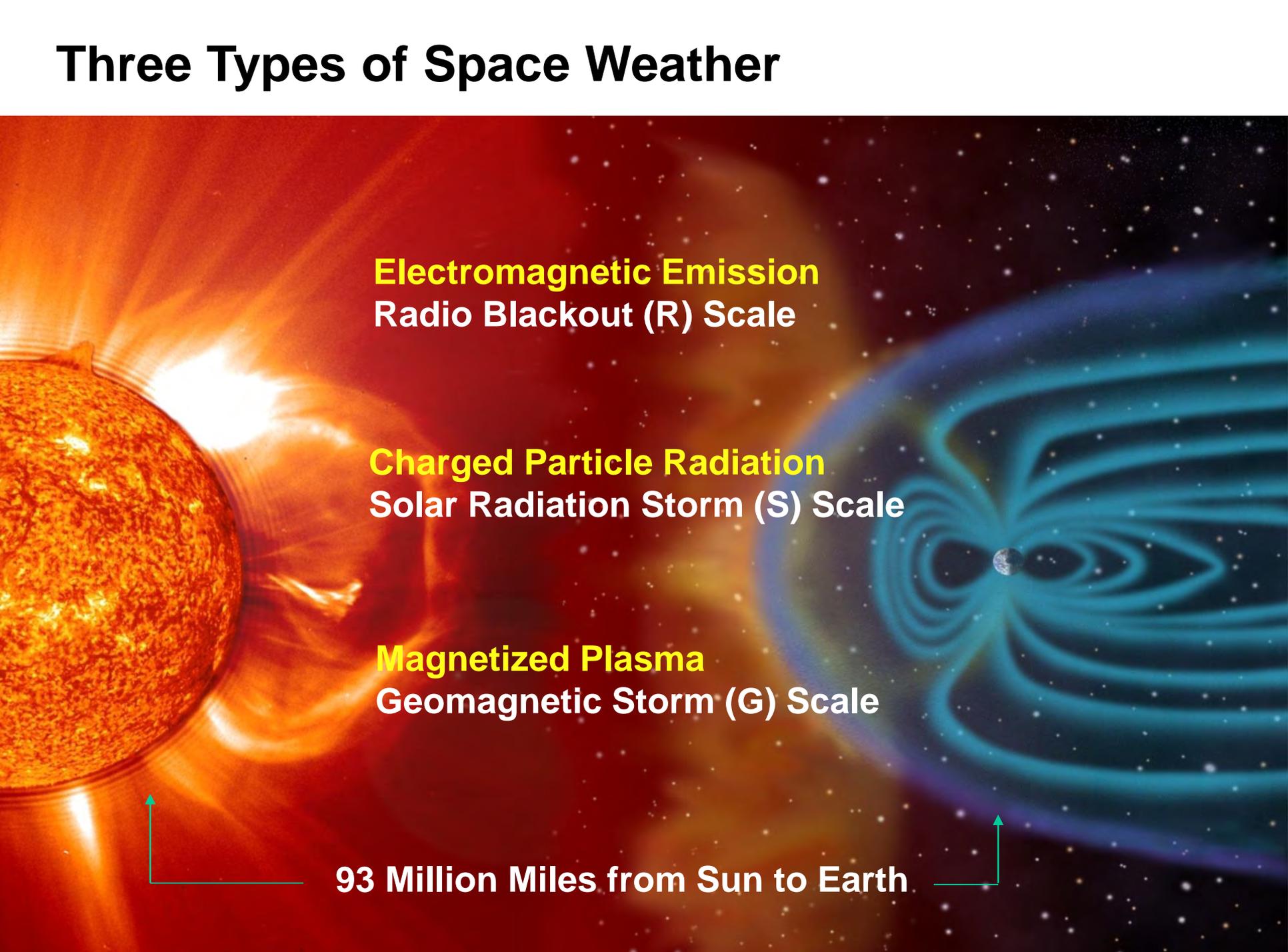
# Three Types of Space Weather

**Electromagnetic Emission**  
Radio Blackout (R) Scale

**Charged Particle Radiation**  
Solar Radiation Storm (S) Scale

**Magnetized Plasma**  
Geomagnetic Storm (G) Scale

93 Million Miles from Sun to Earth

A diagram illustrating the three types of space weather. On the left is a large, glowing orange sun. In the center, a smaller, glowing orange sphere represents Earth, with a blue and white atmosphere. On the right, a large, blue, swirling magnetic field structure represents the magnetosphere. The background is a dark space filled with stars. Three text labels are positioned between the sun and Earth, each with a yellow title and a white subtitle. A double-headed arrow at the bottom indicates the distance between the sun and Earth.

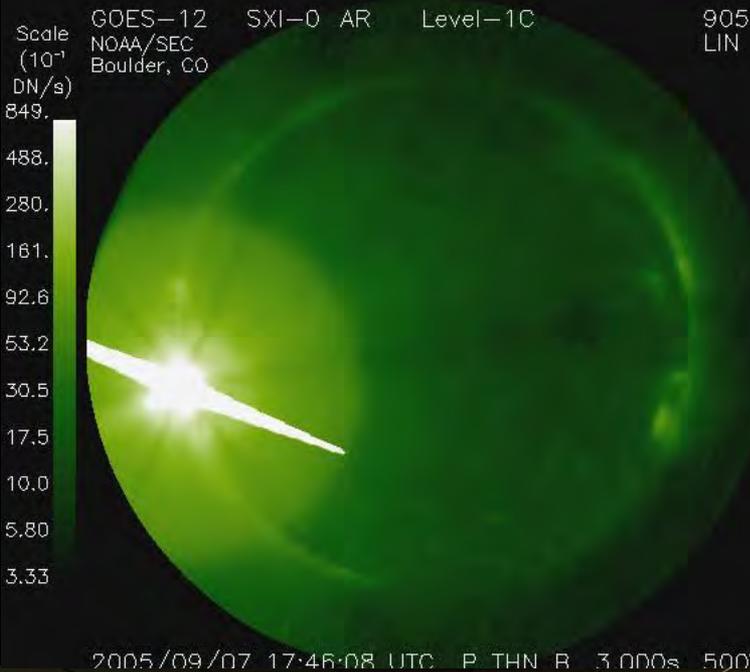
Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yrs)
Scale	Descriptor	Duration of event will influence severity of effects		
<b>Geomagnetic Storms</b>			<b>Kp values* determined every 3 hours</b>	<b>Number of storm events when Kp level was met</b>
<b>G 5</b>	<b>Extreme</b>	<p><b>Power systems:</b> : widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage.</p> <p><b>Spacecraft operations:</b> may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites.</p> <p><b>Other systems:</b> pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.</p>	Kp = 9	4 per cycle (4 days per cycle)
<b>G 4</b>	<b>Severe</b>	<p><b>Power systems:</b> possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid.</p> <p><b>Spacecraft operations:</b> may experience surface charging and tracking problems, corrections may be needed for orientation problems.</p> <p><b>Other systems:</b> induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.</p>	Kp = 8, including a 9-	100 per cycle (60 days per cycle)
<b>G 3</b>	<b>Strong</b>	<p><b>Power systems:</b> voltage corrections may be required, false alarms triggered on some protection devices.</p> <p><b>Spacecraft operations:</b> surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems.</p> <p><b>Other systems:</b> intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.</p>	Kp = 7	200 per cycle (130 days per cycle)
<b>G 2</b>	<b>Moderate</b>	<p><b>Power systems:</b> high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage.</p> <p><b>Spacecraft operations:</b> corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions.</p> <p><b>Other systems:</b> HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.</p>	Kp = 6	600 per cycle (360 days per cycle)
<b>G 1</b>	<b>Minor</b>	<p><b>Power systems:</b> weak power grid fluctuations can occur.</p> <p><b>Spacecraft operations:</b> minor impact on satellite operations possible.</p> <p><b>Other systems:</b> migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.</p>	Kp = 5	1700 per cycle (900 days per cycle)

## Geomagnetic Storms

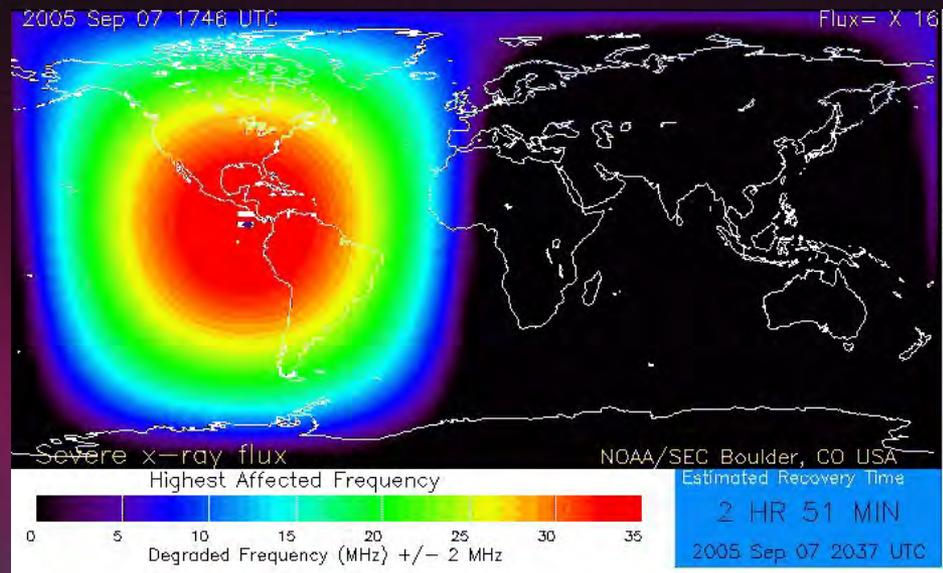
# Solar Flares Radio Blackouts (R Scale)



GOES-12 SXI  
<http://sxi.ngdc.noaa.gov>  
<http://www.sec.noaa.gov/sxi>



- A violent explosion in the Sun's atmosphere with an energy equivalent of a hundred million hydrogen bombs.



## Impacts

HF Communications



GPS Network



Communications

Ground and Space-based



Radar

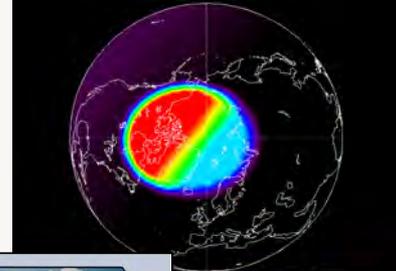
# March 2012 Impacts on Aviation

6-7 March 2012: “**Severe impact** at 2249Z initially affecting CWP [*Central West Pacific*] but by 2400Z, impact peaked and was affecting all communications. 25 ATC messages were delayed.”

- *Air Traffic Communications*

7 March 2012: INCERFA was issued for Air Canada 003 (Vancouver to Tokyo) until communications were established with the flight.

***(INCERFA is issued when there is uncertainty as to the safety of an aircraft and its occupants.)***



Atmospheric Ionospheric Absorption  
Absorption Frequency (MHz)  
25 30 35  
Strongest Pathway Flux  
UTC NOAA SWPC Boulder, CO USA



U.S. DEPARTMENT OF TRANSPORTATION  
FEDERAL AVIATION ADMINISTRATION

**ORDER**  
**JO 7110.10V**  
Effective Date:  
February 9, 2012

Subject: Flight Services

## Section 3. Alerting Service

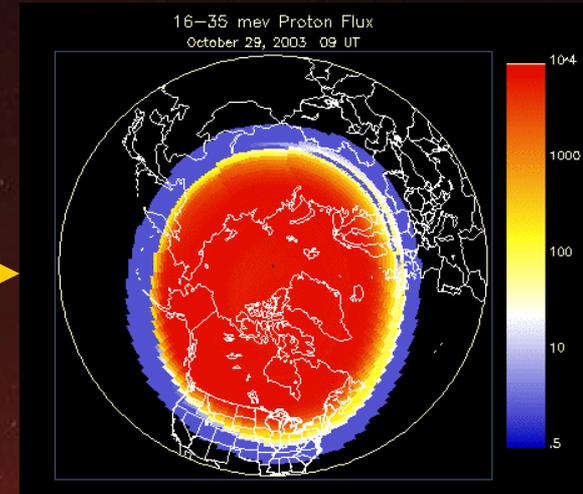
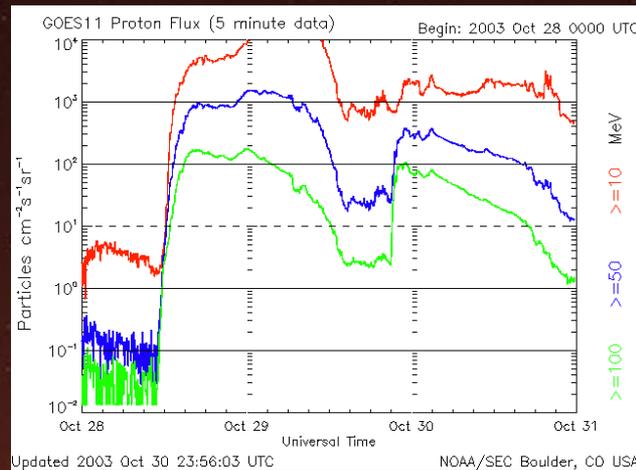
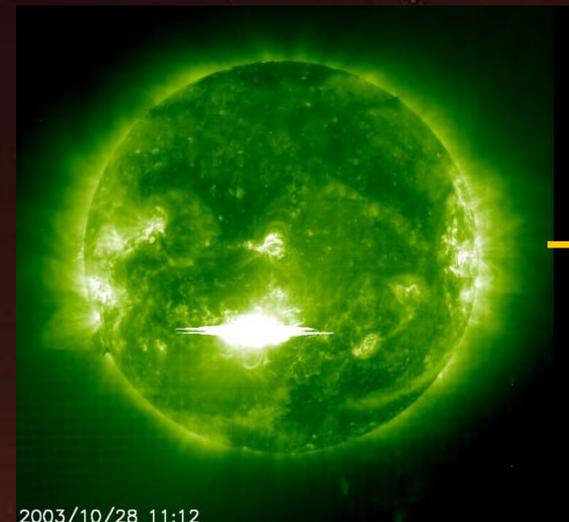
### 7-3-2. ALERTING PHASES

a. Air traffic services units must notify rescue coordination centers immediately when an aircraft is considered to be in a state of emergency in accordance with the following:

1. Uncertainty phase when:

(a) No communication has been received from an aircraft within a period of 30 minutes after the time a communication should have been received, or from the time an unsuccessful attempt to establish communication with such aircraft was first made, whichever is the earlier.

# Solar Radiation Storms (S Scale)



## Impacts...

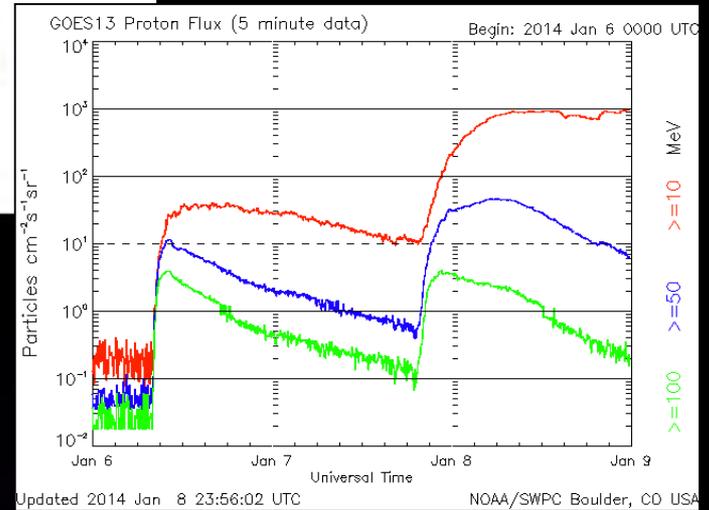
- Satellite Operations (range from loss of data to loss of satellite)
- Aviation (communications and exposure concerns)
- High latitude HF communication outage

January 2014

# Solar flare delays U.S. rocket launch

Solar particles could lead to a launch failure, said chief technical officer

The Associated Press Posted: Jan 08, 2014 2:45 PM ET | Last Updated: Jan 08, 2014 2:45 PM ET



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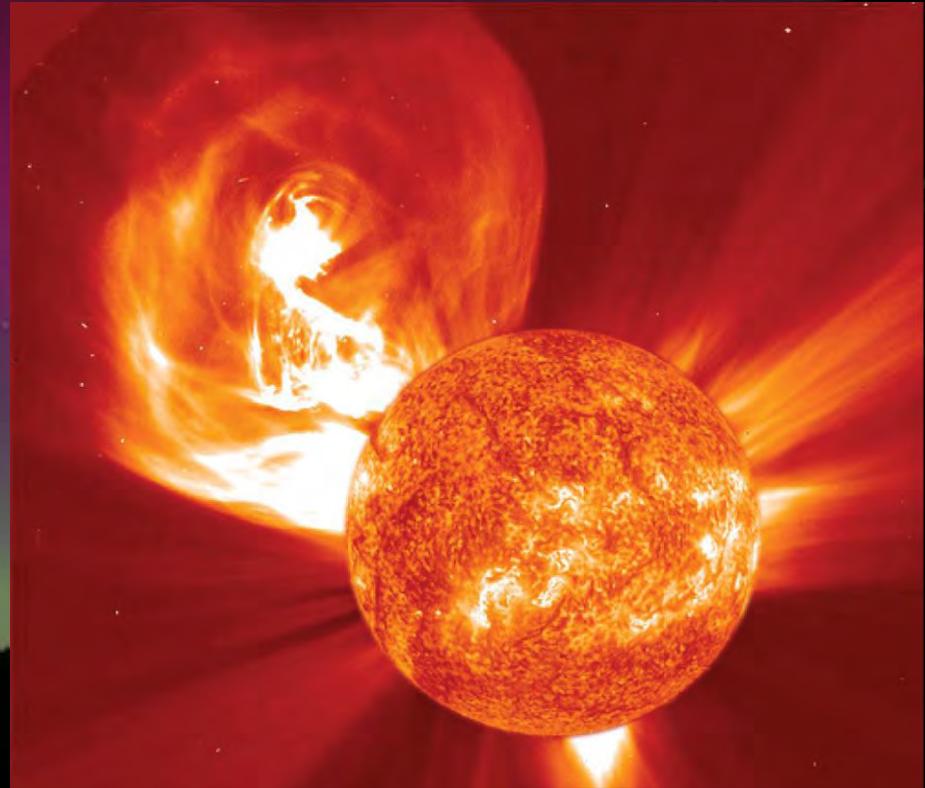
TRENDING: Comet ISON // Skywatching Guide // Mars Rover Curiosity // Solar Flares

## Huge Solar Flare Delays Private Rocket Launch to Space Station until Thursday

by Tariq Malik, Managing Editor | January 08, 2014 08:10am ET

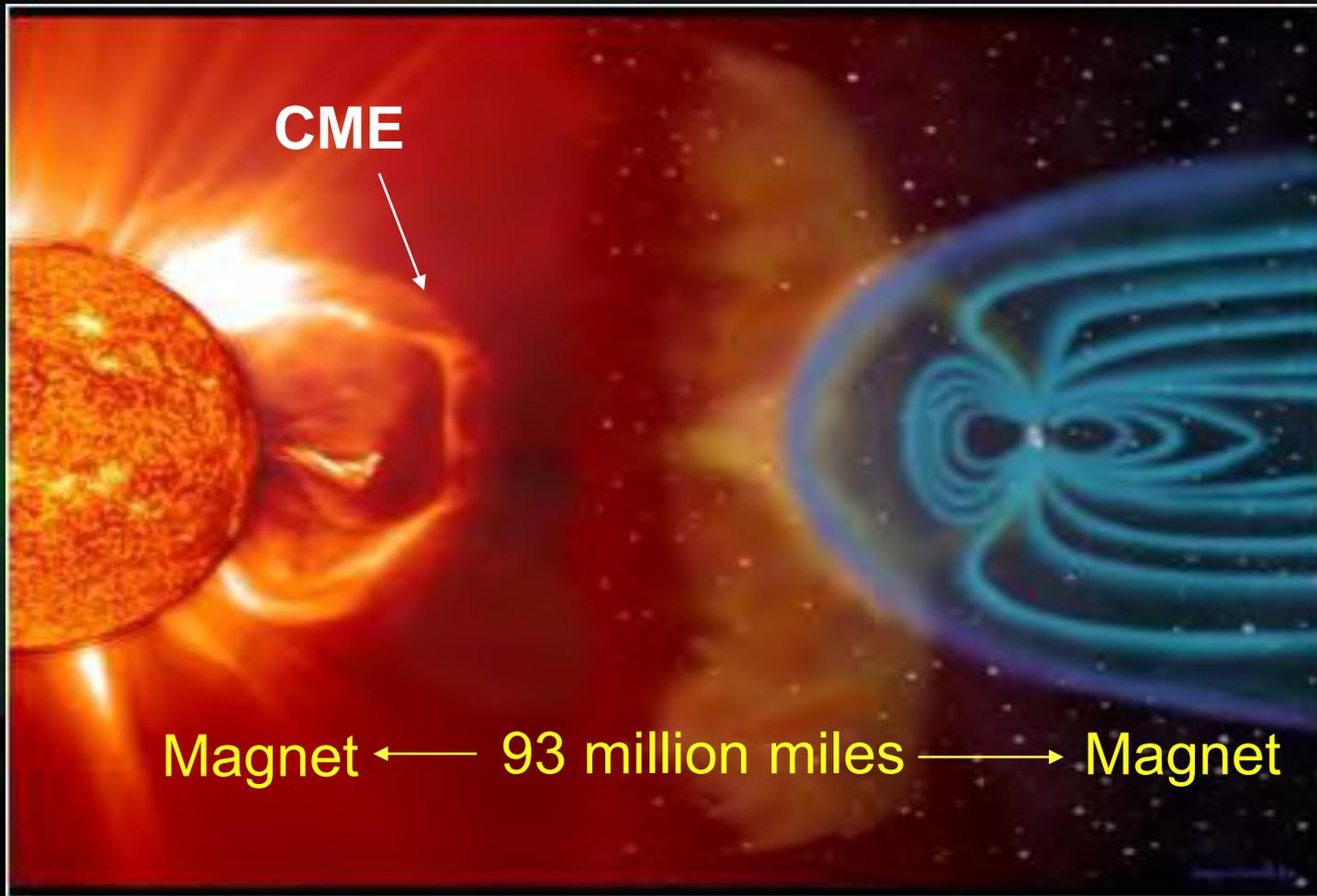
# Geomagnetic Storms (G Scale)

Coronal Mass Ejections (CMEs) create geomagnetic storms



# Geomagnetic Storms

CME: A billion tons of plasma gas and magnetized field moving 1-6 mil mph



*Not to scale (not even close!)*

Duration: hours to a day

Impacts Earth: 15-100 hours after eruption on Sun

# Geomagnetic Storm Impacts

Impacts from geomagnetic storms are wide-ranging with potentially significant consequences.



Satellite Operations



Manned Spaceflight



GPS



Power Grid Operations



Rail

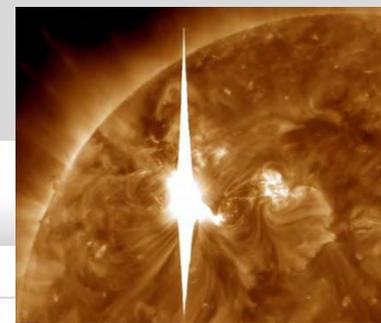


Aircraft Operations

March 2012

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## Solar Flares Knock Out LightSquared Satellite As Run of Bad Fortune Continues

by Karl Bode Friday 16-Mar-2012 tags: [satellite](#) · [business](#) · [wireless](#) · [alternatives](#) · [bandwidth](#) · [trouble](#) · [wireless](#)

Tipped by [viperadamr](#) 

Earlier this week we noted that recent solar flares managed to [knock HughesNet's Spaceway 3 satellite offline](#) for a significant part of Tuesday. User [viperadamr](#)  writes in to note that the flares also took out



-- IMPORTANT OUTAGE NOTIFICATION --

Status: **Unscheduled**

Details of services impacted: All existing Voice, Push-to-Talk (PTT), Mobile Data Services, and PNC customers

START DATE: March 7, 2012

START TIME (UTC\*): 1330

Service Summary:

UPDATE 1 03/07/2012 @ 0943 EST - LightSquared is currently experiencing a satellite network outage over our SkyTerra 1 satellite. Preliminary investigation reveals **that a solar event has created an automatic system safeguard** as a measure to protect the satellite. The recovery procedures are underway which could take from 4 to 24 hours.

# ***Impacts on Electric Power Grid***

- CME impacts Earth's magnetic field
- Fluctuations generate electric fields on Earth. These geomagnetically induced currents (GIC) can flow into power lines and transformers
- Leads to transformer saturation and over-heating, voltage drops, transformer damage, grid collapse

Station 3 Transformer 6 LV exit lead overheating



**Transformer winding**

## **Vulnerability of US grid**

- Northern latitude (location of aurora during geomagnetic storms)
- Areas of relatively high resistive igneous rock
- Very high voltage interconnected transmission network
- Proximity to oceans (conductivity of ocean salt water)



# Extreme space weather events

# Carrington Event, September 1859

*“All our exchanges, from the northern coast of the Island of Cuba gave glowing descriptions of the Aurora Borealis - as bright in the tropics as in the northern zones”* [New Orleans Daily Picayune, September 7, 1859]



Discharges shocked telegraph operators and set the telegraph paper on fire.

# May 1921 Geomagnetic Storm

## **SUNSPOT CREDITED WITH RAIL TIE-UP**

### ***New York Central Signal System Put Out of Service by Play of Northern Lights.***

The sunspot which caused the brilliant aurora borealis on Saturday night and the worst electrical disturbance in memory on the telegraph systems was credited with an unprecedented thing at 7:04 o'clock yesterday morning, when the entire signal and switching system of the New York Central Railroad below 125th Street was put out of operation, followed by a fire in the control tower at Fifty-seventh Street and Park Avenue.

This is the first time that a sunspot has been blamed for such a piece of mischief. From other accounts it appeared

*The New York Times*

Published: May 16, 1921

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## **CABLES DAMAGED BY SUNSPOT AURORA**

**Ships to Be Sent Out to Mend  
Lines Put Out of Service  
by Magnetic Display.**

## **ELECTRIC DISTURBANCES AFFECT FRENCH WIRES**

***Aurora Not Visible, Its Absence  
Being Attributed to Atmos-  
pheric Conditions.***

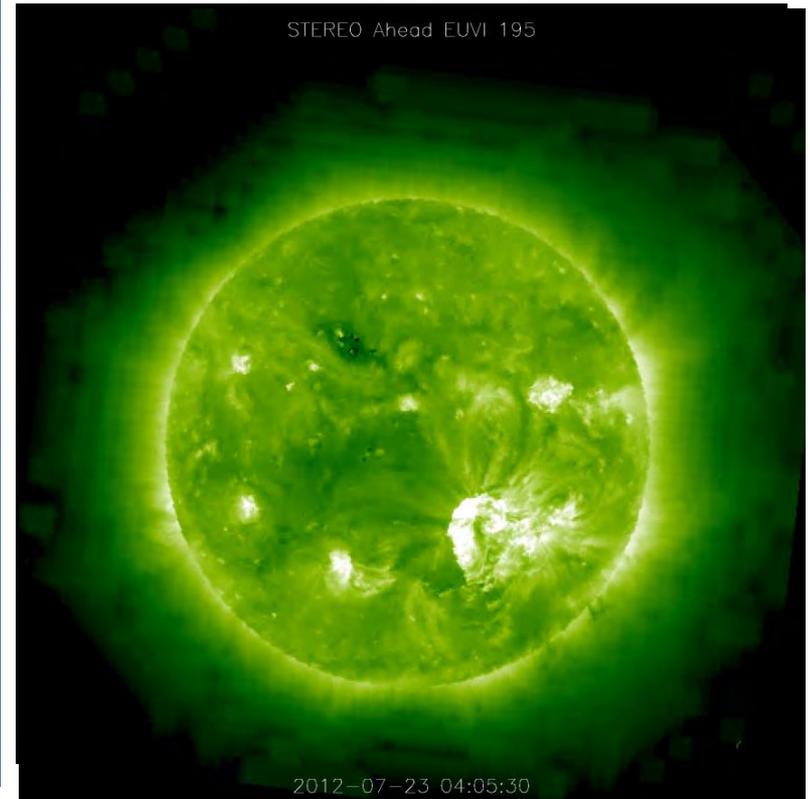
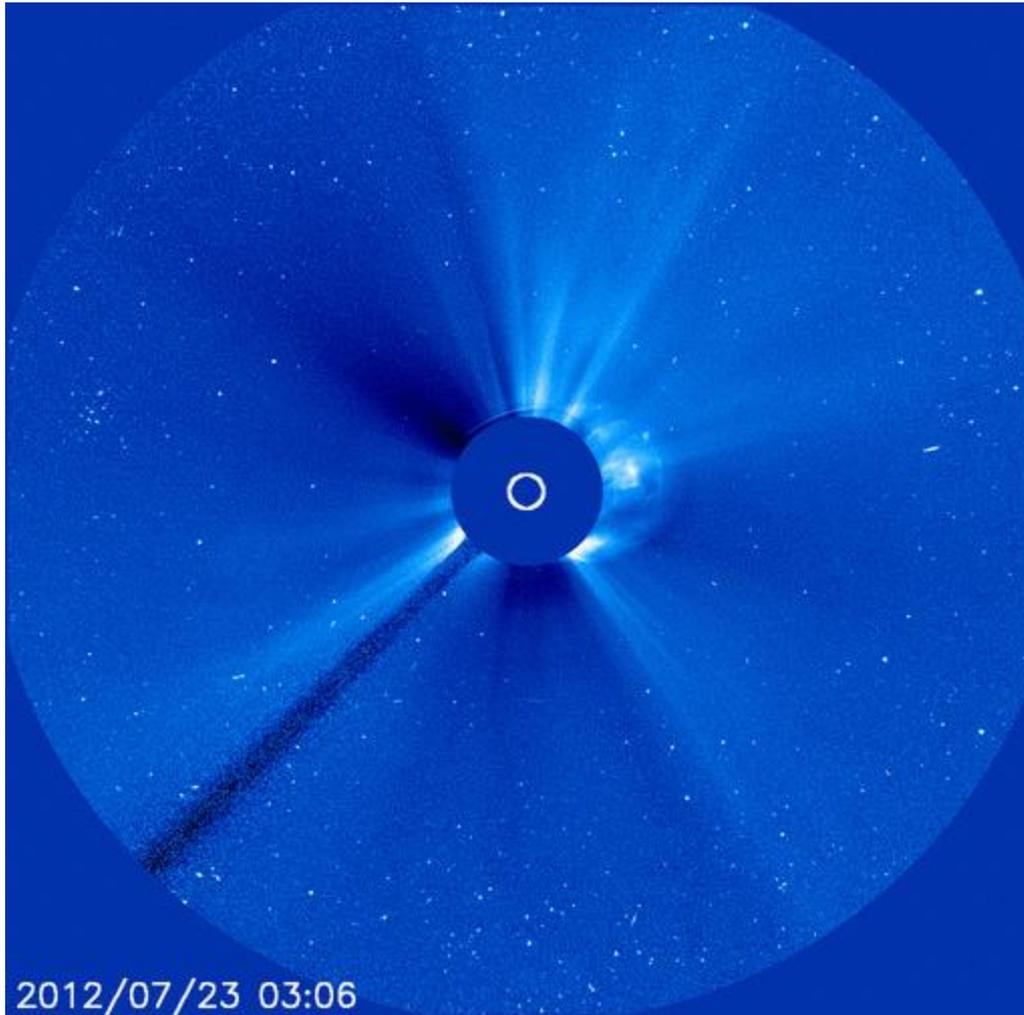
Copyright, 1921, by The New York Times Company  
By Wireless to THE NEW YORK TIMES.

PARIS, May 17.—The disturbance which interrupted telegraphic transmission in the United States last week has been making itself felt also in France.

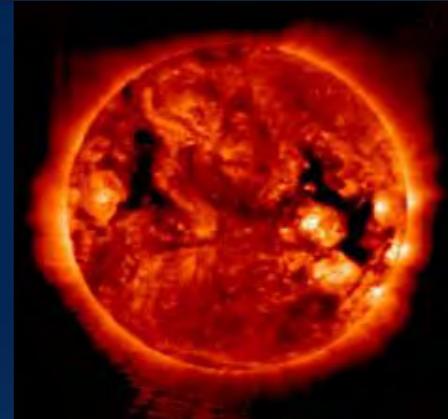
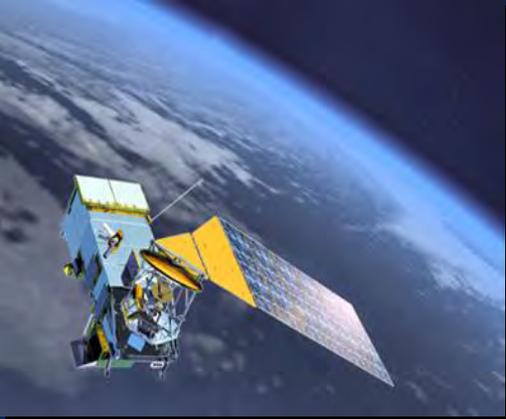
On Saturday night, especially the operators at the central transmission stations came to the conclusion that a strange force had got into their instruments, for nothing would go right. Morse instruments, instead of making dots and dashes, recorded one long line,

# ***23 July 2012 – dodging the bullet!***

Powerful solar flare  
on 23 July, 2012...  
...not Earth-directed



A coronal mass ejection speed:  $\sim 2900$  km/s or 6.5 million mph occur only once every  $\sim 5$  to 10 years.



- *Technology evolution*
- *Interconnection/Interdependency*
- *Reliance on space-based systems*



**Increased vulnerability of critical infrastructure to space weather**

