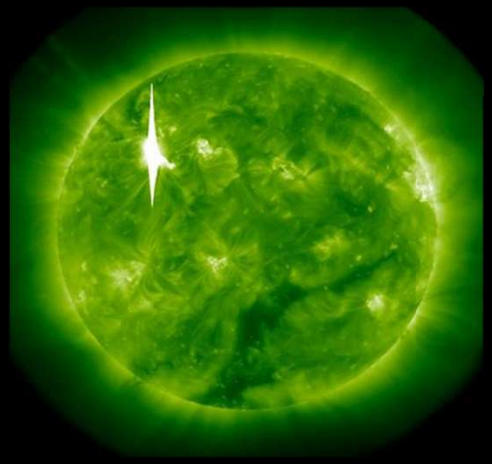
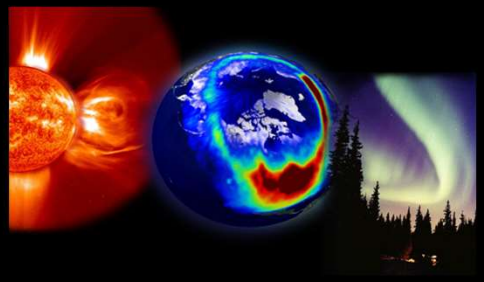
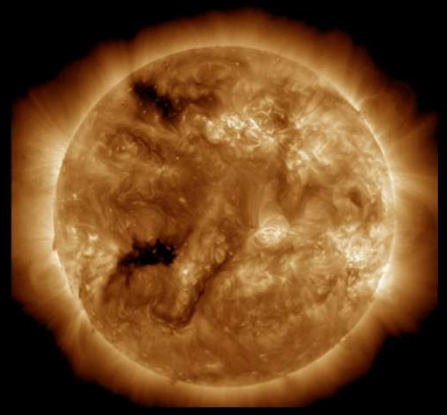
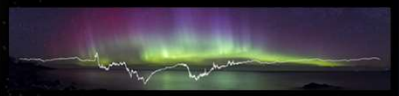
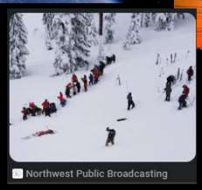
Space Weather
Introduction for EM Preparedness





SWPC: "Safeguarding Society with Actionable Space Weather Information"

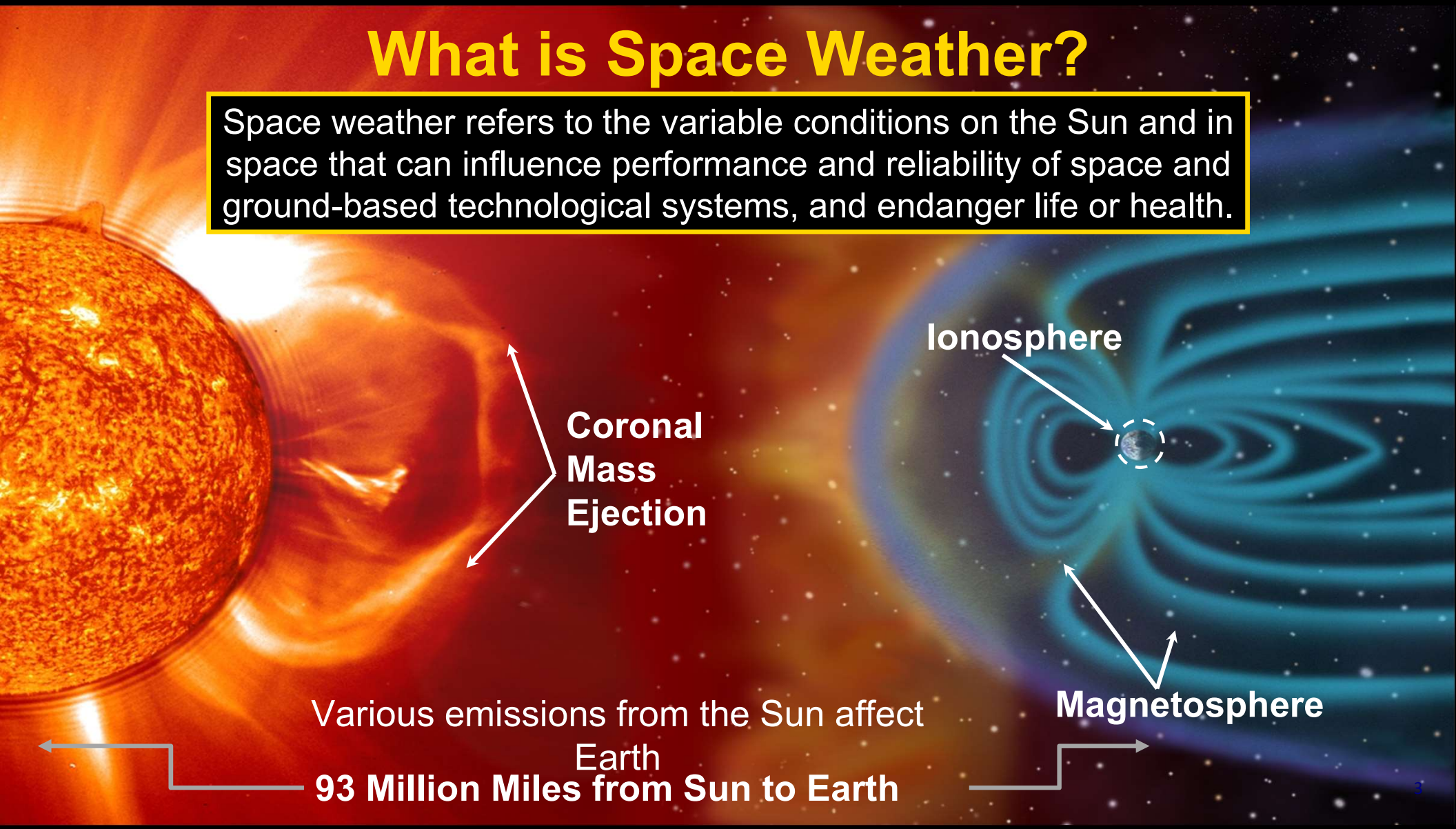
Space Weather Prediction Center
(**SWPC**)
Boulder, CO

"Safeguarding Society with Actionable Space Weather Information"

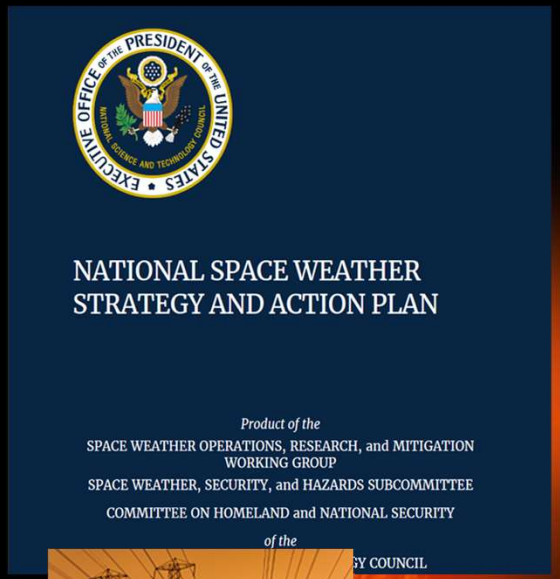
We are the NWS and proud to be part of the mission to protect lives & property – thus a key relationship with EM community

What is Space Weather?

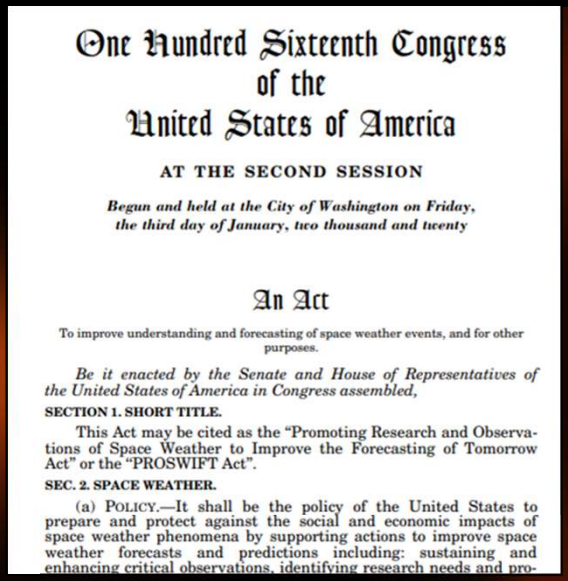
Space weather refers to the variable conditions on the Sun and in space that can influence performance and reliability of space and ground-based technological systems, and endanger life or health.

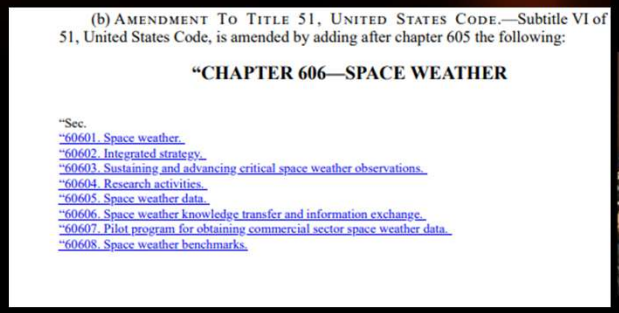


Space Weather Importance recognized by the Federal Government



Whitehouse.gov





Space Weather Advisory Group (SWAG) Meeting at the Department of Commerce

As a Concerning Risk

Space Weather Impacts are wide ranging

Infrastructure and Activities Vital to National Security and the Economy

Satellite Malfunctions; SATCOM Interference/Disruption; Satellite Drag; Pipeline Corrosion
Radiation Exposure; Power Outages; HF Comm Dropouts; GNSS Degradations

Space weather-induced electricity blackout: Daily domestic economic loss in the U.S. = $41.5 billion plus an additional $7 billion loss through the international supply chain.

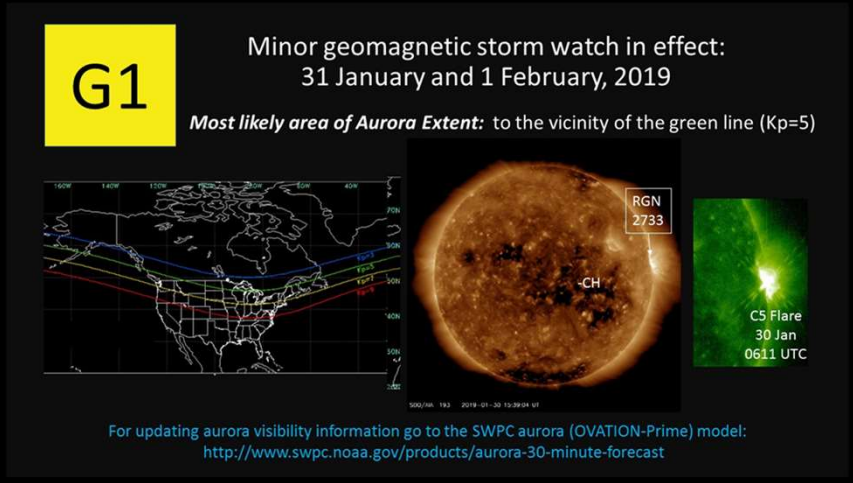
"Quantifying the daily economic impact of extreme space weather due to failure in electricity transmission infrastructure," Centre for Risk Studies, University of Cambridge, Jan 2017

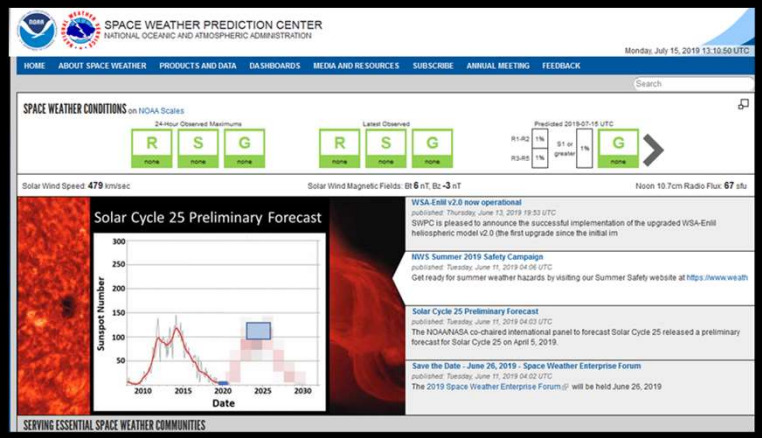
SWPC Forecast Operations (SWFO)

Operations, systems & data monitoring, forecasting, warning, & Alerts, IDSS, etc.

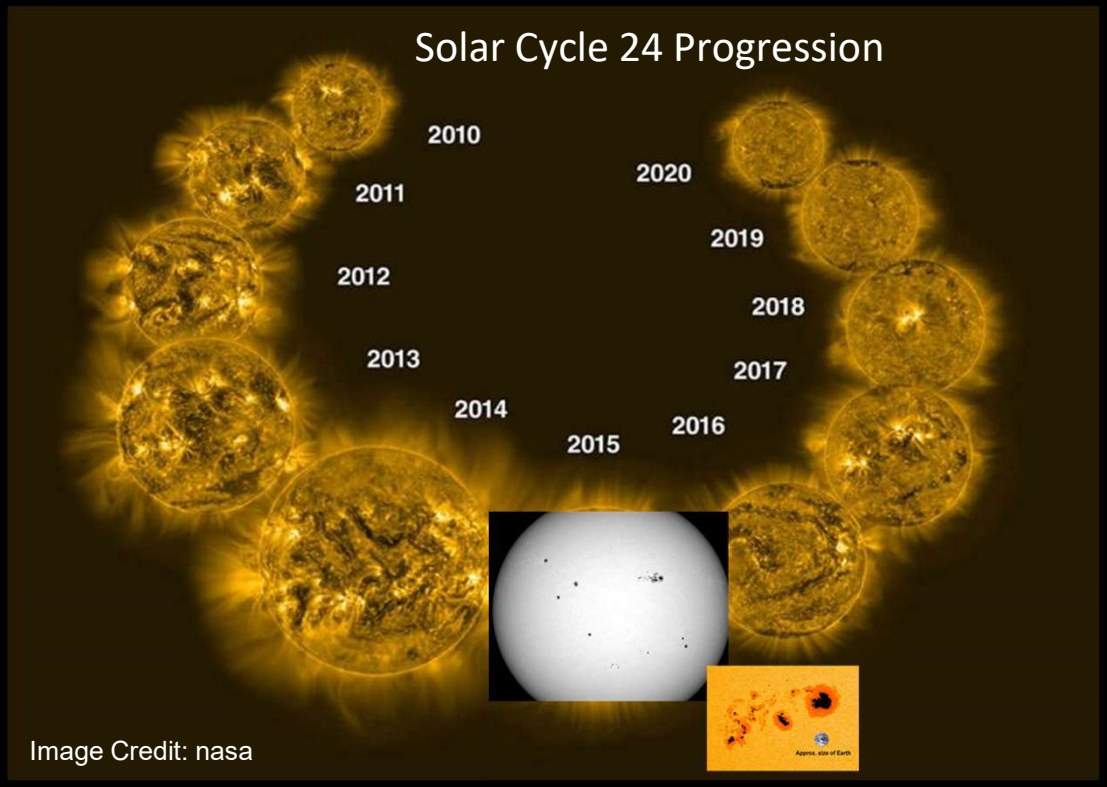
Core partnerships with USAF, NASA, FEMA, NERC

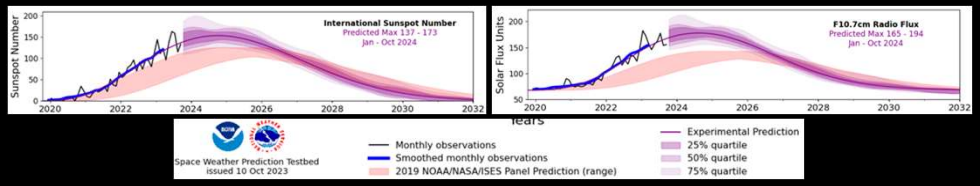
Staffed 24 hours 7 days a week – just like your supporting forecast office



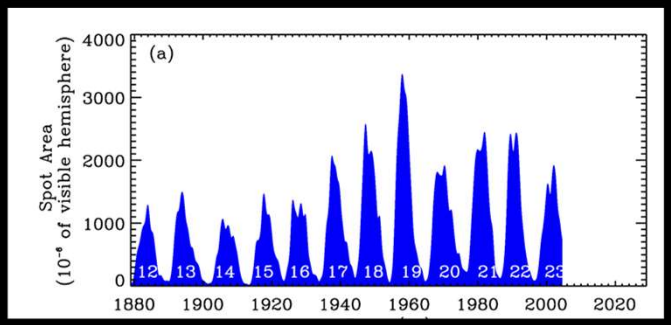


Solar Cycle and Sunspots

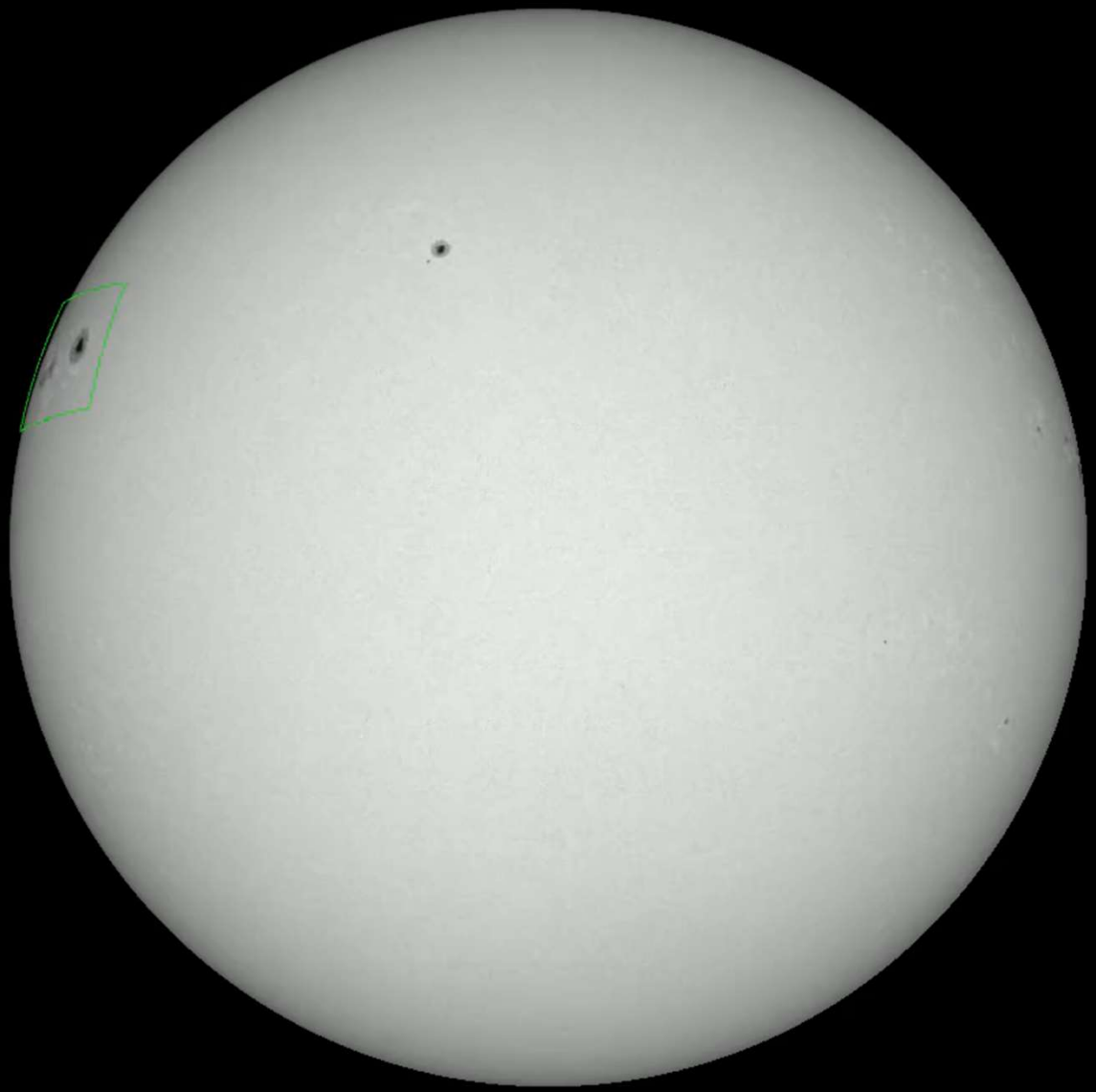




The most sunspots are correlated with solar maximum. This is part of the 11-year Solar Cycle (SC). We are now well on pace to reach solar maximum peak of Solar Cycle 25 in **2024** (this year); but **2025** will also be active!



Sunspot Region 3590 (Feb 19-27th)



2024-02-19T14:19:09.700

Focus areas

(3 main activity types SWPC forecasts)

Impacts & Phenomena Based Forecasts

Solar Radiation Storms **(S-scale) :** related to *Solar Proton Events*

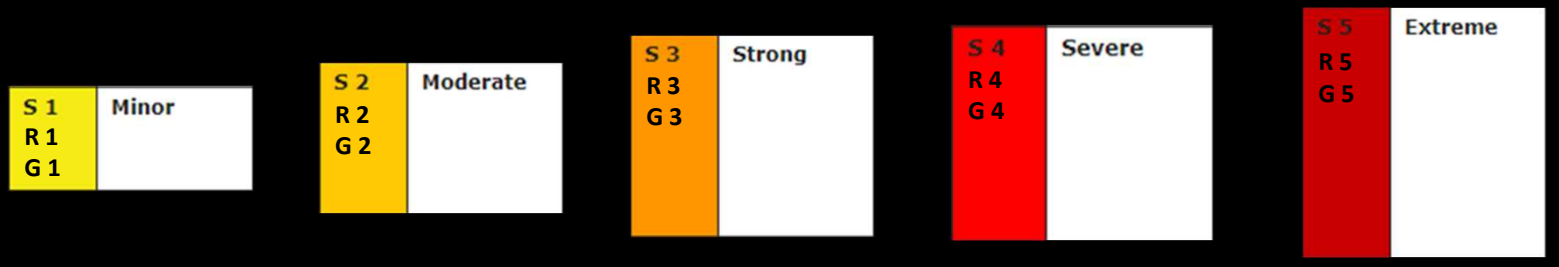
Solar Radiation Storm Warnings and Alerts

HF Radio Blackouts **(R-scale):** as related to *Solar Flares*

Solar Flare Alerts

Geomagnetic Storms **(G-scale):** as related to origin source *Coronal Mass Ejection* (CME), *Coronal Hole* (CH)

Geomagnetic Storm Watches, Warnings, and Alerts

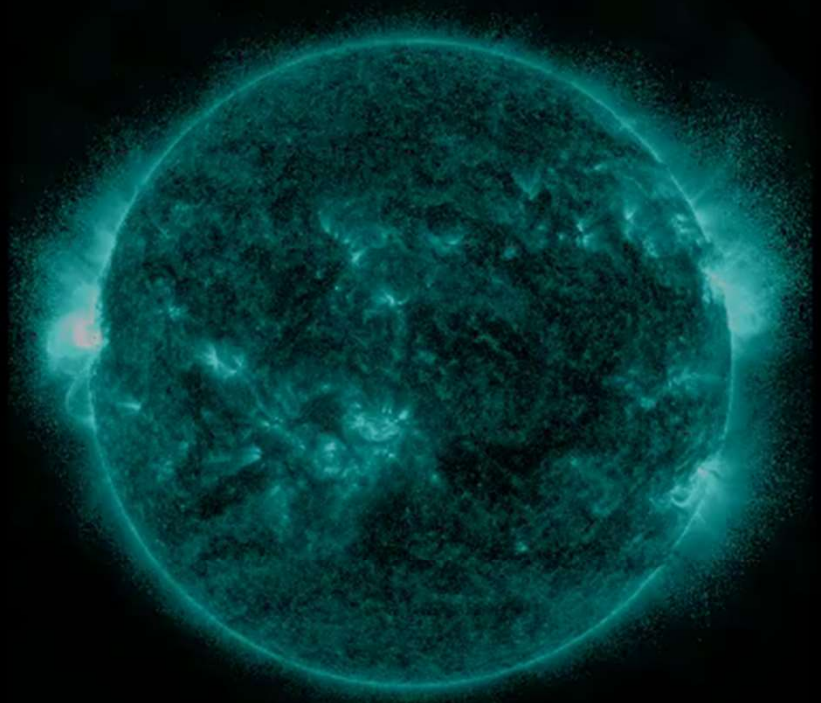


Solar Flares

R3 **Dec 31st: X5 flare from the east limb of the Sun - largest flare of SC25 to that point**

Location of a flare on the Earth-facing disk does not matter.

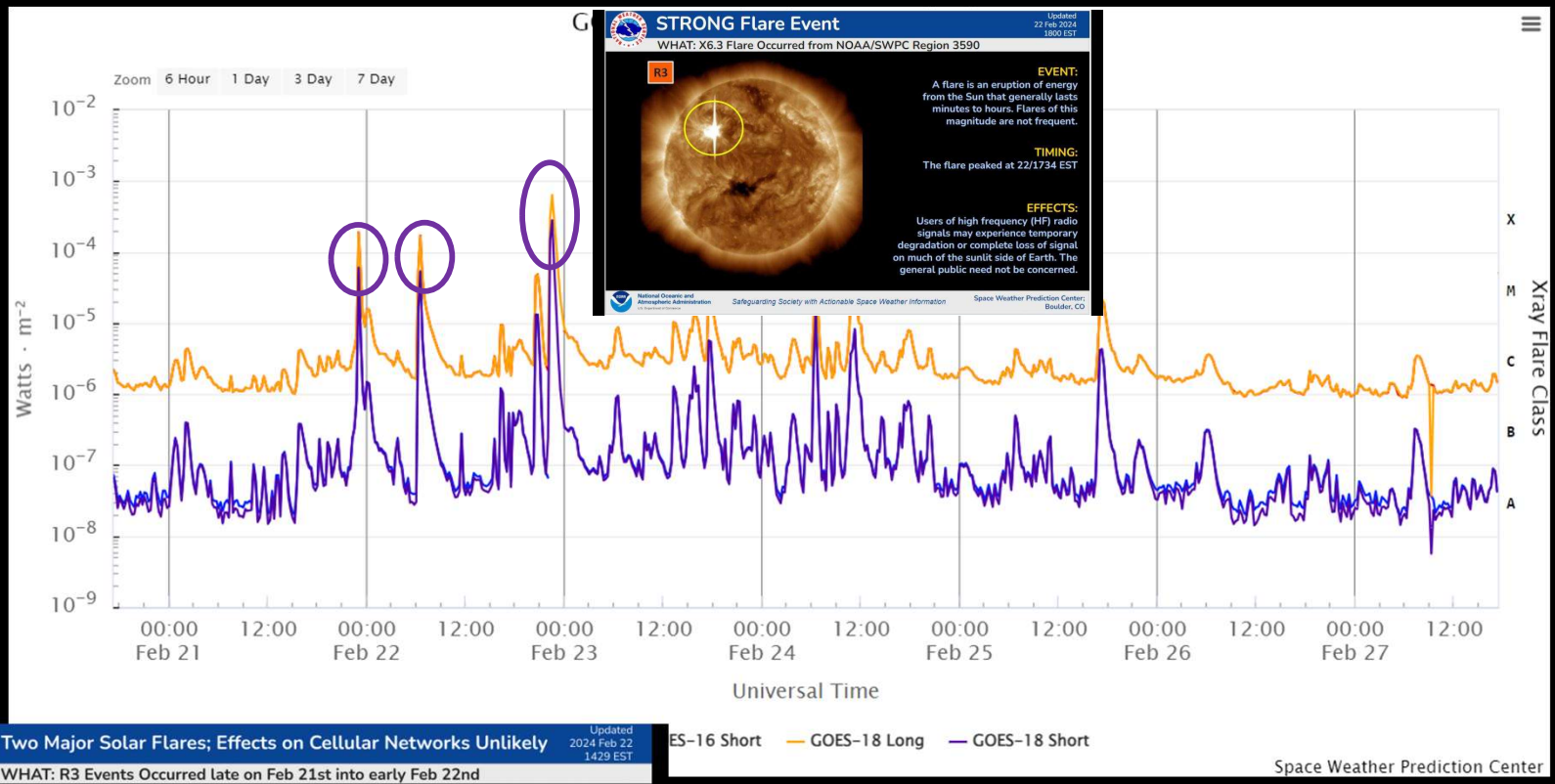
The impact on our sunlit side of Earth's ionosphere is immediate.



Their X-ray energy strength correlates to the likelihood of certain types of HF radio interference or signal absorption on the **sunlit** side of Earth; and relates to geographic area of impact.

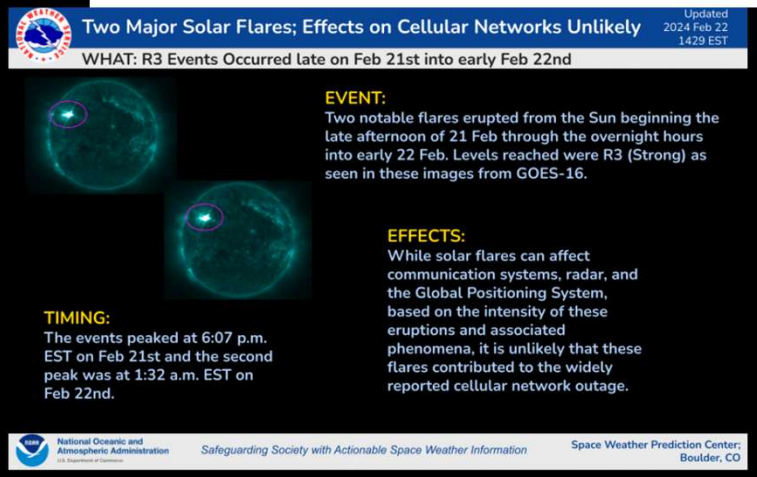
A concern for Ham radio users and other types of HF communications (usually voice modulation and skywave); mainly 3 – 30 Mhz

Trio of R3 Solar Flares 21-22 February



All three flares were quite impulsive (quick to rise and decrease).

So, this would have lessened their impact in duration as well.



All these flares took place when most of North America was not on the direct daylight side of our planet. So, any impacts were felt elsewhere

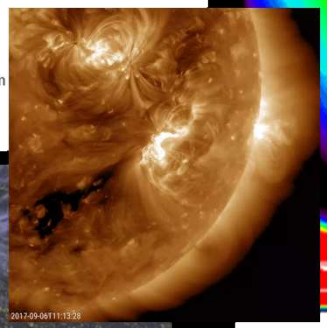
When Extreme Space Weather and Catastrophic Terrestrial Weather come together September 2017

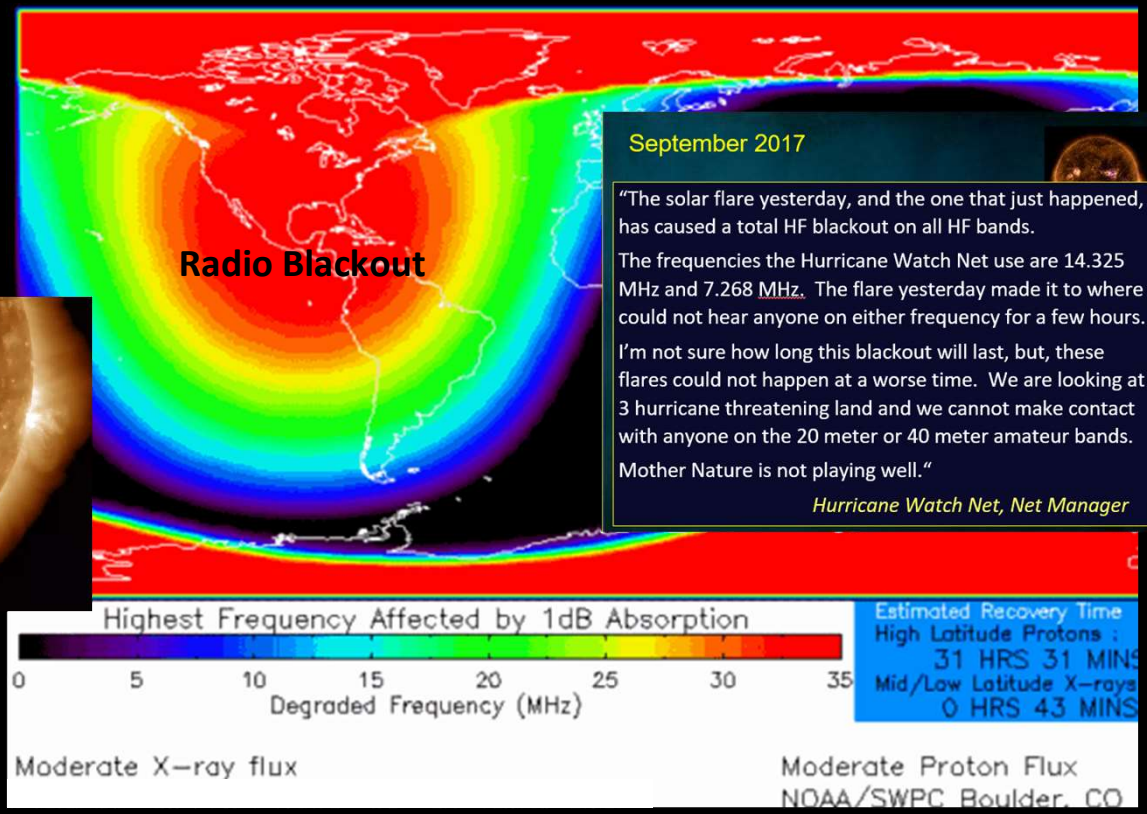
EOS NEWS ▾ NEWS FROM AGU JOURNALS ▾ TOPICS & DISCIPLINES ▾ OPINIONS ▾ BLOGS AGU'S CENTENNIAL

SPACE SCIENCE & SPACE PHYSICS | Scientific Press Releases

Solar Flares Disrupted Radio During 2017 Hurricane Irma

On 6 September 2017, as Category 5 Hurricane Irma hit the Caribbean's Leeward Islands, and Tropical Storm Jose hovered in the wings, another storm erupted on the Sun.





This flare and it's effects lasted a few hours

HF Radio Comm from the Caribbean Islands (Ham Radio in particular) was nearly impossible during the hurricane disasters & crisis response for several hours. Hurricane Watch Net & Aviation Communication notably impacted.

Frequency (Radio) Bursts

We cannot forecast these; but we do monitor for them thanks to the USAF Solar Electro-Optical Network (SEON)

Strongest Solar Flare of this Solar Cycle

Updated 2023 Dec 14 1900 EST

WHAT: Multiple Aviation Communication Impacts Associated with this Event

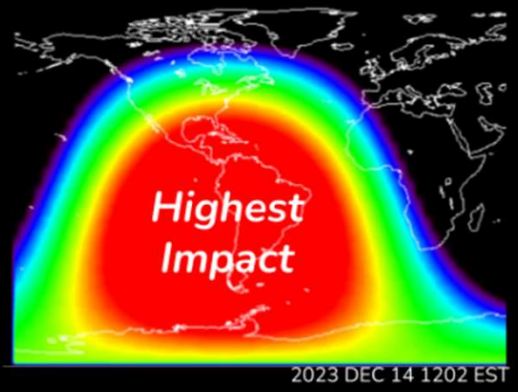
Amazing Event - likely one of the largest solar radio events ever recorded

Radio communication impacts between approximately 1200 - 1400 EST Thu

CWSUs report degraded communications across Nation
- ZKC, ZMP, ZAU, ZNY, ZOB
- "... Never seen anything like this..." - ZOB

Possible Earth-directed Coronal Mass Ejection (CME) being analyzed

Dec 14th

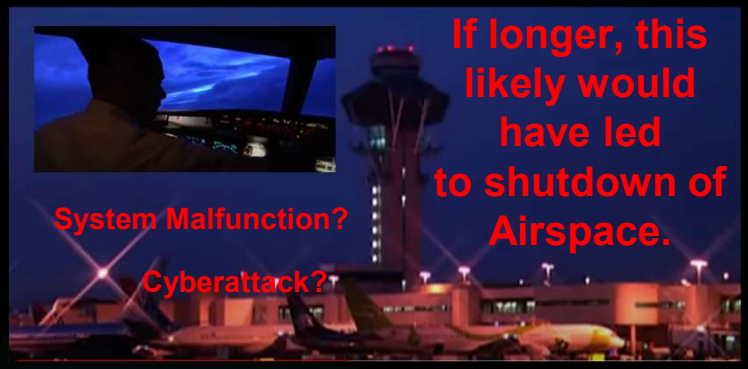


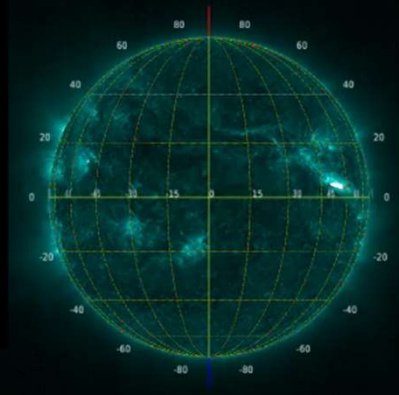
10,000 times normal background!

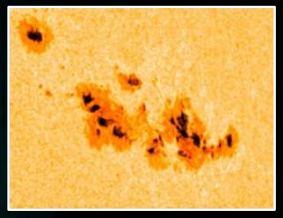
National Oceanic and Atmospheric Administration

Safeguarding Society with Actionable Space Weather Information

Space Weather Prediction Center; Boulder, CO





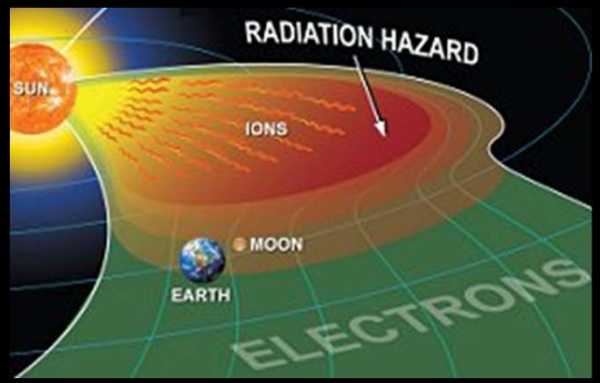


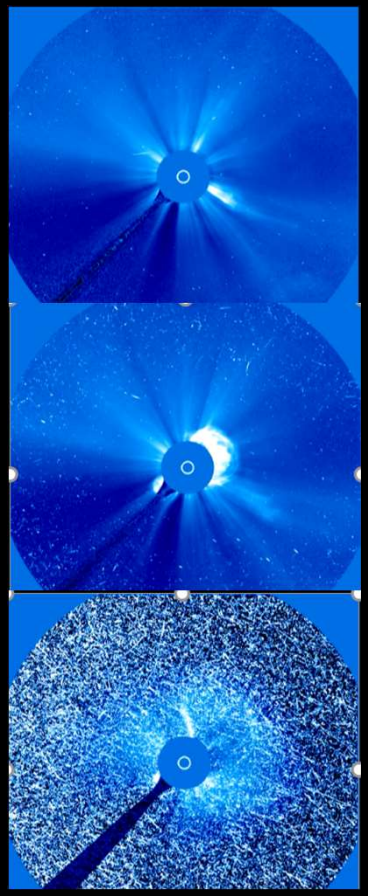
Can make radio communication difficult or unclear on frequencies other than HF bands. Additional Air Traffic Control (ATC) channels impacted dramatically on higher communication bands over U.S. in VHF-UHF on Dec 14th (8 minutes)

Could also be issue for urban environment communication repeater systems.

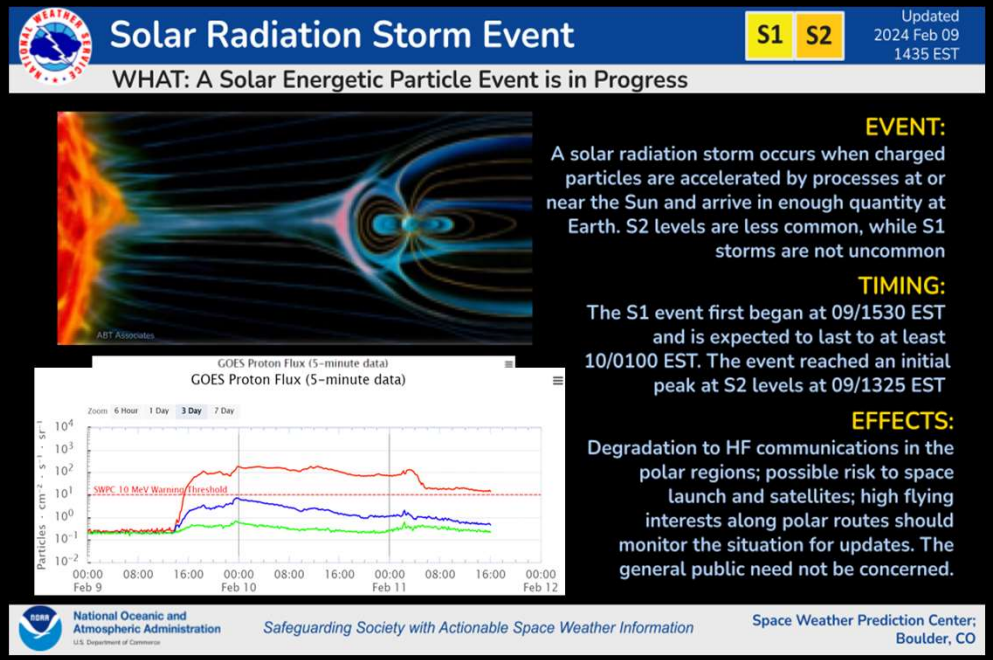
Also, concern for military assets and interests.

Solar Radiation Storms





Feb 9-13th



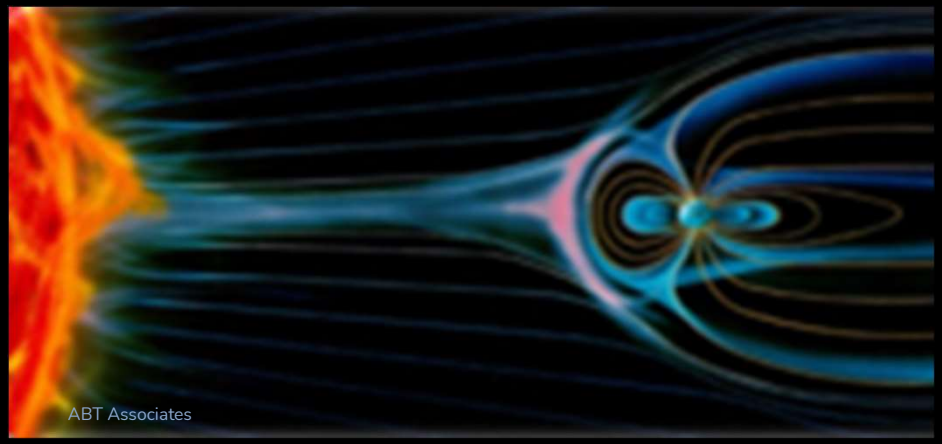
These storms are measured not only by the amount of solar energetic particles (protons), but also by there energy levels (MeV).

Can adversely affect aviation – increased radiation exposure risk to astronauts and aircrews at high altitudes near polar regions; relates to HF communication outages extending from polar regions; can delay space launch and cause increased risk of anomalies to satellites

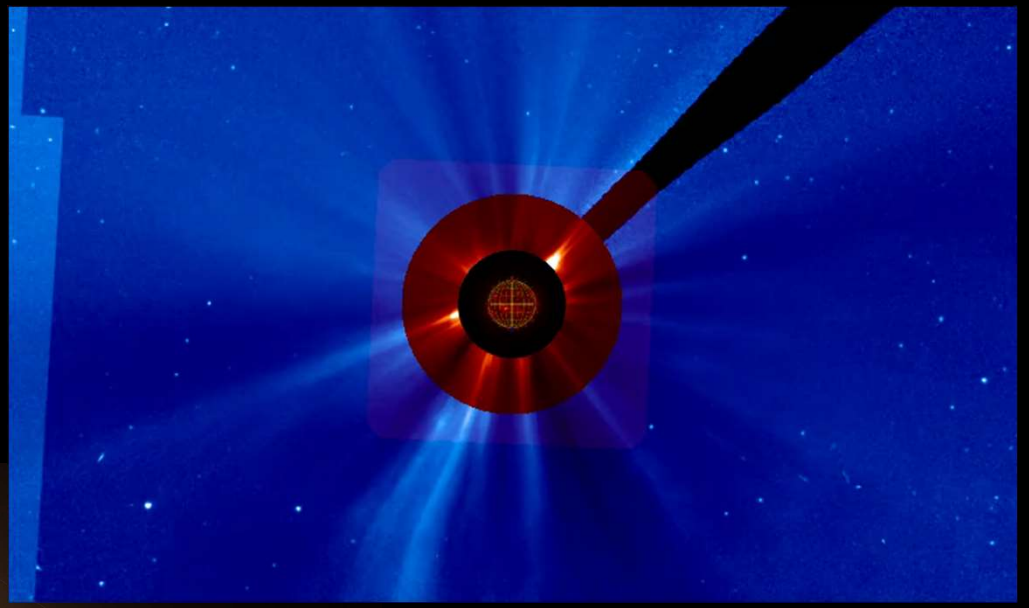
We communicate with NASA everyday about the threat and risk of these events.

Solar Radiation Storms

And the underlying cause: Solar Energetic Particles (Primarily Protons)



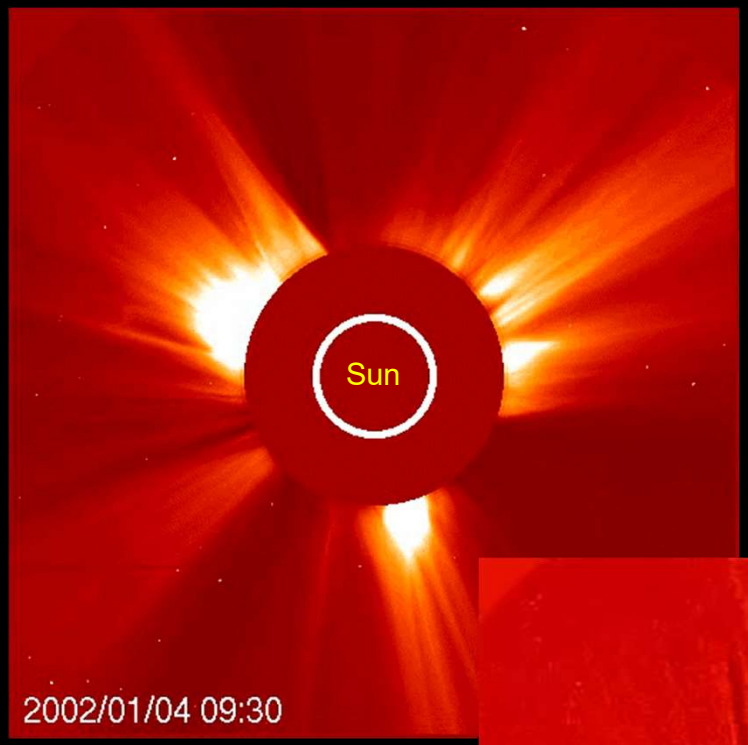
Feb 9th



Impact potential increases with higher flux and energy levels: 10 MeV (some space operations)
Different energy levels: 30 MeV (launch); 50 MeV (USAF); 100 MeV (NASA/SRAG)
*** Higher energy levels (500 MeV) are of particular concern to aviation ***

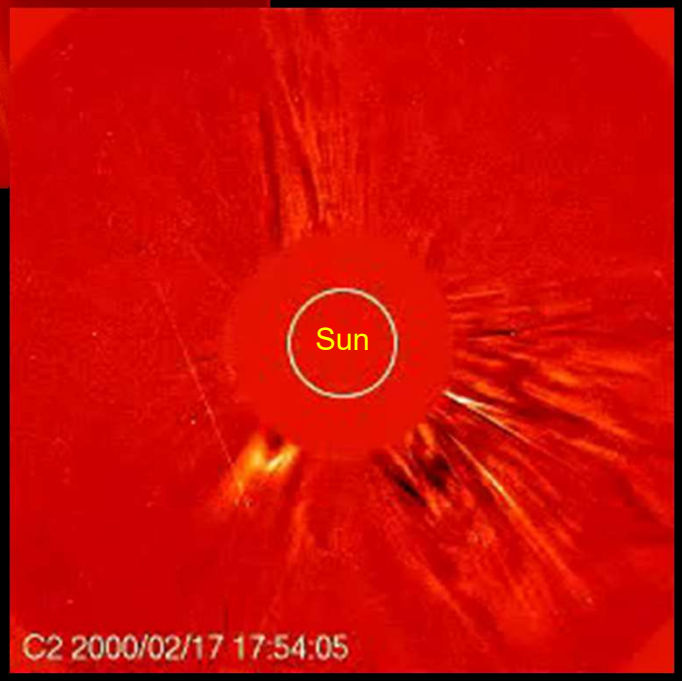
Coronal Mass Ejections (CME)

Tremendous expulsions of solar material from or through the solar corona, carrying embedded magnetic fields.



Fastest Earth-directed CMEs can get here in 15 hours. Usually, they are slower and take 2 to 4 days.

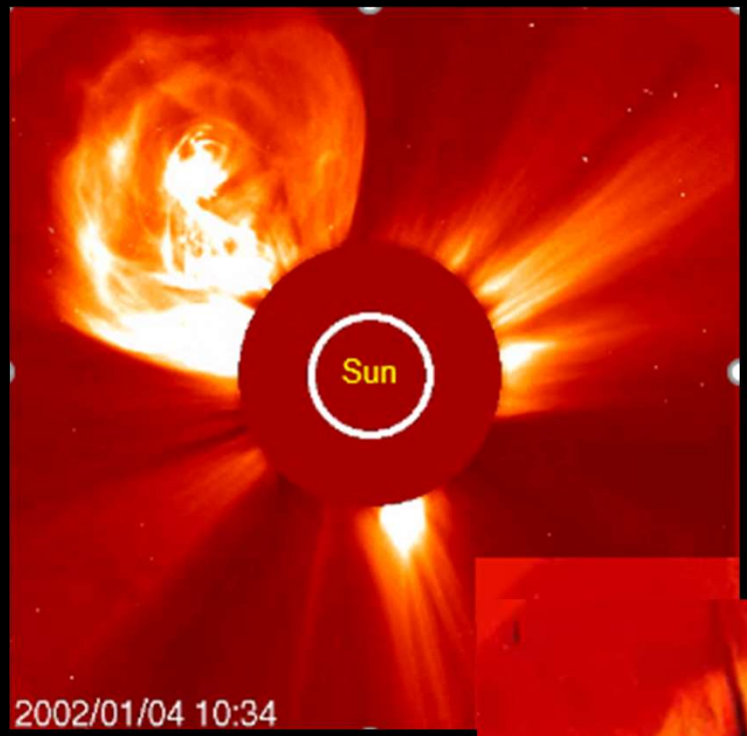
Their impact to our magnetosphere can cause major changes resulting in **Geomagnetic Storms**.



We analyze and parametrize any CME for model submission in order to determine possibility of any Earth directed component.

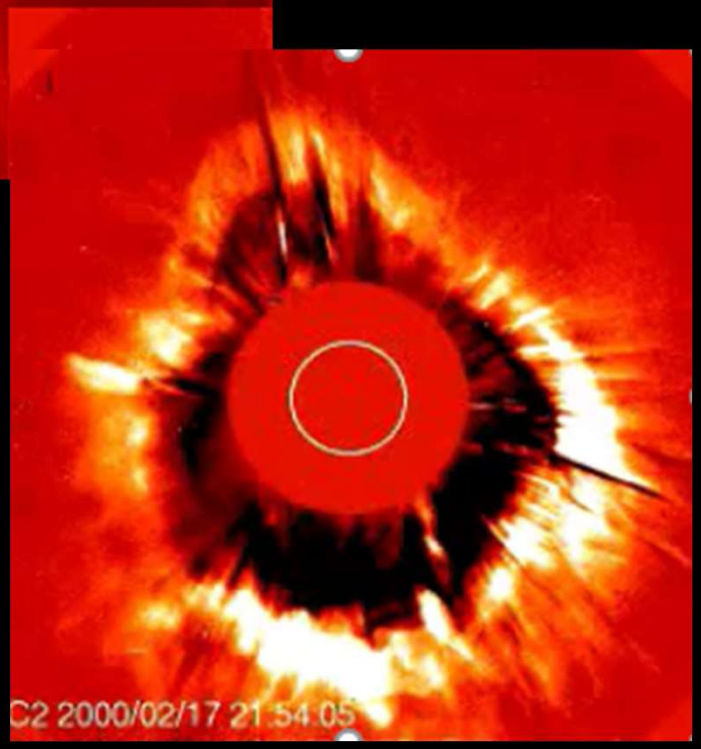
Coronal Mass Ejections (CME)

CMEs expand quite rapidly as they move outward from the Sun.



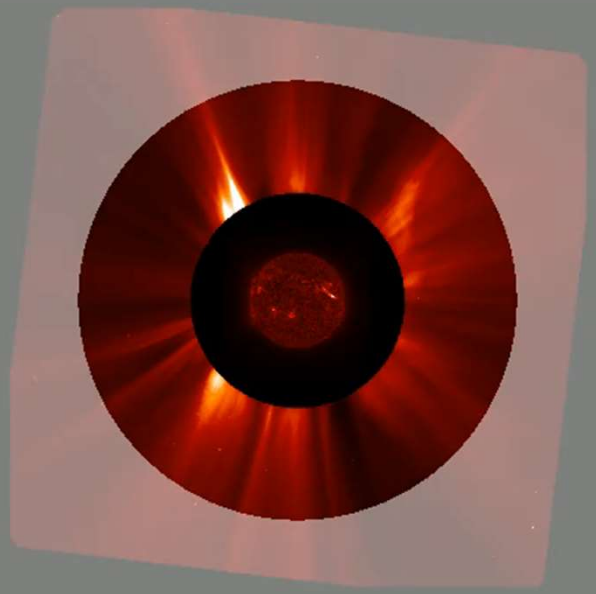
93 million miles is lots of travel time and thus plenty of expansion as the CME transits interstellar space

Even those near the solar limb can still reach Earth and result in **Geomagnetic Storms**.



Fastest, historical CMEs could be observed earlier on the same day of potential arrival

December 14th Flare and associated CME



Geomagnetic Storms

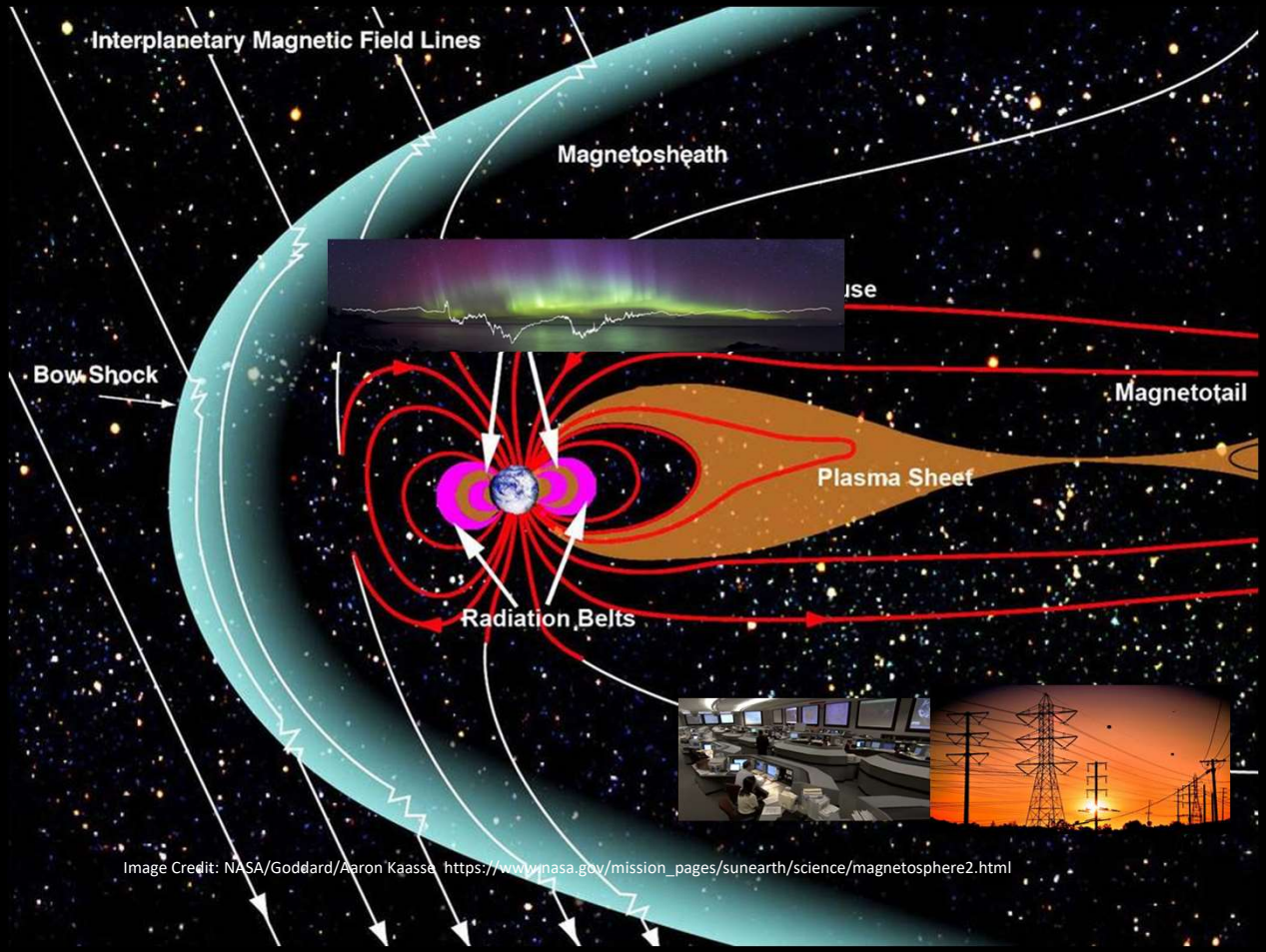
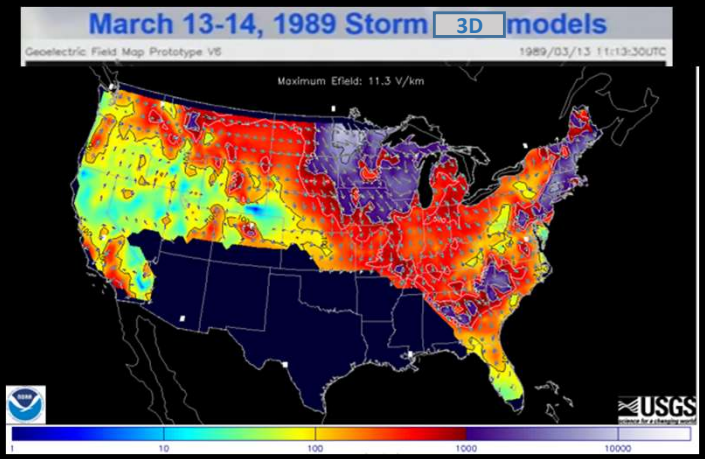


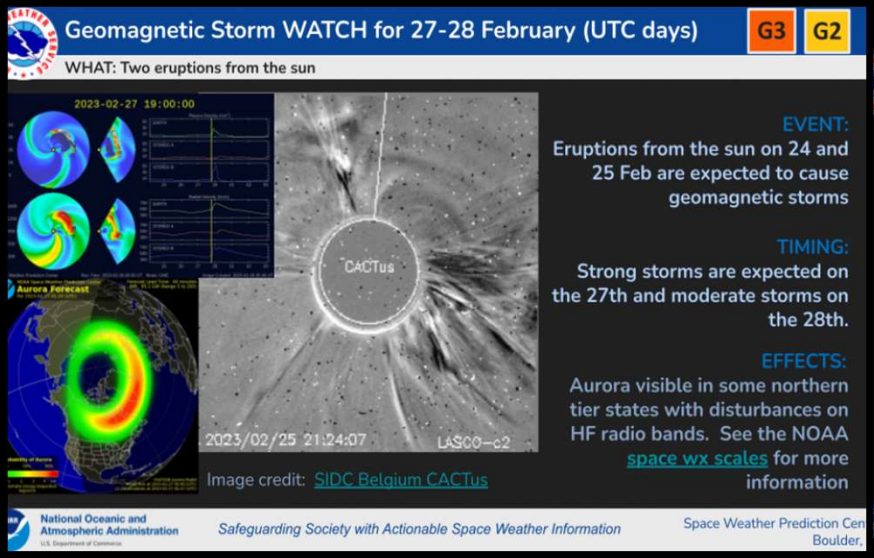
Image Credit: NASA/Goddard/Aaron Kaasse https://www.nasa.gov/mission_pages/sunearth/science/magnetosphere2.html

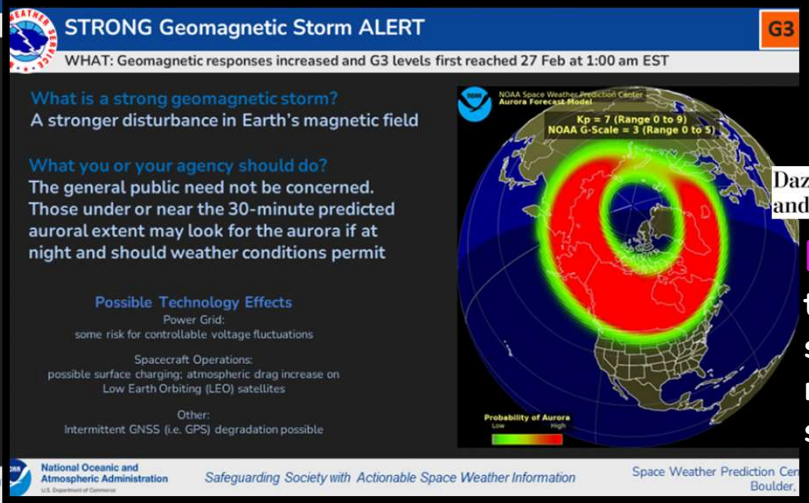
When a CME strikes and envelopes Earth's magnetic field, storms may begin. In particular, if the CME mag field connects with Earth's.



Can produce problematic induced currents on the power grid systems and can lead to upper atmospheric conditions that can cause variety of communication (SATCOM included) & navigation accuracy problems

G1-G4 Events already in 2023



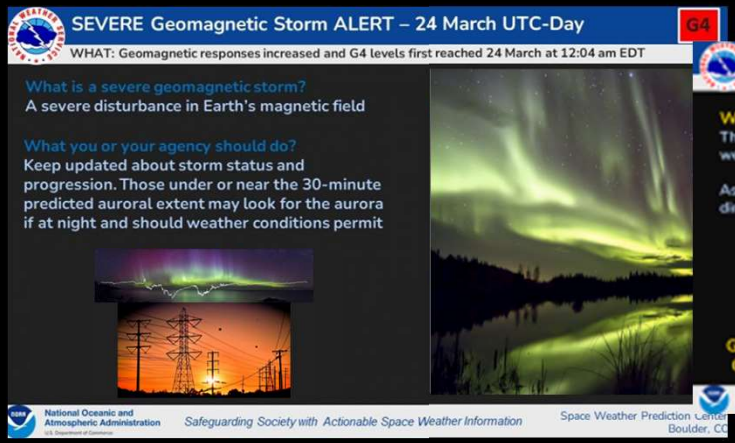


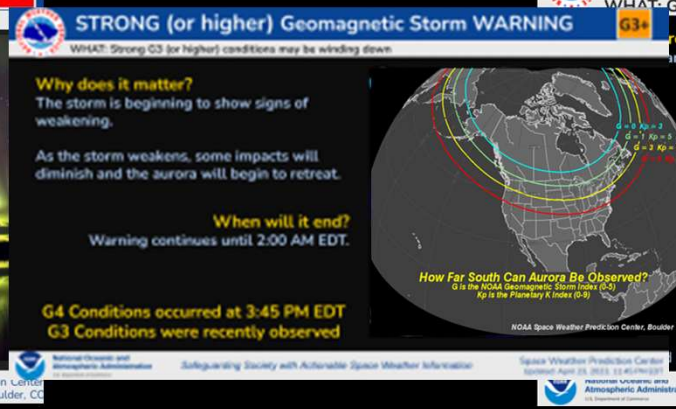
The Washington Post

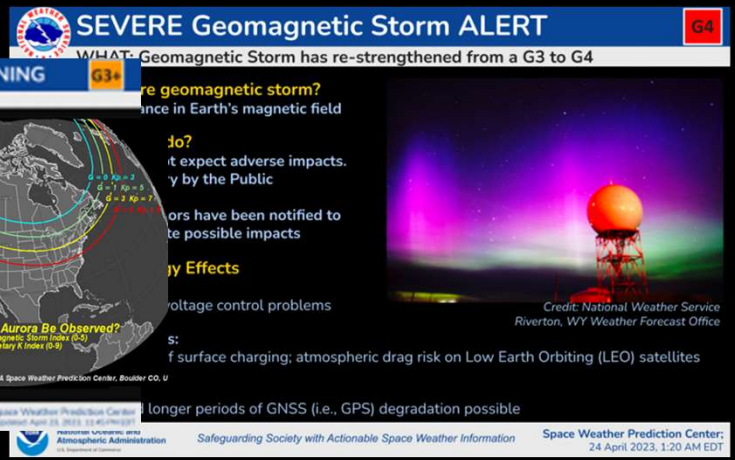
Dazzling aurora lit up Sunday night sky and may shine again Monday

Feb 27th

the best aurora sightings across much of the U.S. in some time







Continuing Chances of NOAA Space Weather Scale Activity in 2024 and on into 2025

Geomagnetic Storms:

Forecast probabilities and intensities out 3 days

More Calls & Queries

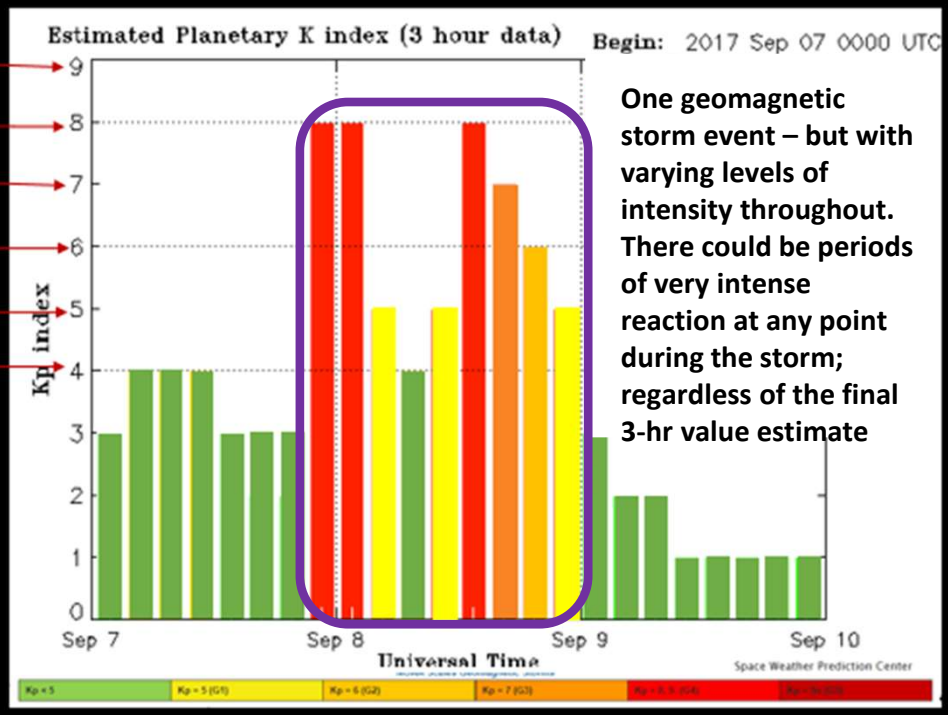
FEMA Call

NERC Hotline Call

ATC Pacific / NASA Call

K5/G1 Warning

1st Warning Issued



One geomagnetic storm event – but with varying levels of intensity throughout. There could be periods of very intense reaction at any point during the storm; regardless of the final 3-hr value estimate

Estimated in real-time; with a final value attributed at the end of each 3-hour period. This can cause confusion, because we may not reach expected levels every 3 hours. Think of it like a rain gauge being emptied every 3 hours – but the heavy rain event continues, with varying amounts of precipitation rates

Warnings issued for Kp 4 up to Kp 7 and greater

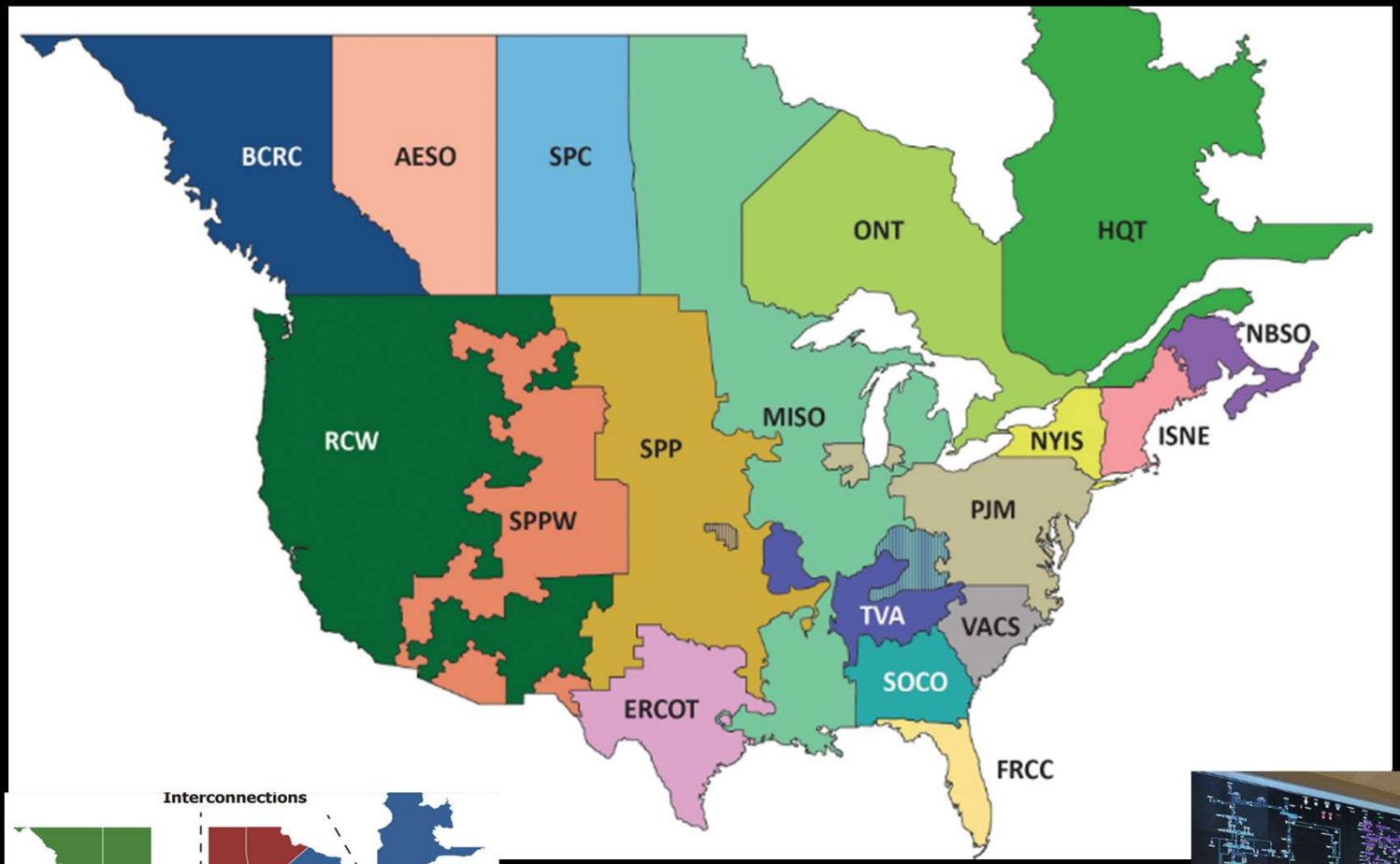
Alerts issued at each Kp level

Based on Estimated Planetary K-index (8 magnetometer stations).

Kp5 = G1 Kp6 = G2 Kp7 = G3 Kp8-K9m = G4 Kp9z = G5

*each Kp level divided into three levels: m (-); z (0); and p (+)

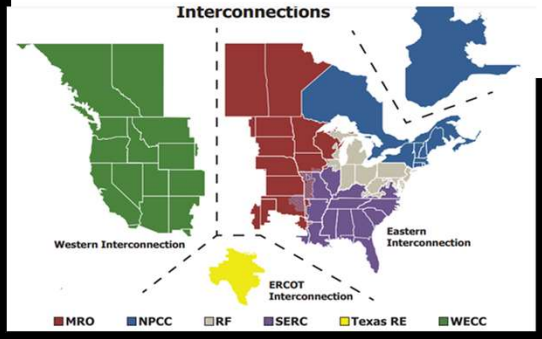
North American Energy Reliability Corporation (NERC) Reliability Coordinators (RC) throughout the Interconnections



Mitigating Power Outage Potential to our Interconnected Power Grid:

NERC Hotline Call

All RC's are on the NERC hotline call when we initiate the NERC hotline call beginning at G3

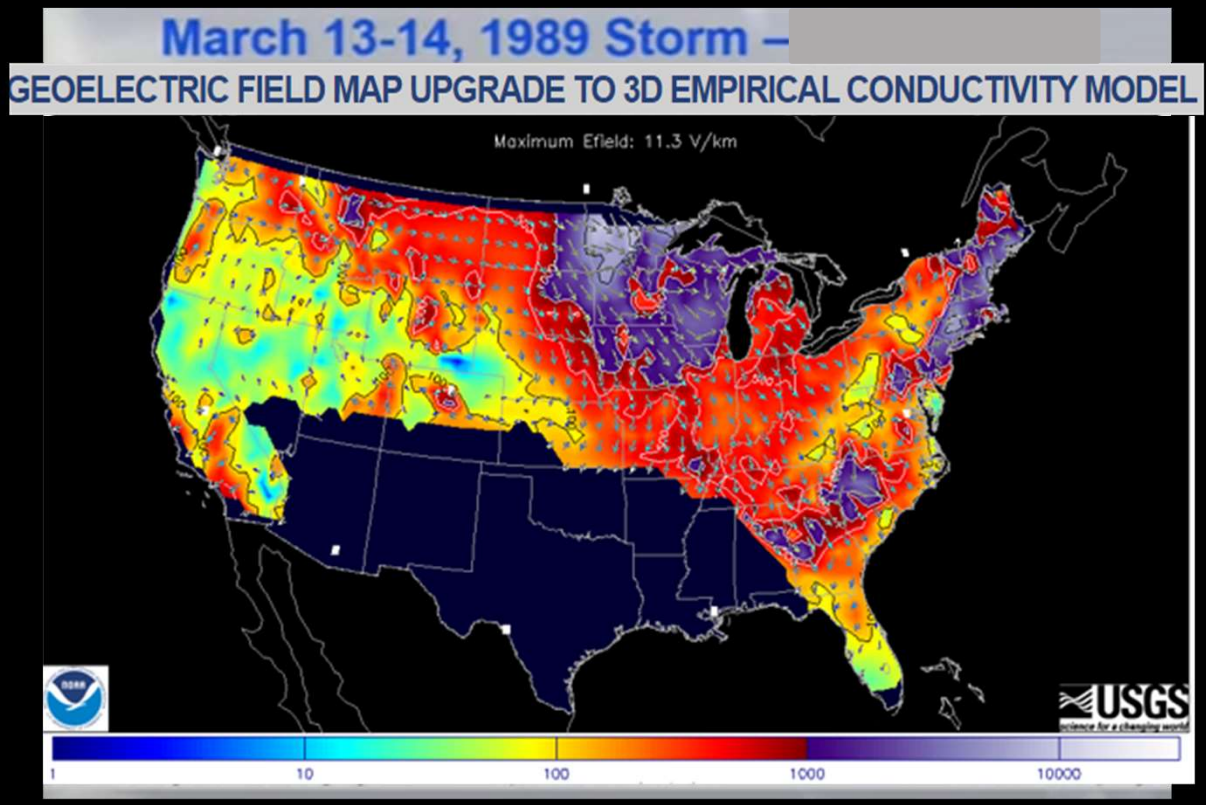


The three (really four) Interconnections are electrically tied together during normal system conditions and operate at a synchronized frequency at an average of 60 Hz

Geoelectric Field Model

"nowcast" model projection with calculated voltage per kilometer approaching 1V/km are noteworthy; 12V/km may be impactful

Geoelectric fields are the electric potential on the earth's surface and is directly related to rate of change in magnetic fields. They have amplitude and direction, and act as a voltage source that can cause GICs to flow along conductors – such as transmission lines



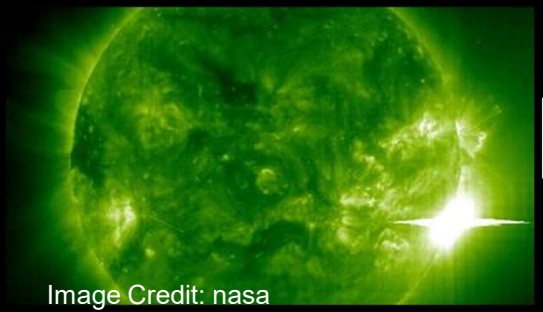
A measure of the induction hazard to artificial conductors, such as power lines.

Can be used to estimate induced geomagnetic current (GIC) integration along conducting pathways.

This model is our interpretation of the strength of GICs. Just like NWS radars observe storm echoes, this model gives estimations of the GIC potential on high voltage transmission lines.

Normal Sequence of Events

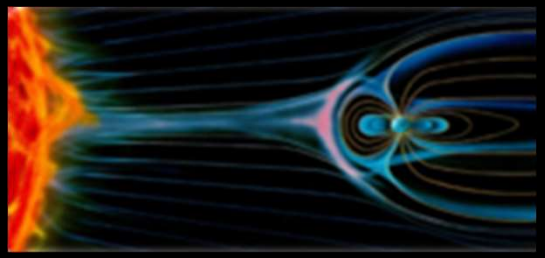
with regards to Watches, Warnings, and Alerts (WWA)



R2

ALERT
Sent at R2 or greater

Probabilities predicted in 3-day forecast; a flare occurs (speed of light), effect already taking place in outer atmosphere



S1

WARNING
Sent for S1 or greater
ALERT
Sent for each S1-S5 level

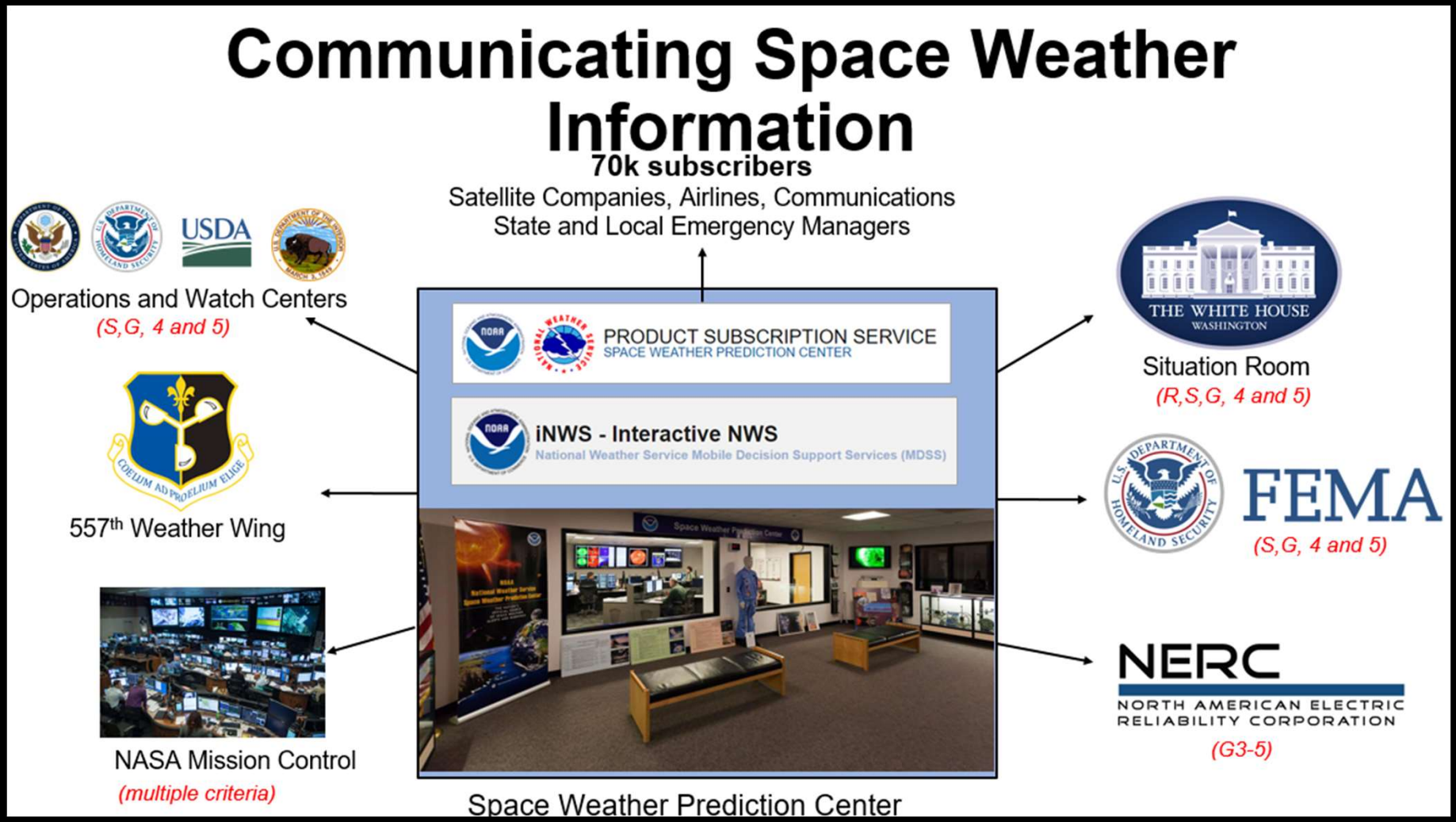
Probabilities predicted in 3-day forecast;
Can be nearly speed of light, but warnings possible

G3

WATCHES
Sent for G1-G4 or greater
WARNING
Sent for Kp4-7+ (G1-G3+)
ALERT
Sent for each level through Kp 9z (G1-G5)

Geomagnetic Storms can be predicted out to 3 days; so watches and warnings possible. Science limits threshold capabilities however

Space Weather Messaging & Communication



Significant Space Weather Event Actions

Space Weather Event Alert & Notification – Emergency Response

- Directly or indirectly cause or exacerbate a major disaster or emergency.
- Interfere with or seriously degrade FEMA's response & recovery capability.

Notification / Action

S4-S5 Radiation Storms

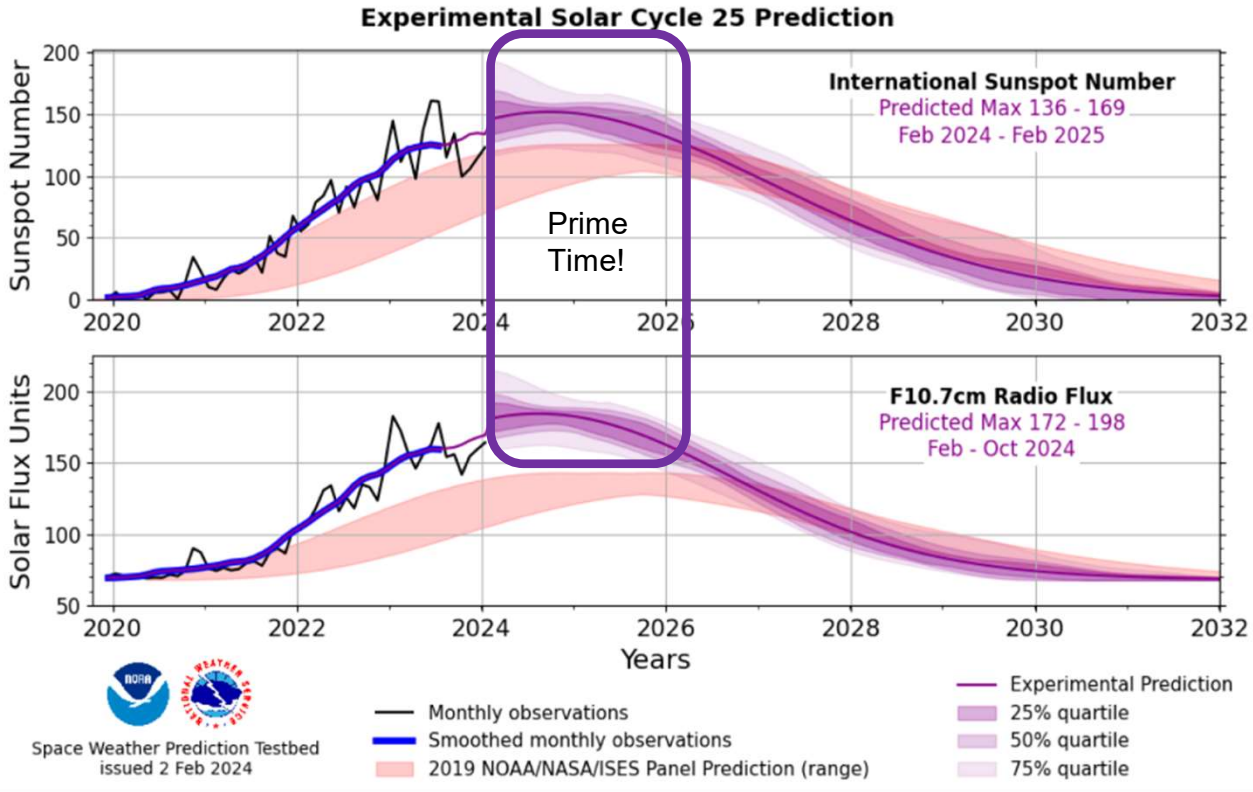
G4-G5 Geomagnetic Storms

- FEMA Operations Center (FOC) — **Notify Leadership**
- FOC Alternate West (FAOC) — **ENS to MOCs & Watches; Send Plain Language Email**
- National Watch Center — **Notify NOC; Broad Distro Plain Language Email**
- FAOC- East — **NAWAS / WAWAS** ***(S5, G5 only)***

Emergency notification system (ENS)
FEMA MERS Operations Center (MOC)
National Operations Center (NOC)
National Warning System (NAWAS)
Washington Metropolitan Area Warning System (WAWAS)

Current Solar Cycle 25 is ramping up; currently above the original forecast margin of error

Solar Cycle Progression Updated Prediction (Experimental)



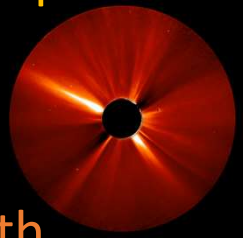
Notable Space Weather Events

Carrington Event, 1-2 September 1859:
Most significant event on record. Telegraph system world-wide impacted. Aurora visible in Central America.

Hydro-Quebec Storm, 14 March 1989:
Power blackout in Montreal and entire province of Quebec.
Severely damaged New Jersey transformers. Numerous U.S. grid anomalies.

Operation Anaconda, Afghanistan, 4 March 2002:
Three U.S. soldiers killed - space weather disrupted satellite communications.

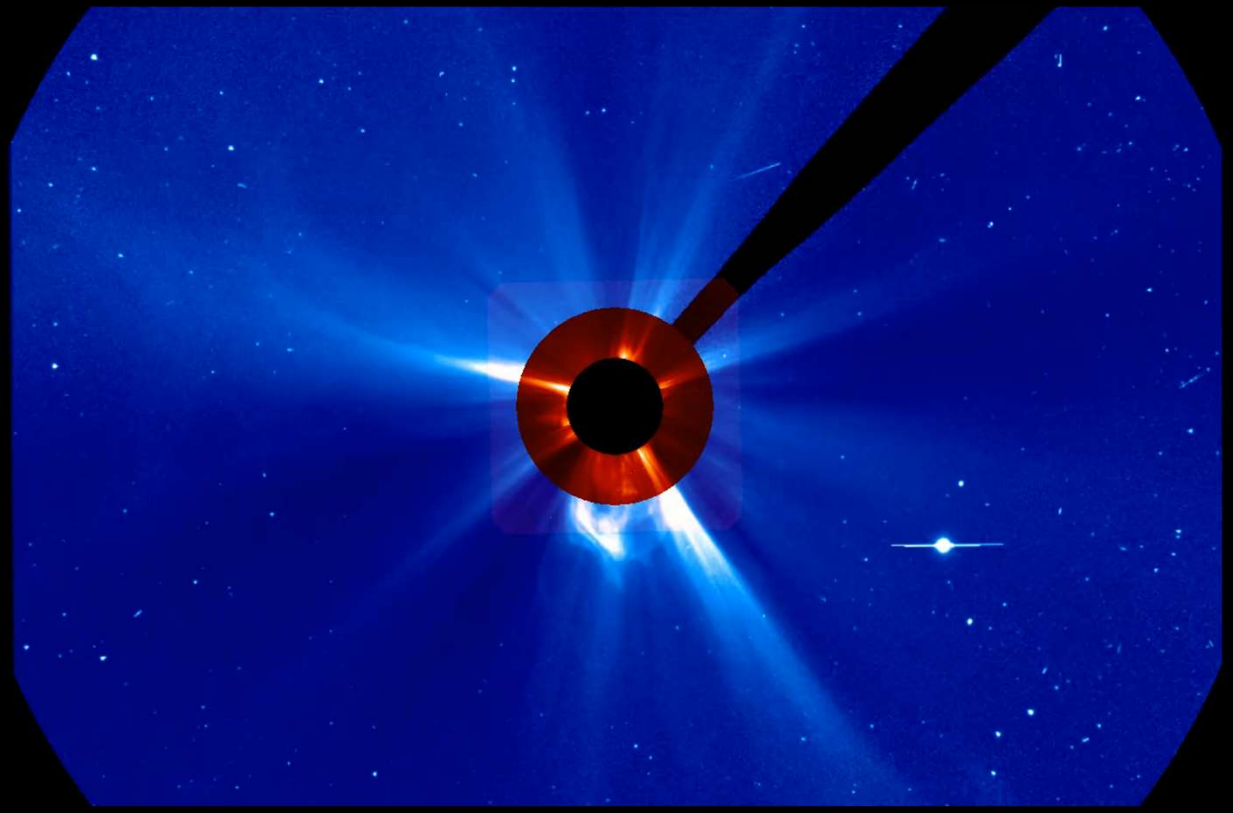
Halloween Storms, October 2003:
Power grid outage in Malmo, Sweden; damage to South Africa grid; Japan loses satellite.



Near Miss, 23 July 2012:
"Century class" event, but the eruption site was 90 deg ahead of Earth.

SpaceX Starlink Loss, 3 February 2022:
Loss of 38 of 49 satellites due to a minor geomagnetic storm.

… and even more recently



Potentially, a Severe event if aimed at Earth

Carrington CME event reached Earth in about 18 hours

This could have reached Earth in a little over 24 hours

- What would have happened here at Earth is unknown, **but that is why planning is important**

Massive CME ripped from the Sun late on 12 March, 2023

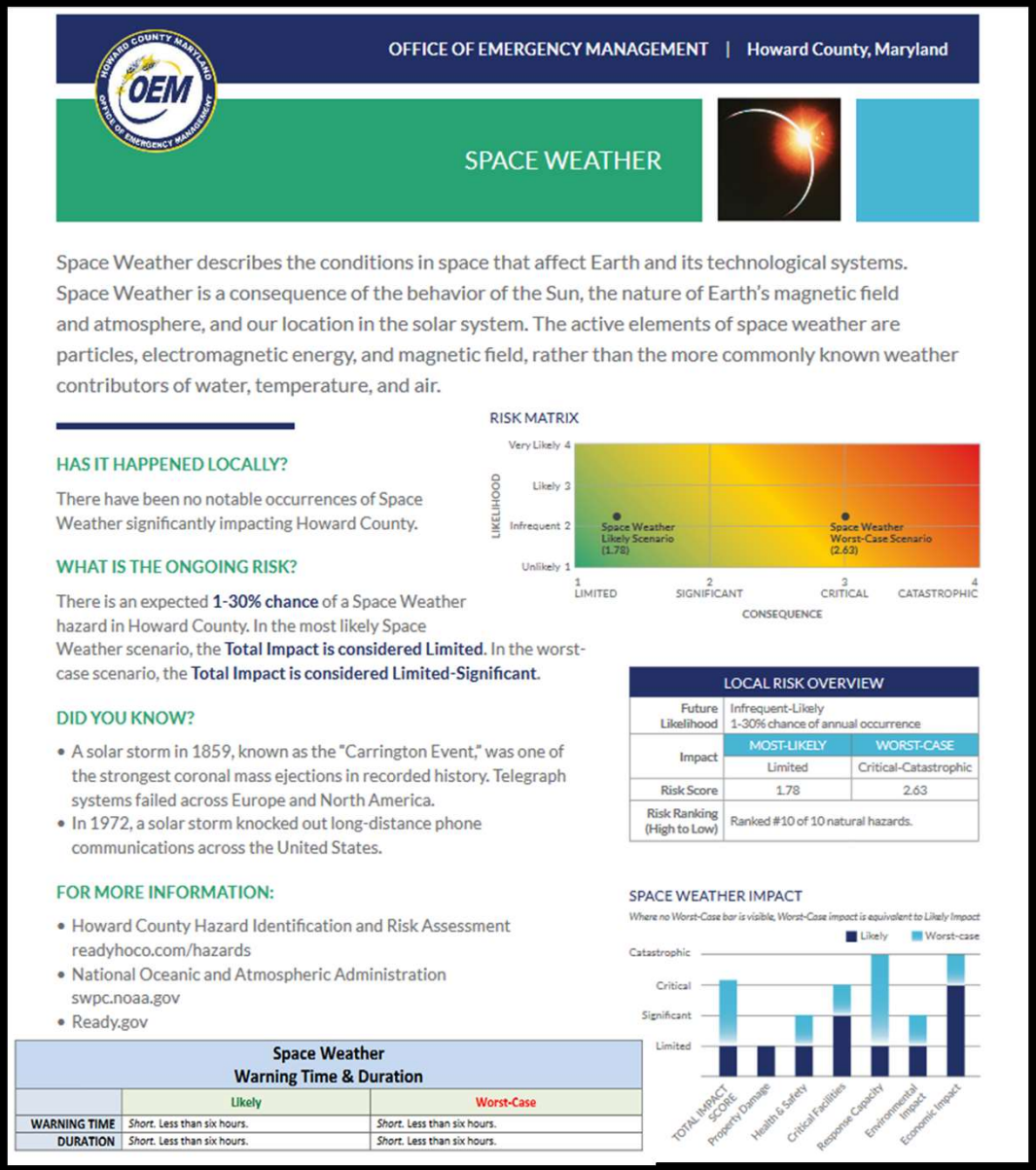
Analysis from NASA Moon to Mars Space Weather Office measured the CME at 2,127 km/s (a rare event)

CME was fortunately from the far-side of the Sun

Headed completely away from Earth; but still we were impacted by an S1 Event (Minor Solar Radiation Storm) – quite extraordinary for these energentic particles (protons) to reach Earth from this event

Emergency Management

Space weather is one of the 26 distinct hazard types identified by Howard County Emergency Management as a possible threat into Hazard Identification & Risk Assessment (HIRA)



OFFICE OF EMERGENCY MANAGEMENT | Howard County, Maryland

SPACE WEATHER

Space Weather describes the conditions in space that affect Earth and its technological systems. Space Weather is a consequence of the behavior of the Sun, the nature of Earth's magnetic field and atmosphere, and our location in the solar system. The active elements of space weather are particles, electromagnetic energy, and magnetic field, rather than the more commonly known weather contributors of water, temperature, and air.

HAS IT HAPPENED LOCALLY?

There have been no notable occurrences of Space Weather significantly impacting Howard County.

WHAT IS THE ONGOING RISK?

There is an expected **1-30% chance** of a Space Weather hazard in Howard County. In the most likely Space Weather scenario, the **Total Impact is considered Limited**. In the worst-case scenario, the **Total Impact is considered Limited-Significant**.

DID YOU KNOW?

- A solar storm in 1859, known as the "Carrington Event," was one of the strongest coronal mass ejections in recorded history. Telegraph systems failed across Europe and North America.
- In 1972, a solar storm knocked out long-distance phone communications across the United States.

FOR MORE INFORMATION:

- Howard County Hazard Identification and Risk Assessment readyhoco.com/hazards
- National Oceanic and Atmospheric Administration swpc.noaa.gov
- Ready.gov

RISK MATRIX

LOCAL RISK OVERVIEW		
Future Likelihood	Infrequent-Likely 1-30% chance of annual occurrence	
Impact	MOST-LIKELY	WORST-CASE
	Limited	Critical-Catastrophic
Risk Score	1.78	2.63
Risk Ranking (High to Low)	Ranked #10 of 10 natural hazards.	

SPACE WEATHER IMPACT

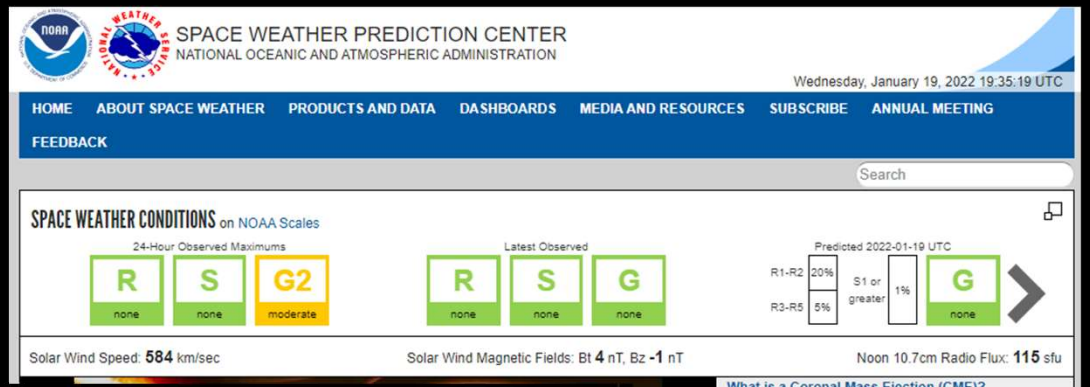
Where no Worst-Case bar is visible, Worst-Case impact is equivalent to Likely Impact

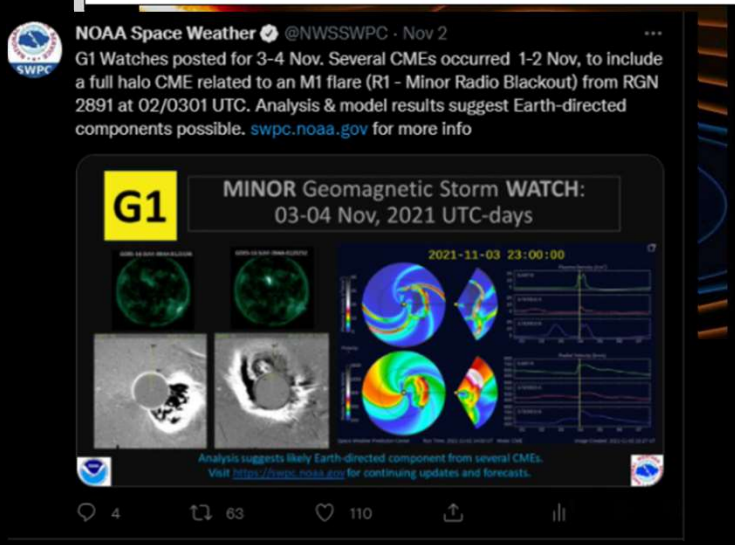
Space Weather Warning Time & Duration		
	Likely	Worst-Case
WARNING TIME	*Short.* Less than six hours.	*Short.* Less than six hours.
DURATION	*Short.* Less than six hours.	*Short.* Less than six hours.

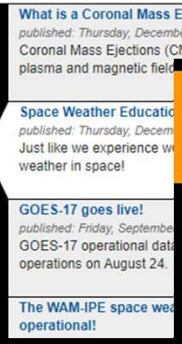
More and more requests for information on space weather hazard planning

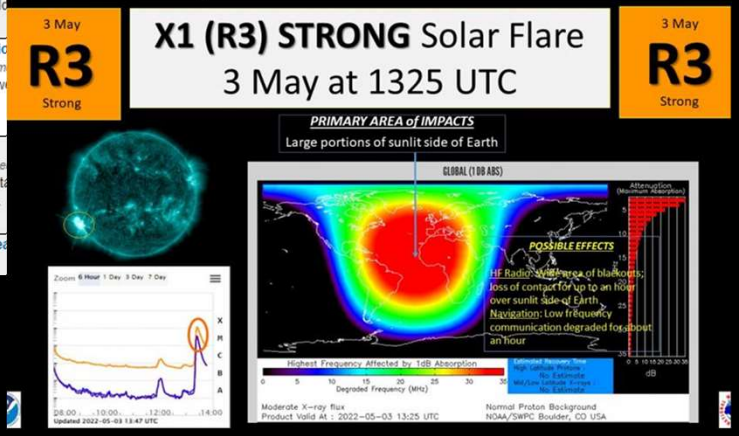
We work closely with EM officials as we can at city, county, state, national, and even international levels. The requests for support continue to grow

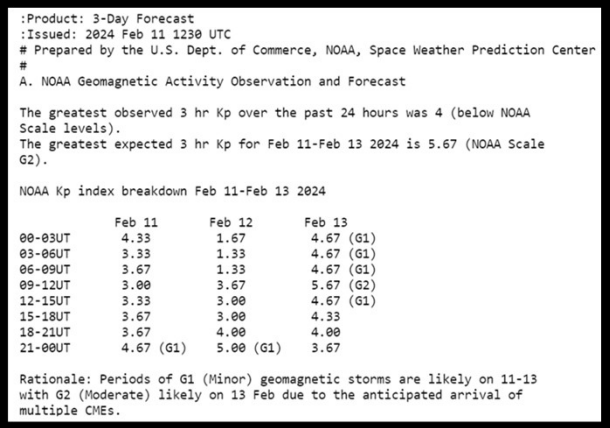
How to STAY Informed







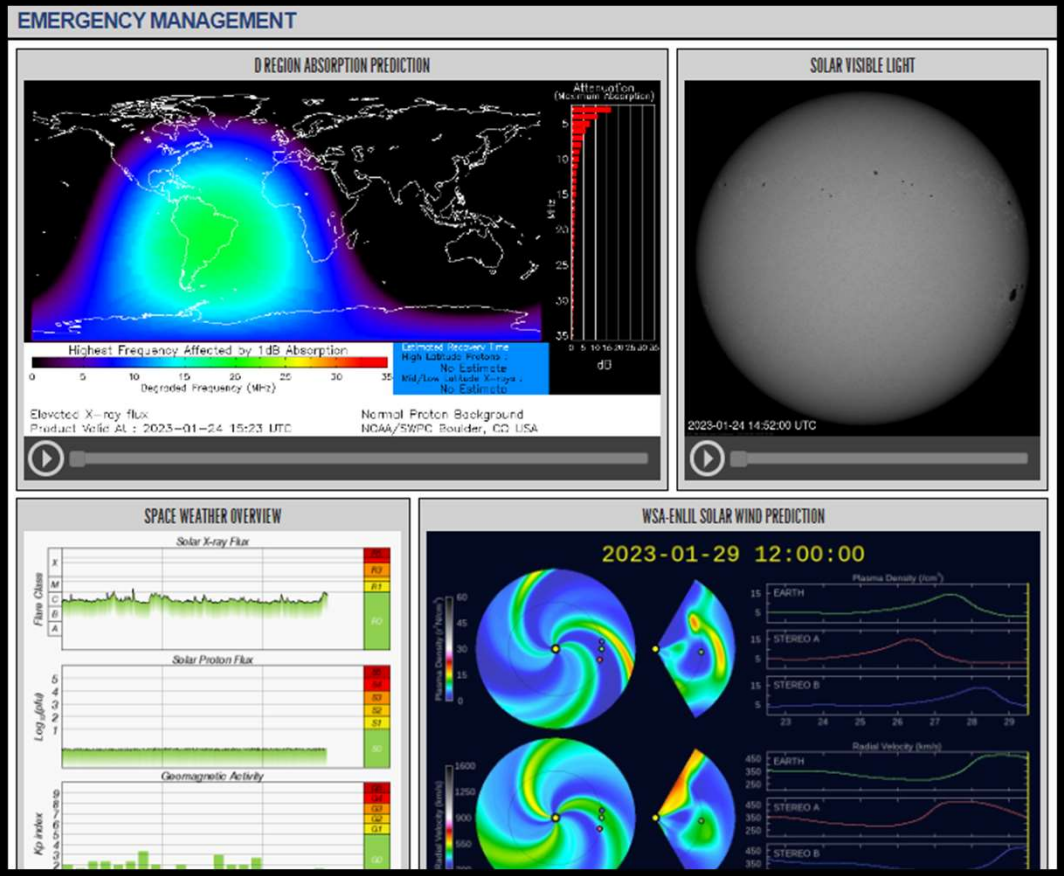


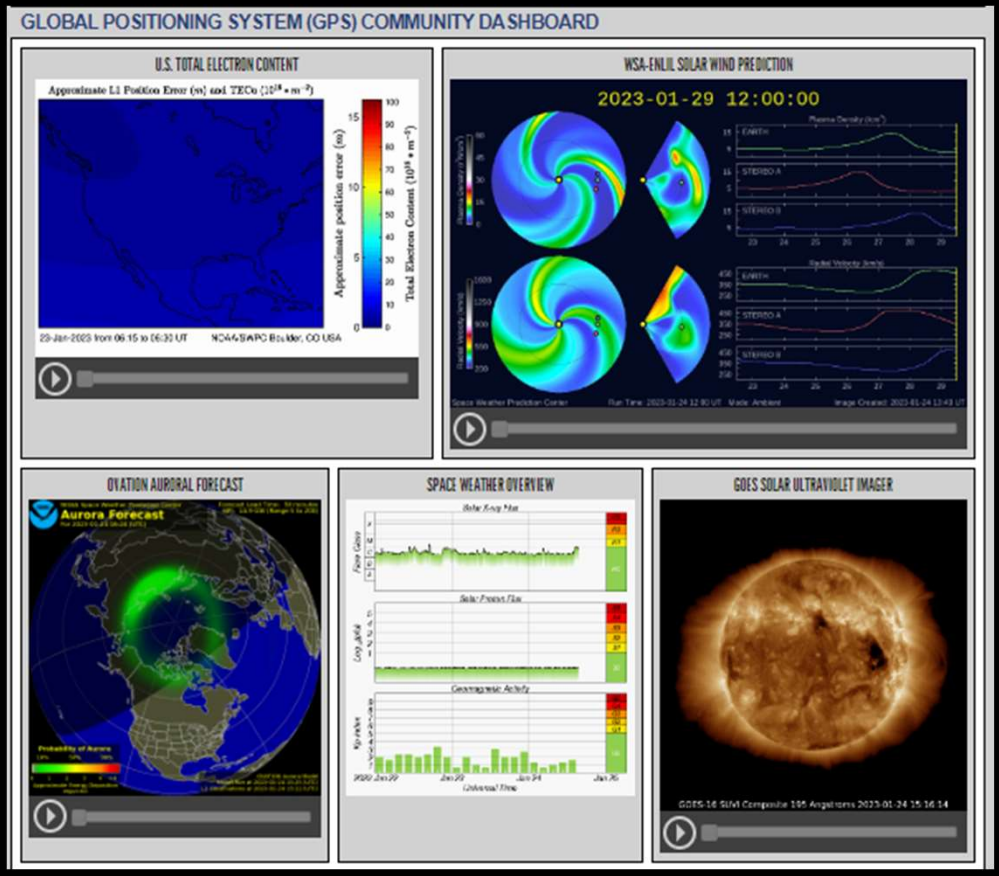


```
:Product: 3-Day Forecast
:Issued: 2024 Feb 11 1230 UTC
# Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
#
A. NOAA Geomagnetic Activity Observation and Forecast

The greatest observed 3 hr Kp over the past 24 hours was 4 (below NOAA
Scale levels).
The greatest expected 3 hr Kp for Feb 11-Feb 13 2024 is 5.67 (NOAA Scale
G2).

NOAA Kp index breakdown Feb 11-Feb 13 2024

             Feb 11       Feb 12       Feb 13
00-03UT       4.33         1.67         4.67 (G1)
03-06UT       3.33         1.33         4.67 (G1)
06-09UT       3.67         1.33         4.67 (G1)
09-12UT       3.00         3.67         5.67 (G2)
12-15UT       3.33         3.00         4.67 (G1)
15-18UT       3.67         3.00         4.33
18-21UT       3.67         4.00         4.00
21-00UT       4.67 (G1)    5.00 (G1)    3.67

Rationale: Periods of G1 (Minor) geomagnetic storms are likely on 11-13
with G2 (Moderate) likely on 13 Feb due to the anticipated arrival of
multiple CMEs.
```

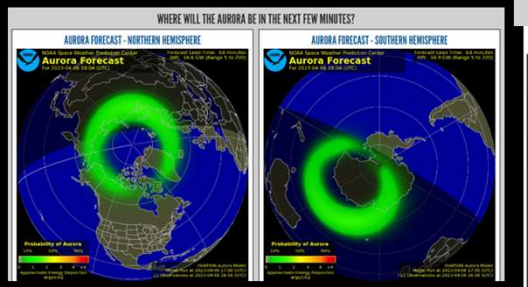
Webpage: **swpc.noaa.gov**

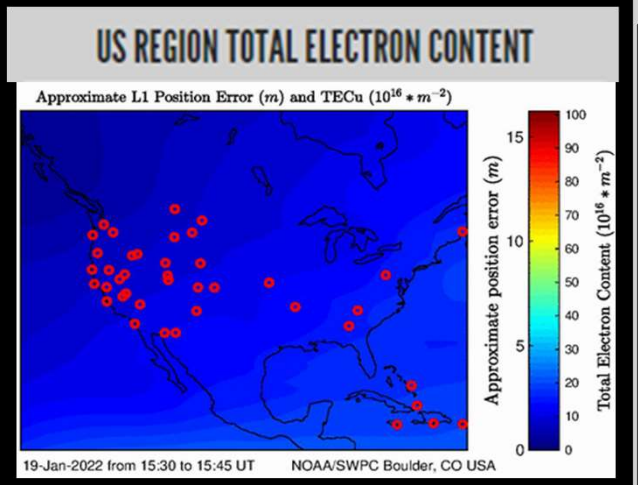
SWPC Dashboards for the EM Community

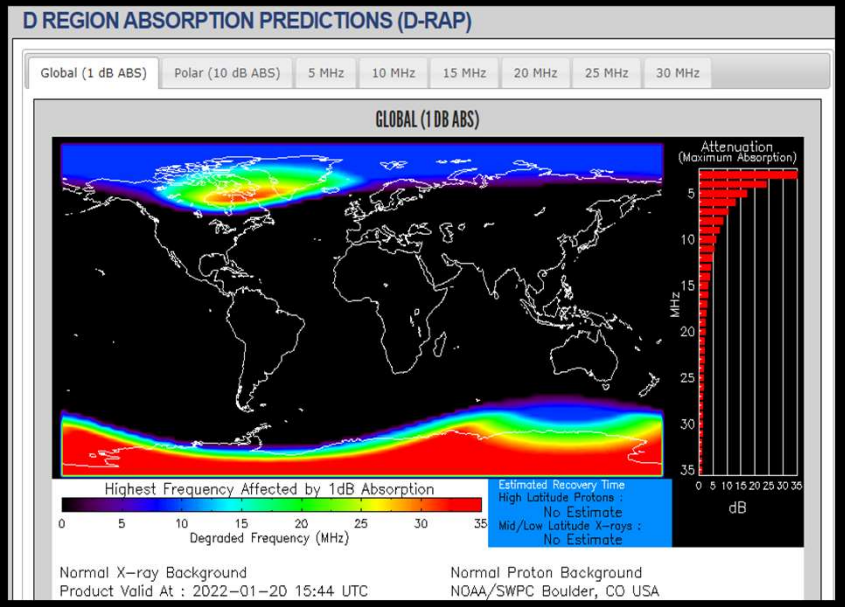


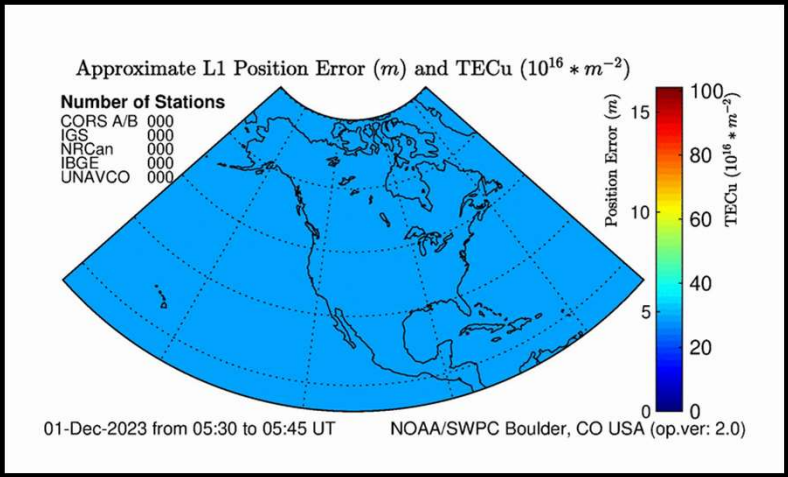


Some Models of Note for EM



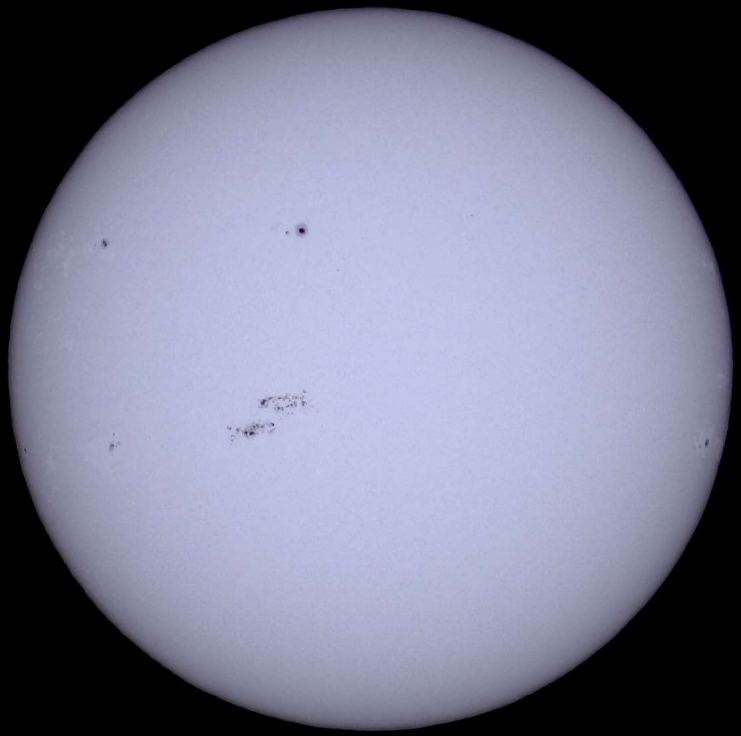


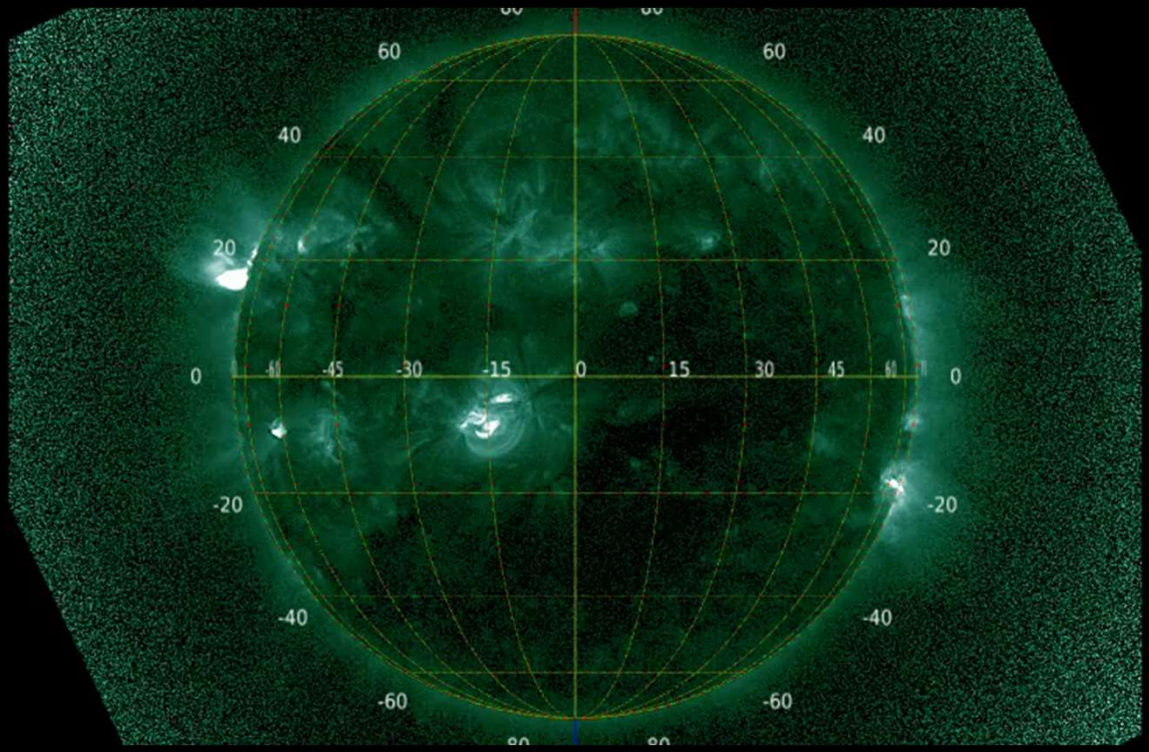




GNSS accuracy mainly single frequency methods - **TEC**
i.e. cell phone navigation, emergency locaters
HF Comm blackouts/degradations - **D-RAP**
i.e. land/marine mobile systems; HAM radio
GIC induced current on power grid – **Geoelectric Model**

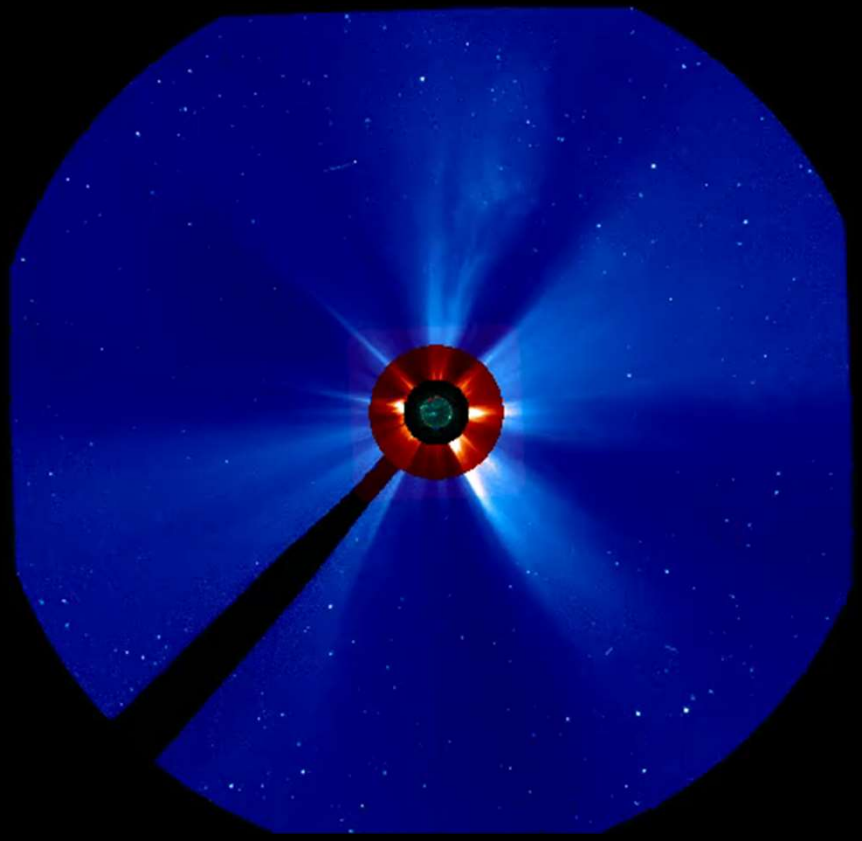
22 March 2024 – Sunspots/Flares





Massive and magnetically complex active region sunspot group to the south and a much smaller and moderately complex active region sunspot group to the north. The northern spot group erupted with an X1 (R3) long duration flare (few hours). The southern group also flared shortly afterwards. SWPC forecasters made calls to NASA and Oakland ATC when flare activity reached M5 (R2).

22-23 March 2024 – CME/Radiation Storm



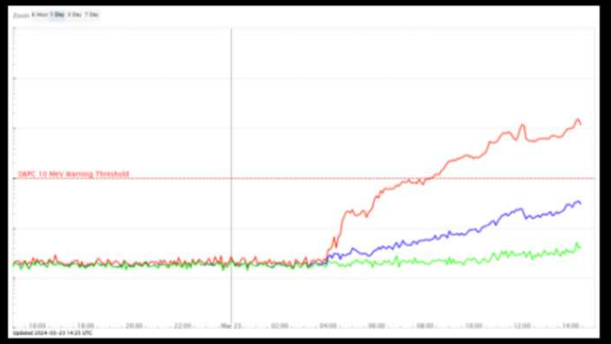
MODERATE Solar Radiation Storm Event S2

WHAT: A Solar Energetic Particle Event is in Progress

EVENT:
The greater than 10 MeV proton flux became enhanced following an X1.1 flare at 23/0133 UTC. Solar radiation storms at S1-S2 (Minor-Moderate) levels have been observed.

TIMING:
S1 (Minor) levels were observed beginning at 23/0815 UTC, and S2 (Moderate) levels began at 23/1405 UTC.

EFFECTS:
Degradation to HF communications in the polar regions; possible risk to space launch and satellites; high flying interests along polar routes should monitor the situation for updates. The general public need not be concerned.



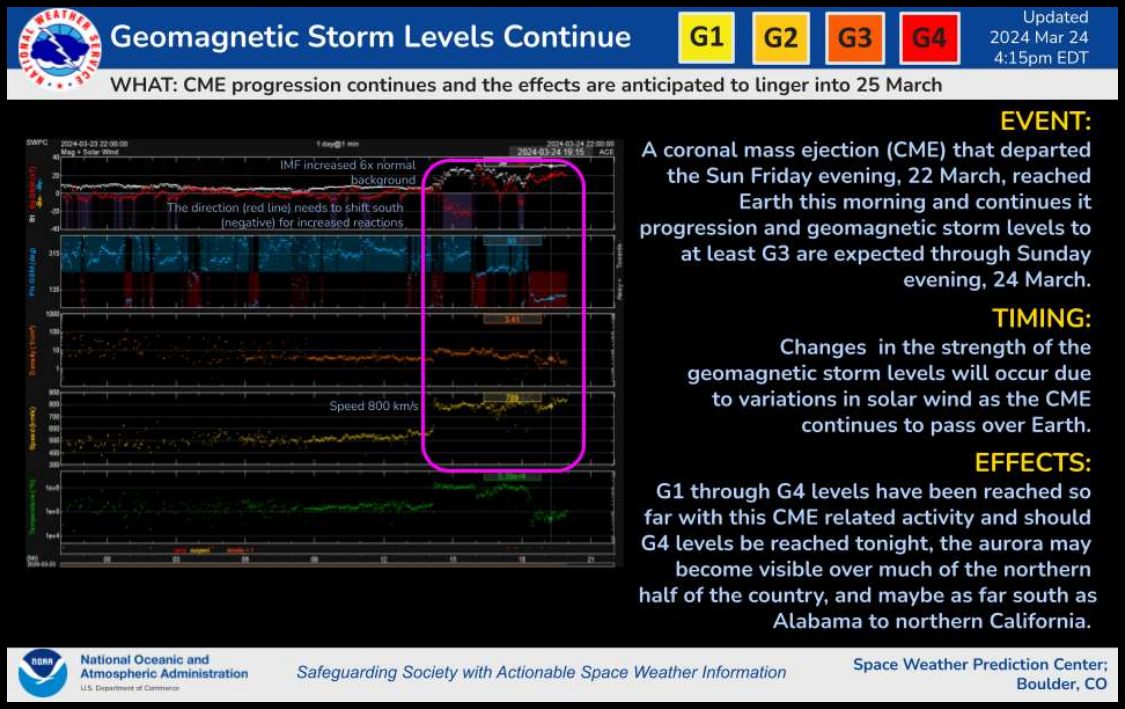
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

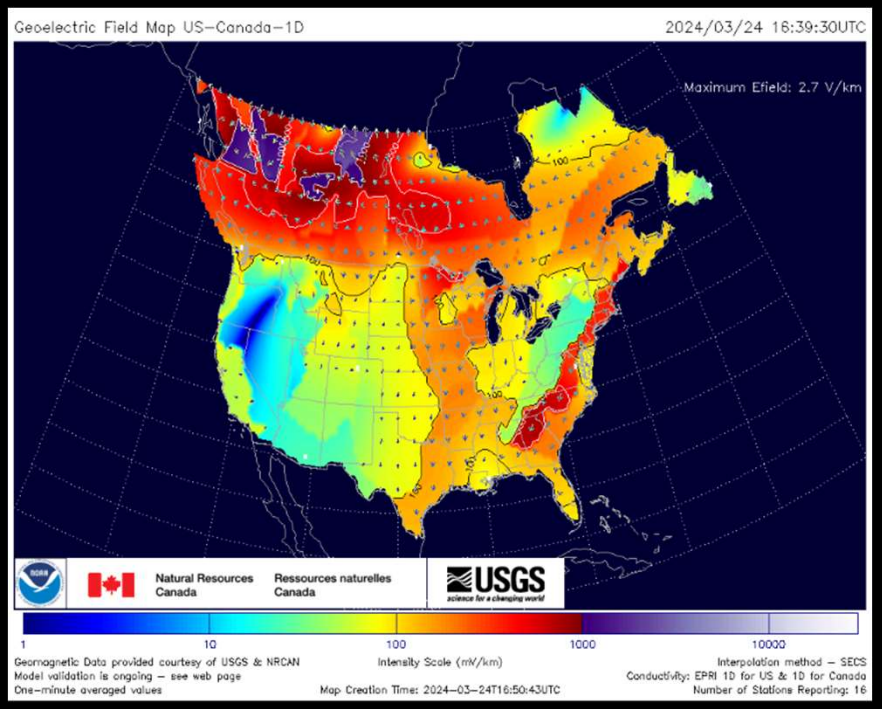
Safeguarding Society with Actionable Space Weather Information

Space Weather Prediction Center; Boulder, CO

Several hours later, energetic particles (protons) arrive at GOES-16/18. SWPC forecasters call NASA/SRAG among others. About 6 hours later, imagery from the NASA coronagraph at L1 (1 million miles from Earth) captures the associated CME departing the Sun. It is a full halo and SWPC forecasters begin analyzing and modelling the CME for anticipated Earth arrival timing and intensity. Speed over 1000 km/s (fast)

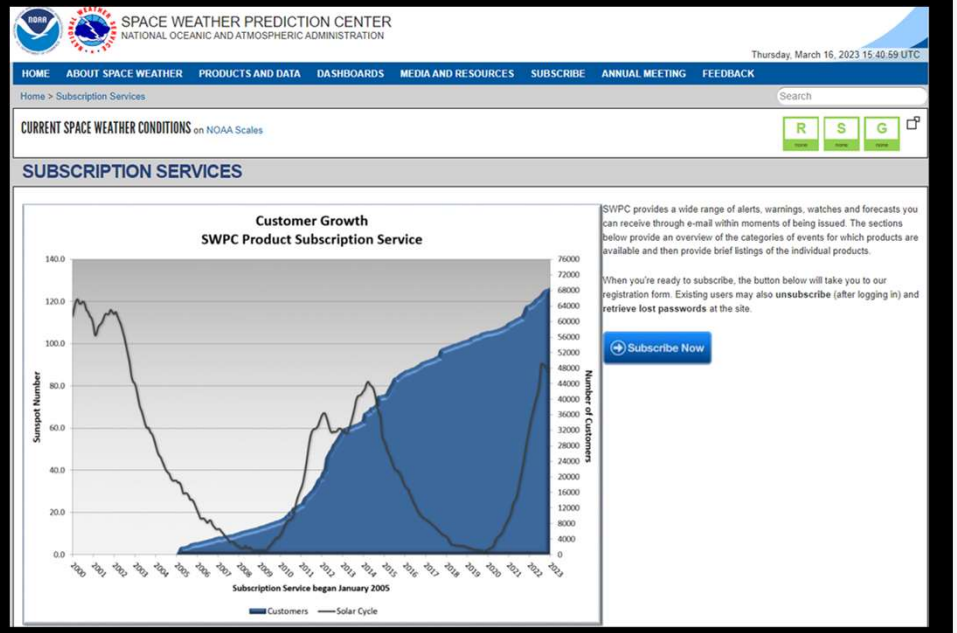
24 Mar - Geomagnetic Storms

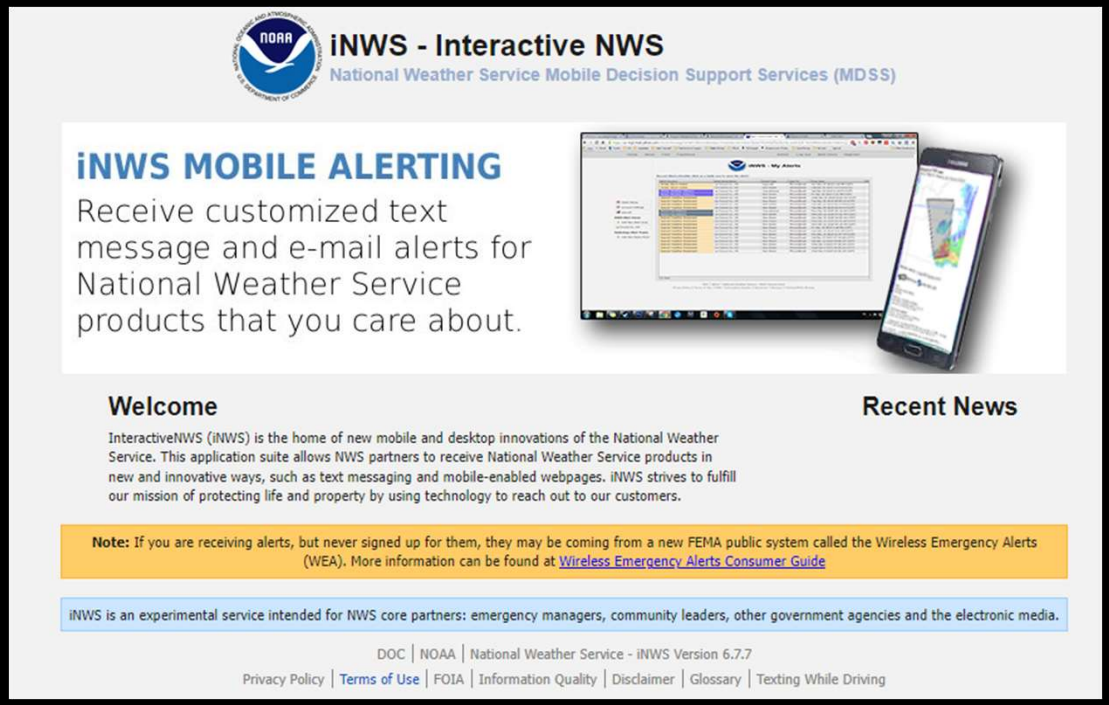




CME shock arrives at L1 as observed by DSCOVR/ACE spacecraft. SWPC forecasters issue Sudden Impulse warning for benefit of the power grid. Decent SI observed less than 30 minutes later. Geomagnetic responses rapidly escalate and SWPC forecasters begin calling specific transmission operation centers, Oakland ATC, NASA/SRAG, NWS SOC. At G3 (NERC Hotline Call), at G4 – FEMA WOC and Denver MOC contacted.

How to **GET** Informed





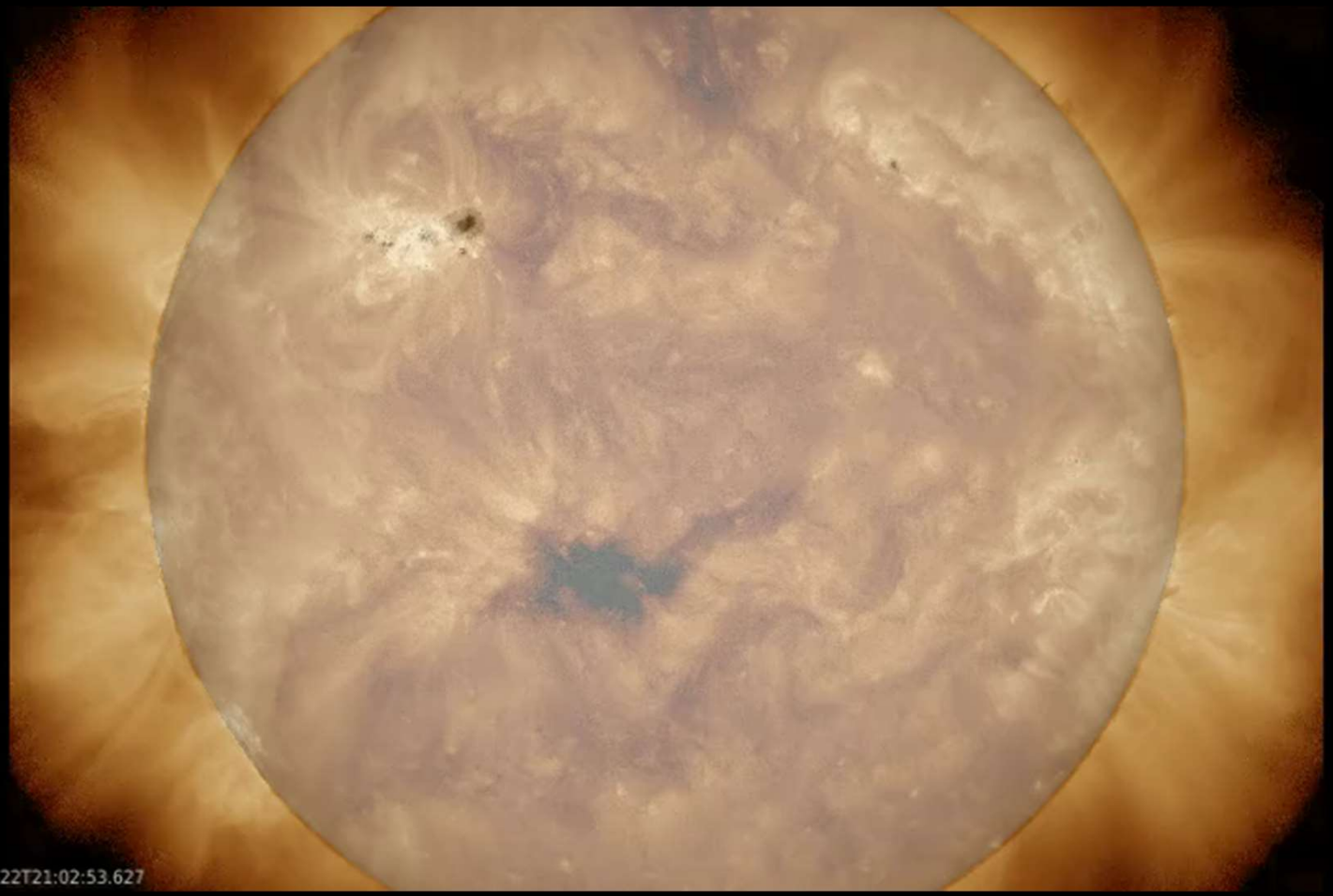
SWPC PSS for direct emails of many various products and WWA

*NWS INWS for direct text messages and/or emails of primary WA

*experimental service intended only for NWS core partners, EMs, and other government agencies

Feb 22nd – X6 flare (R3): Largest of Solar Cycle 25 thus far

Large and complex sunspot group Region 3590 over northeast area of the Sun (top left) erupted with an X6 flare on 22 Feb.

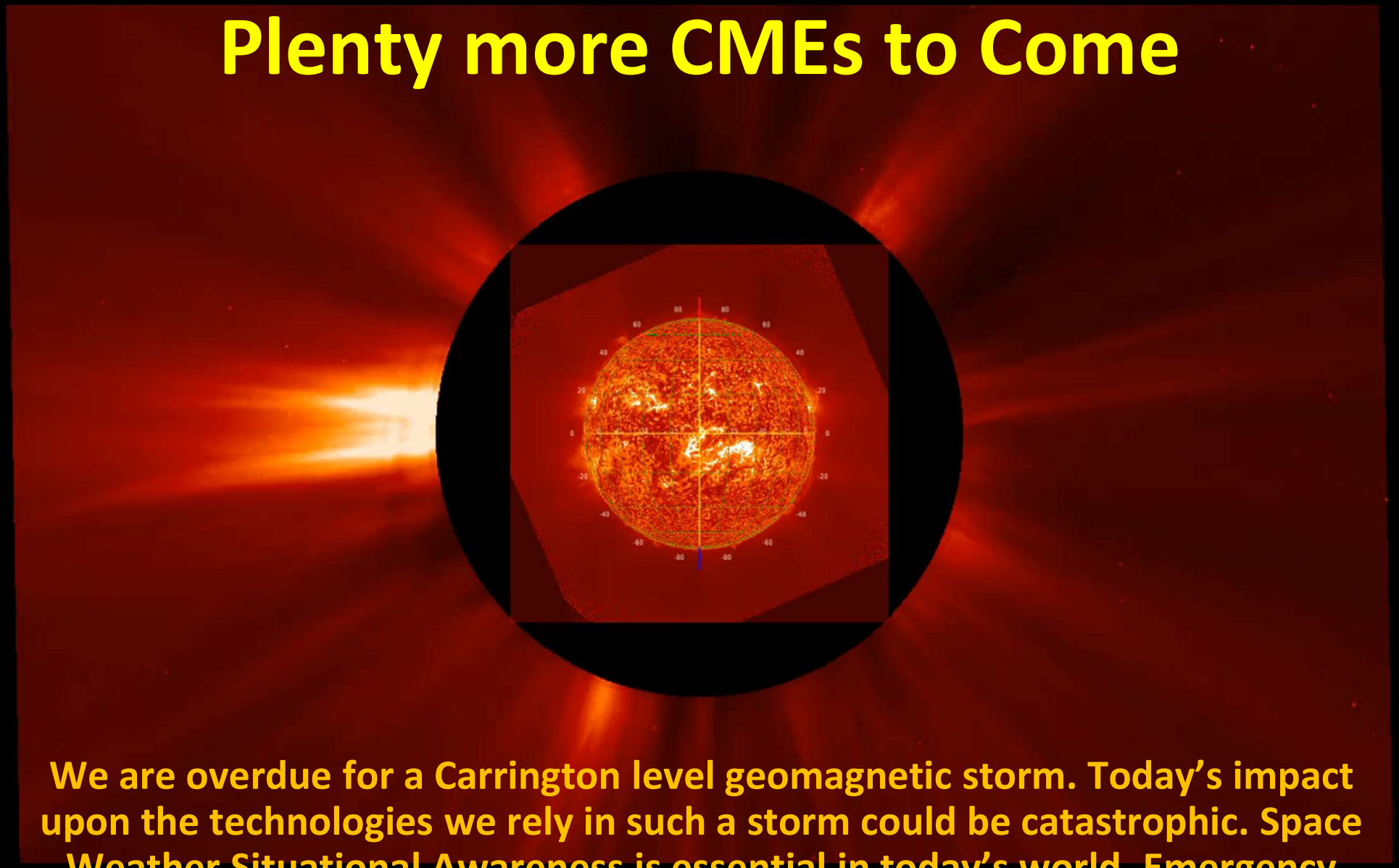


This animation blends imagery we use from the NASA SDO satellite to look at sunspots and also the lower corona. So you can see the flare erupt in relation to a very tight and magnetically complex area of Region 3590.

All animations courtesy of jehlioviewer

Quite surprisingly, this flare and the other R3 events over two days did not have any associated CME

Solar Maximum is Coming
Plenty more CMEs to Come



We are overdue for a Carrington level geomagnetic storm. Today's impact upon the technologies we rely in such a storm could be catastrophic. Space Weather Situational Awareness is essential in today's world. Emergency Preparedness and Readiness is necessary for such and extremely impactful event. You are all KEY in our shared protection of lives & property mission!

Thank You. And Thank You again for all you do!

POC for your space weather questions or needs

Shawn Dahl – SWPC Service Coordinator
shawn.dahl@noaa.gov

NOAA SWPC SPACE WEATHER PREDICTION CENTER

Additional Training and Resources:

https://emilms.fema.gov/is_0066/

https://www.fema.gov/sites/default/files/2020-07/fema_incident-annex_space-weather.pdf

https://www.swpc.noaa.gov/content/education-and-outreach

"Safeguarding Society with Actionable Space Weather Information"