



Enhancing National Resilience to the Effects of Space Weather



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Program Coordinator
Space Weather Prediction Center
National Weather Service
National Oceanic and Atmospheric Administration

Mile High Dice
9 Nov 2022

Overview



- Growing need for space weather services
- Space weather types and their impacts
- Extreme space weather events
- Federal Government response

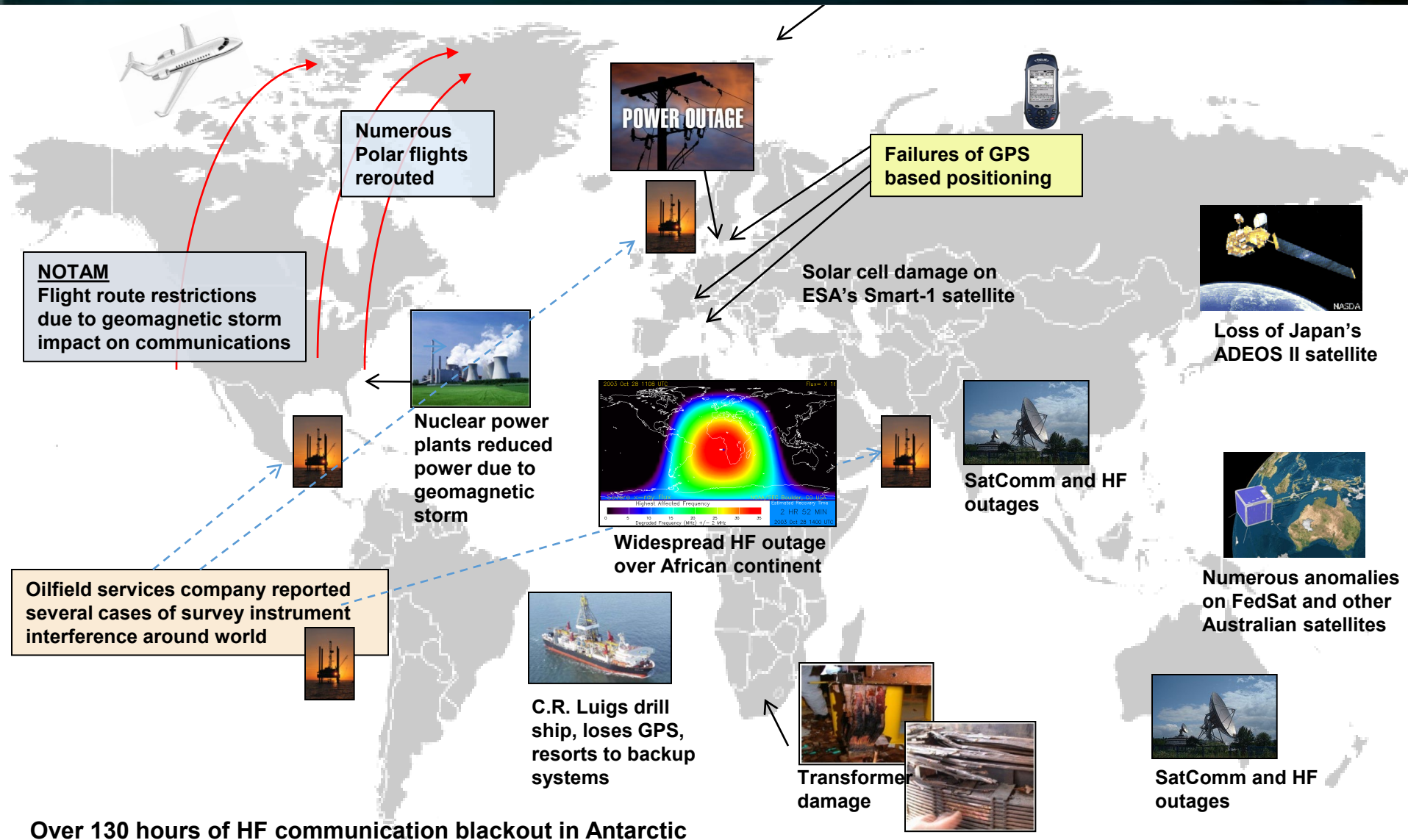
Space Weather affects most critical infrastructure sectors - Impacts security, national economic security, and national public health and safety



Growing interdependencies across critical infrastructure systems have increased the potential vulnerabilities to space weather

Space Weather – Global Impacts

October 2003



Feb 2022 Geomagnetic Storm – Loss of 38 SpaceX Starlink Satellites

3 Feb - Launch of **49 satellites**

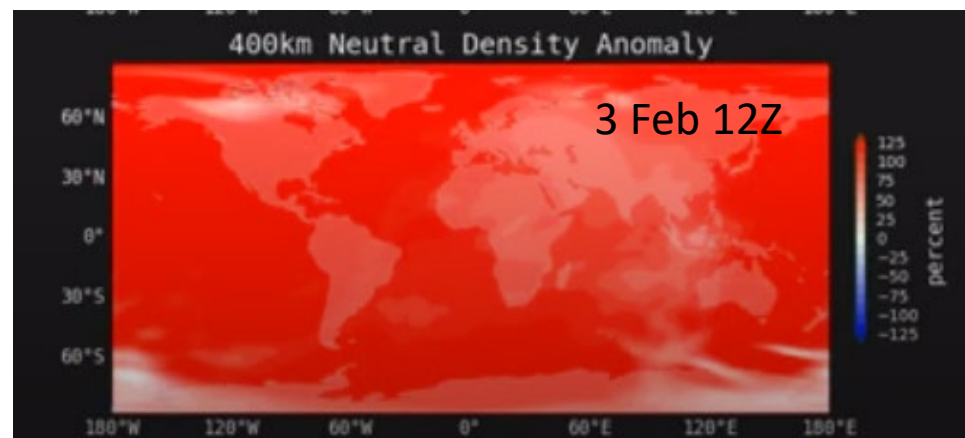
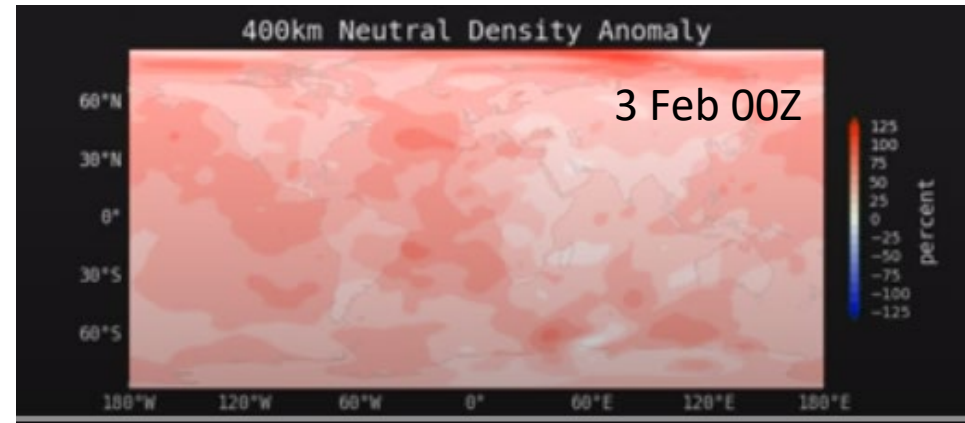
3-4 Feb - **Prolonged Geomagnetic Storm**

SWPC model showed over **100% increase in neutral density** at 400 km

Increased neutral density at Very Low Earth Orbits (VLEO) altitudes **enhanced the atmospheric drag** on the Starlink satellites

- Unable to complete orbit raise resulting in atmospheric re-entry and loss of 38 satellites

Economic losses between **\$12-24M**



Uses of Space Weather Watches and Warnings

Space Operations

- Postpone launch of satellite
- Turn off/safe instruments and/or spacecraft in orbit

Electric Power Grid

- Adjust/reduce system load
- Disconnect components
- Postpone maintenance

Airlines

- Divert polar flights
- Change altitude

GPS/Navigation

- Postpone activities
- Redo survey
- Use backup systems



SPACE

Sep 2017

How a Solar Flare Amped Up Chaos of Hurricane Irma

By Meghan Bartels July 31, 2018

Mar 2012

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

by Karl Bode Friday 16-Mar-2012 tags: satellite · business · wireless · alternatives wireless



STARS AND STRIPES Mar 2012

Home News Sports Travel Military Life Opinion Classifieds Rewards Dig

Branches Middle East Europe Pacific U.S. Americas Africa Stripes Central

General: Recent solar storm interfered with Air Force satellite

Nov 2015

NOAA Space Weather Prediction Center

The Nation's official source of space weather alerts, watches and warnings (exclusive of the responsibilities of DOD)

NOAA Space Weather Watches and Warnings are based on the NOAA Space Weather Scales:

Geomagnetic Storms (G-scale)



NOAA Space Weather Scales

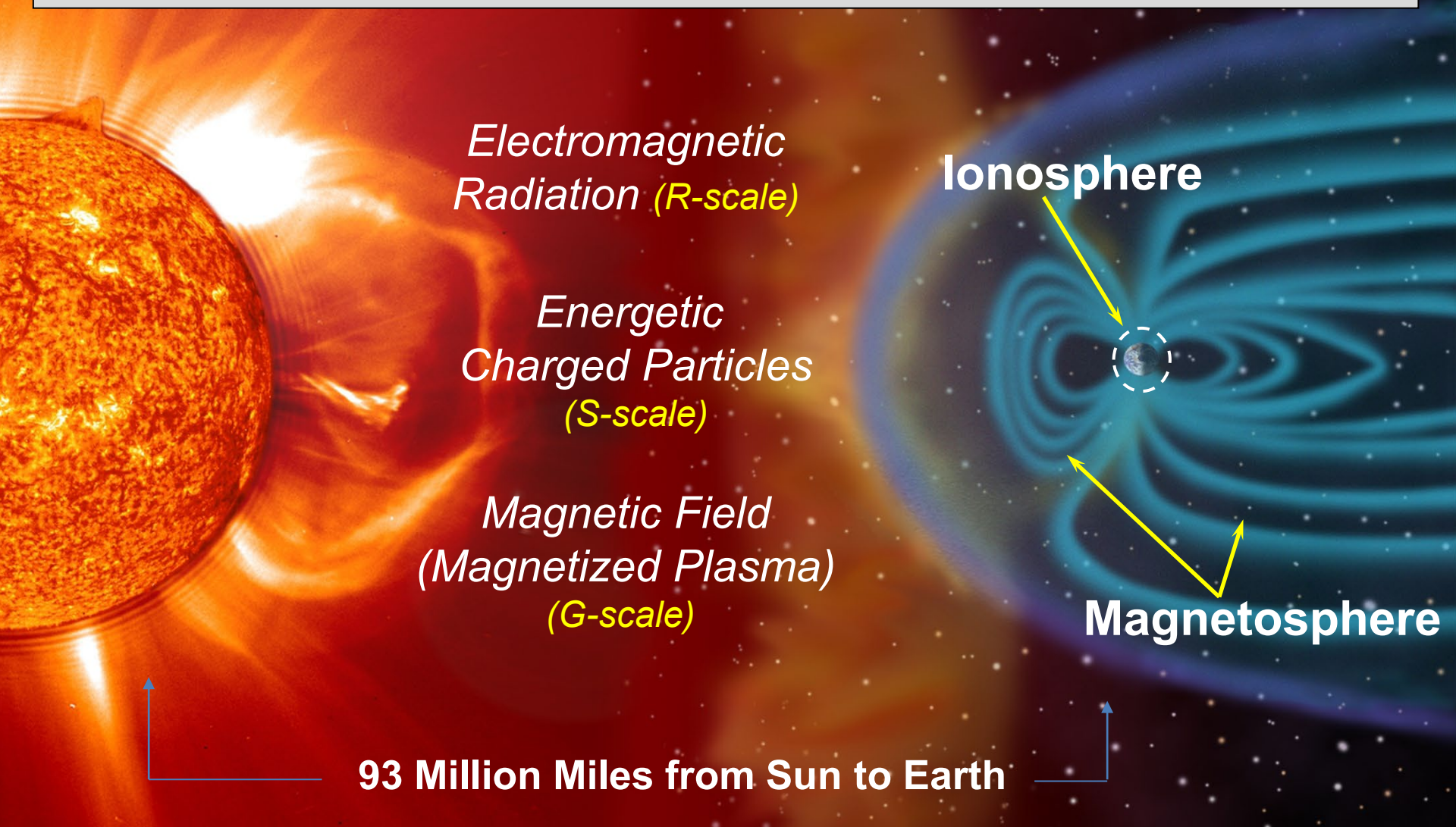
Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms				
G 5	Extreme	<u>Power systems:</u> widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage.	Severe** downward shifted 2 hours	Number of storm events when Kp level was met; (number of storm days) 4 per cycle (4 days per cycle)
		<u>Spacecraft operations:</u> may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. <u>Other systems:</u> 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.)**	Kp=9 Kp=9 Kp=9	
G 4	Severe	<u>Power systems:</u> possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. <u>Spacecraft operations:</u> may experience surface charging and tracking problems, corrections may be needed for orientation problems. <u>Other systems:</u> 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.)**	Kp=8, including a 9- Kp=8 Kp=8	100 per cycle (60 days per cycle)
		<u>Power systems:</u> voltage corrections may be required, false alarms triggered on some protection devices. <u>Spacecraft operations:</u> surface charging may occur on satellite components, drag may increase on low Earth-orbit satellites, and corrections may be needed for orientation problems. <u>Other systems:</u> 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 Florida and southern Texas (typically 40° geomagnetic lat.)**	Kp=7 Kp=7 Kp=7	200 per cycle (130 days per cycle)
G 3	Strong	<u>Power systems:</u> high-latitude power system may experience voltage sags, transformer saturation may cause transformer damage. <u>Spacecraft operations:</u> corrective action to orientation may be required by ground control; possible changes in drag affect orbit predictions. <u>Other systems:</u> HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**	Kp=6 Kp=6 Kp=6	600 per cycle (360 days per cycle)

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	<u>Power systems</u> : widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. <u>Spacecraft operations</u> : may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. <u>Other systems</u> : 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.)**.	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	<u>Power systems</u> : possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. <u>Spacecraft operations</u> : may experience surface charging and tracking problems, corrections may be needed for orientation problems. <u>Other systems</u> : 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.)**.	Kp=8, including a 9-	100 per cycle (60 days per cycle)



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.



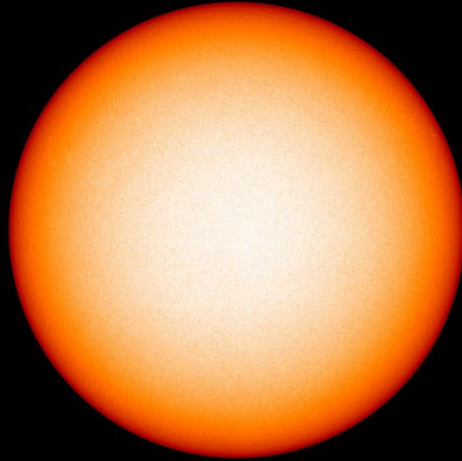
Sunspots



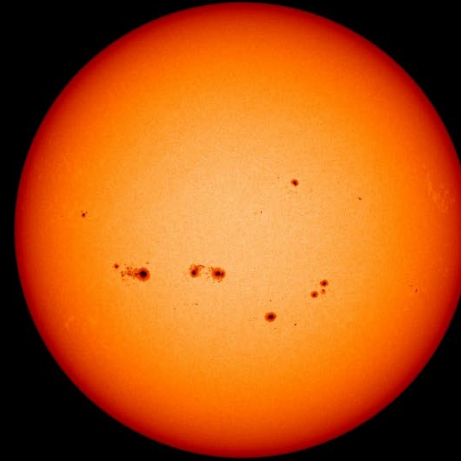
2003/10/20 00:00

The Solar Cycle

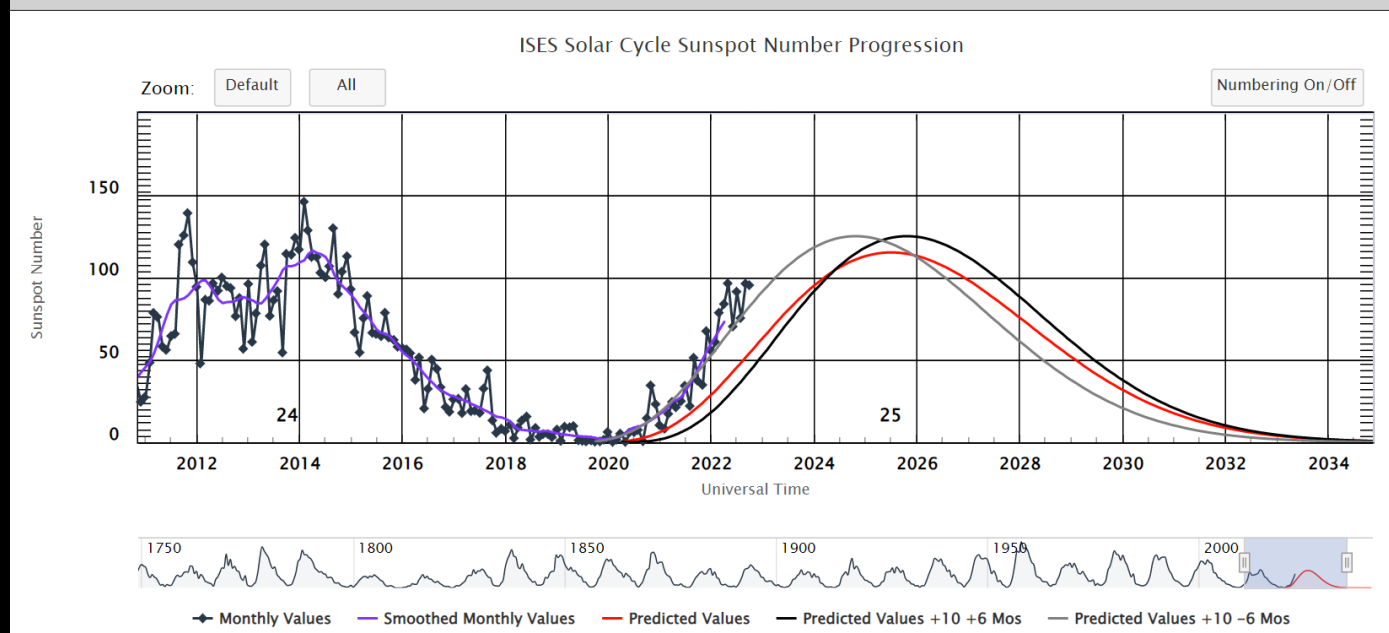
SOLAR MINIMUM



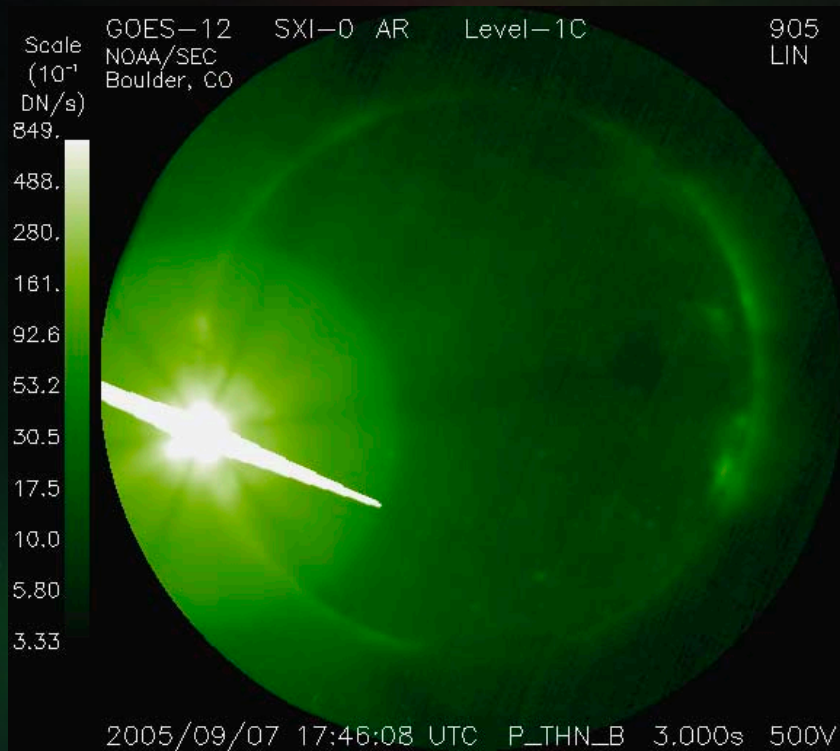
SOLAR MAXIMUM



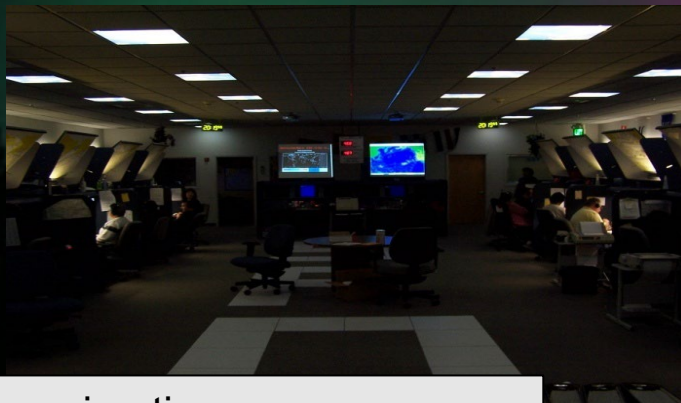
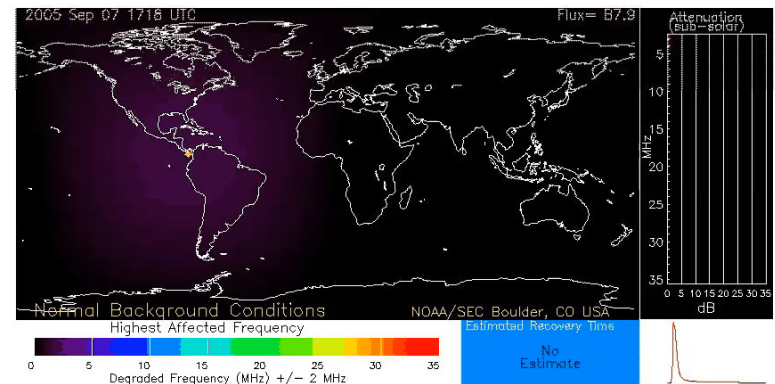
SOLAR CYCLE PROGRESSION



Solar Flares Radio Blackouts (R Scale)



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



- No warning time
- Duration: minutes to 3 hrs

Impacts



GPS Network

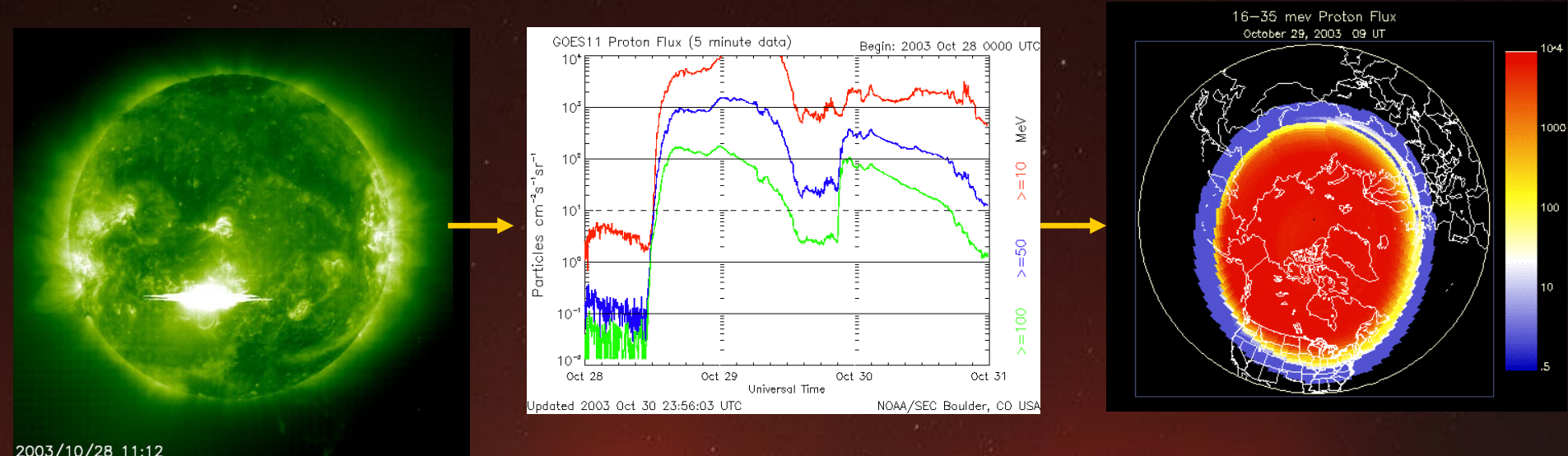


Communications
Ground and Space-based



Radar

Solar Radiation Storms (S Scale)



Impacts...

- Satellite Operations (range from loss of data to loss of satellite)
- Aviation (communications and exposure concerns)
- NASA – Both manned and robotic spaceflight

Warning time – minutes to a few hours
Duration: hours to days

We got lucky!

Apollo 16



Solar Flare 1972 August 07

Big Bear Solar Observatory



Apollo 17



~~(S)~~ As a result of the extensive analytical effort, the Naval Ordnance Systems Command on 5 September advised CINCPACFLT and all others concerned that there was a high degree of probability that all the sensitive and some insensitive DSTs seeded in NVN waters had been detonated by the solar storm activity in early August.

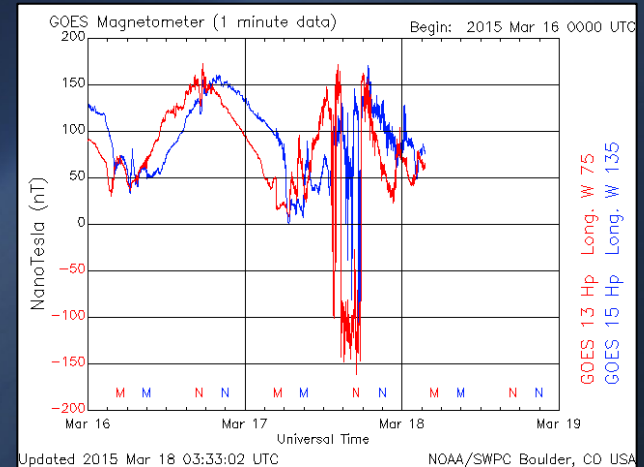
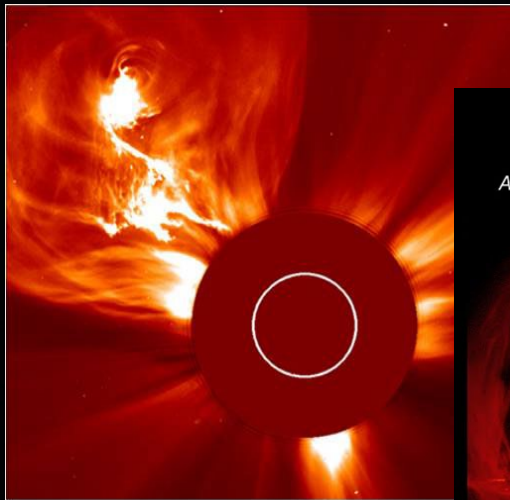
Declassified: excerpt from U.S. Navy Report, Mine Warfare Project Office - The Mining of North Vietnam, 8 May 1972 to 14 January 1973. (Knipp et al, Oct 2018)

SPACE A Solar Storm Detonated U.S. Navy Mines During the Vietnam War

Inclement space weather caused dozens of the sea bombs to explode, recently declassified documents reveal

Geomagnetic Storms (G-Scale)

Coronal Mass Ejections (CMEs) create geomagnetic storms

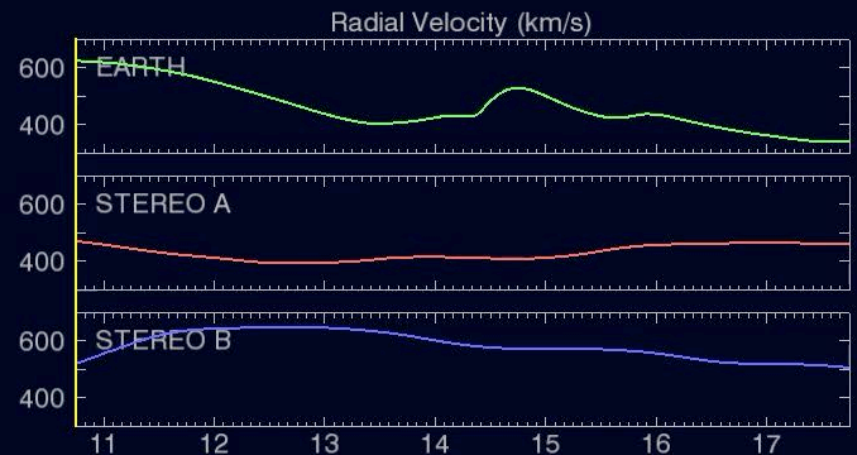
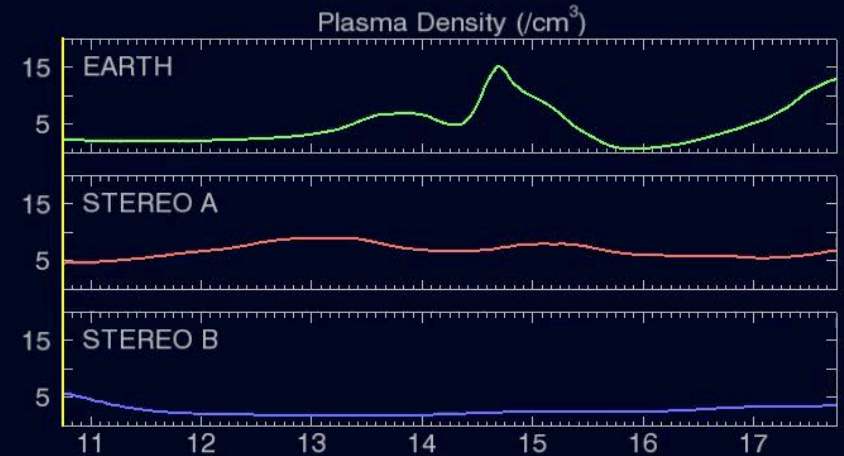
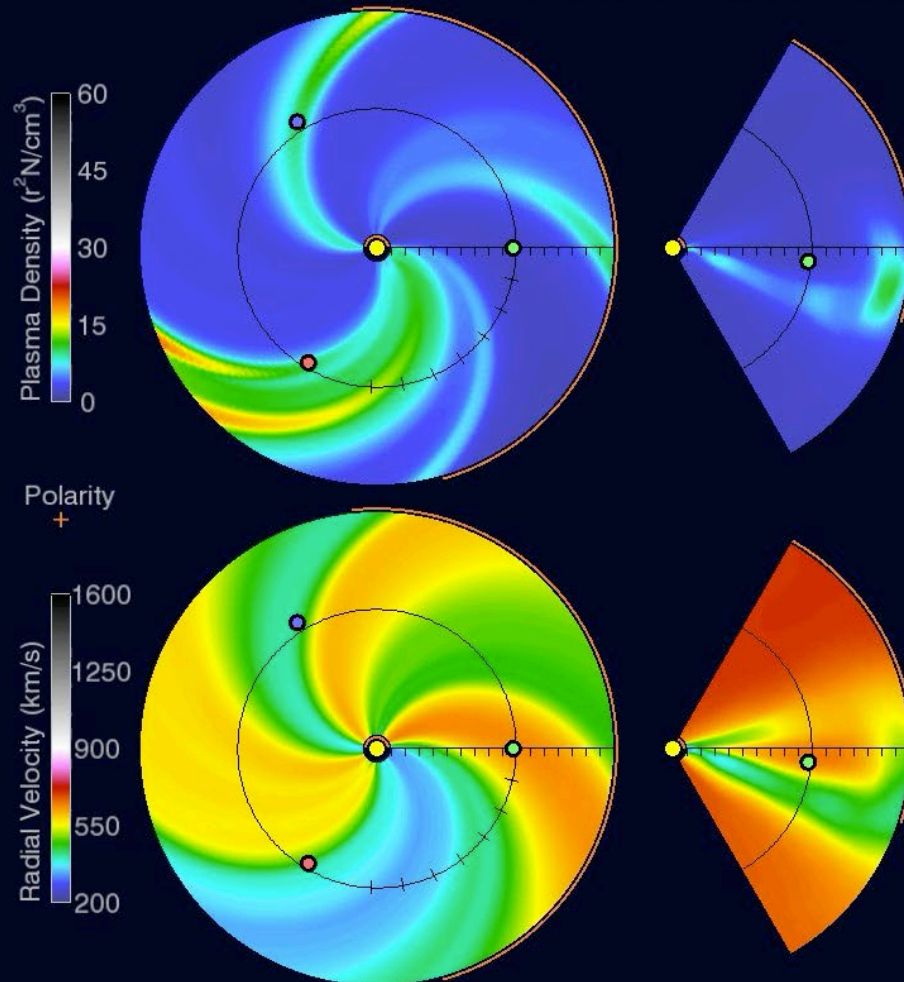


Impacts:

- Electric Power Grid
 - Communications: Ground and Space-based
 - GPS Systems
 - Satellite operations
 - Pipelines
- CME Sun-Earth transit: ~15 – 100 hours
 - Geomagnetic storm duration: Hours to a day or two
 - Creates ionospheric storms, geomagnetically induced currents, aurora



2018-02-10 18:00:00



Space Weather Prediction Center

Run Time: 2018-02-12 18:00 UT Mode: CME

Image Created: 2018-02-12 19:21 UT

Wang-Sheeley-Arge (WSA)-Enlil Solar Wind Prediction Model



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



Transformer winding failure

Vulnerability of US grid

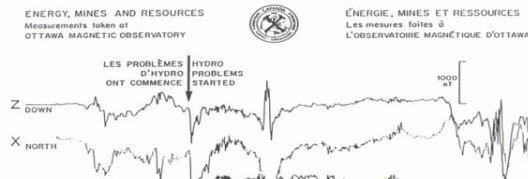
- Northern latitude (location of aurora during geomagnetic storms)
- Areas of relatively high resistive igneous rock
- Very high voltage interconnected transmission network
- Proximity to oceans (conductivity of ocean salt water)

HYDRO-QUEBEC PRESS RELEASE

Direction Relations Publiques
HYDRO-QUEBEC
MONTREAL, CANADA

MARCH 13 BLACKOUT CAUSED BY AN EXCEPTIONALLY STRONG MAGNETIC STORM

Montreal, March 15, 1989 - Hydro-Quebec confirms that the March 13 blackout was caused by the strongest magnetic storm ever recorded since the 735-kv power system was commissioned. At 2:45 AM the storm, which resulted from a solar flare, tripped five lines from James Bay and caused a generation loss of 9,450 MW. With a load of some 21,350 MW at that moment, the system was unable to withstand this sudden loss and collapsed within seconds, thereby causing the further loss of generation from Churchill Falls and Manio-Outardes.



Information Notice No. 90-42:

FAILURE OF ELECTRICAL POWER EQUIPMENT DUE TO SOLAR MAGNETIC DISTURBANCES

Specific events occurred at the Three Mile Island Unit 1, Hope Creek Unit 1, and Salem Unit 1 nuclear power plants. ...inspection of the generator step-up transformer... severe overheating, melted low-voltage service connections in phases A and C, and insulation discoloration in phase B. On September 19, at Salem Unit 2 nuclear power plant, a second solar storm damaged the generator step-up transformer. Sep 1990

Significant grid problems have occurred...



Department of Homeland
Security
Information Analysis and
Infrastructure Protection
Daily Open Source
Infrastructure Report
for 03 November 2003

Energy Sector

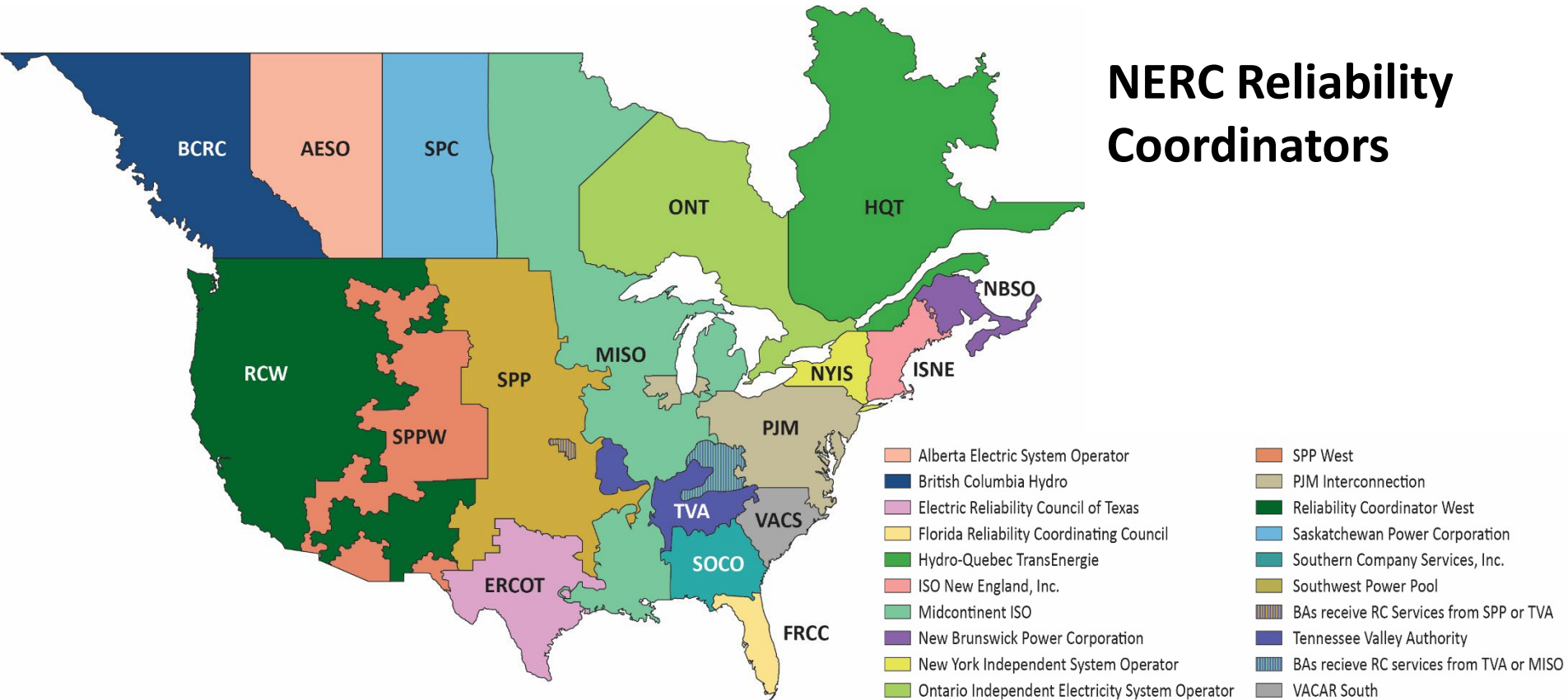
Current Electricity Sector Threat Alert Levels: **Physical:** Elevated, **Cyber:** Elevated
Scale: LOW, GUARDED, ELEVATED, HIGH, SEVERE [Source: ISAC for the Electricity Sector (ES-ISAC) - <http://esisac.com>]

Current Nationwide
Threat Level is
ELEVATED
SIGNIFICANT RISK OF
TERRORIST ATTACKS
[For info click here](http://www.whitehouse.gov/homeland)
www.whitehouse.gov/homeland

October 31 - Sun storm causes problems for Swedish power system. The solar storm has caused technical glitches in Sweden's power system in the past few days and may be to blame for a blackout that affected 50,000 people on Thursday, October 30.

Space Weather Event Alert & Notification – Power Grid

- SWPC provides warnings to Reliability Coordinators through the North American Electric Reliability Corporation (NERC) Hotline



NERC is the electric reliability organization for North America, subject to oversight by the Federal Energy Regulatory Commission and governmental authorities in Canada

Space Weather Event Alert & Notification – Emergency Response

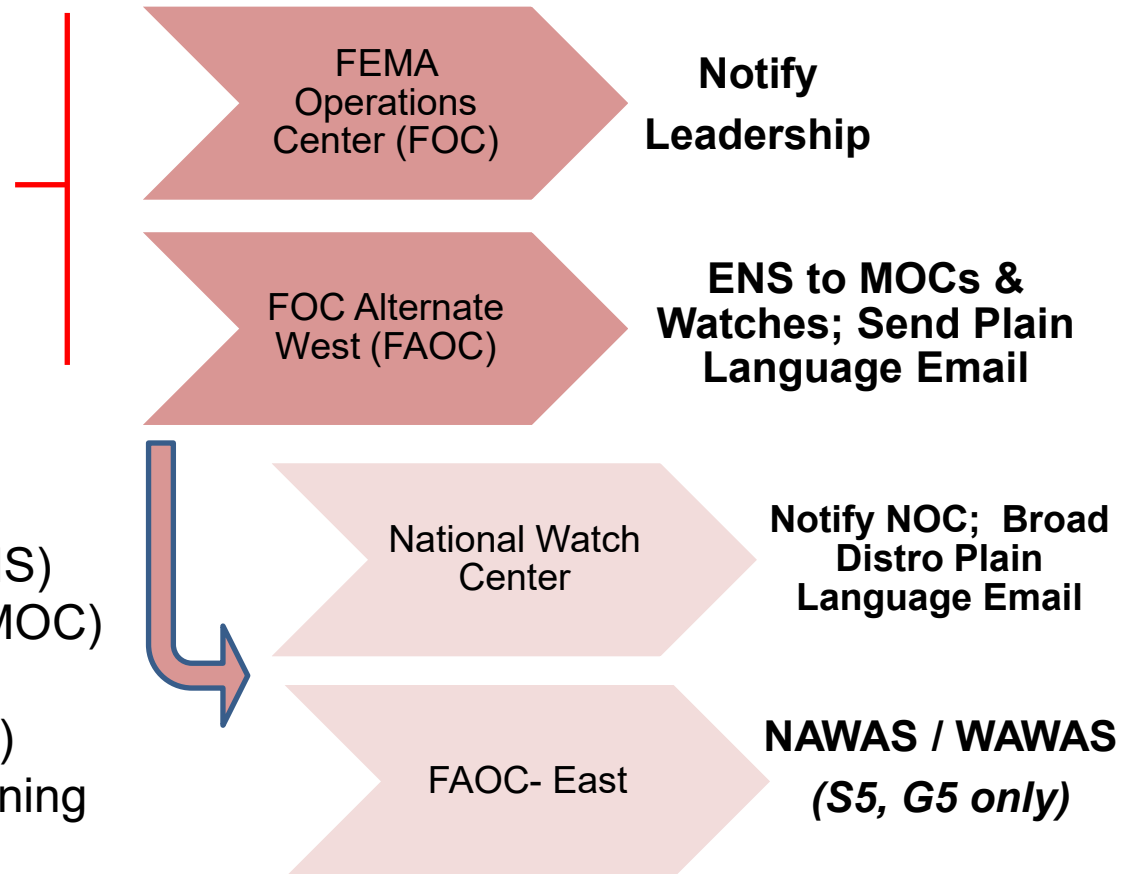


- Directly or indirectly cause or exacerbate a major disaster or emergency.
- Interfere with or seriously degrade FEMA's response & recovery capability.

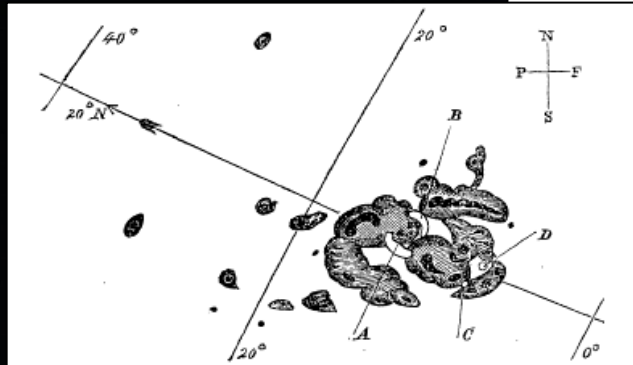
S4-S5 Radiation Storms

G4-G5 Geomagnetic Storms

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



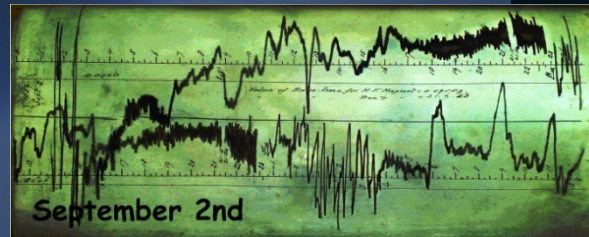
Extreme Events: Carrington – Sep 1-2, 1859



Description of a Singular Appearance seen in the Sun on September 1, 1859. By R. C. Carrington, Esq.

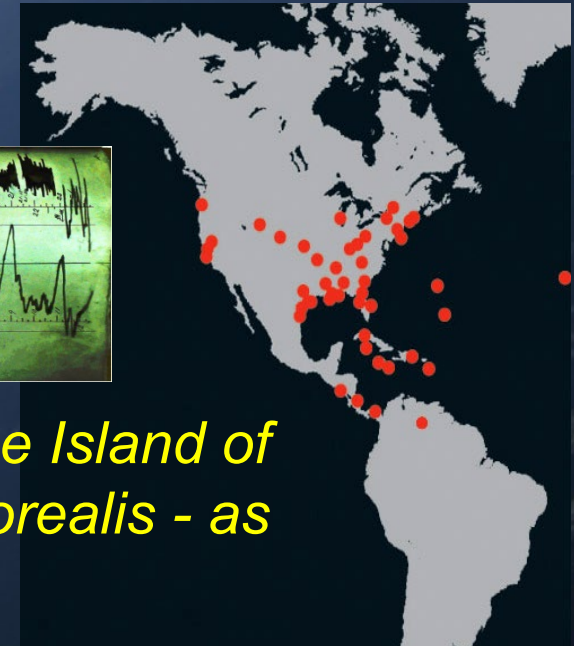
While engaged in the forenoon of Thursday, Sept. 1, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare. The image of the sun's disk was,

~18 hours later...



“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



Visible Aurora, Sep 2

23 July 2012 – Near miss

Powerful solar flare on
23 July, 2012

SPACE.com

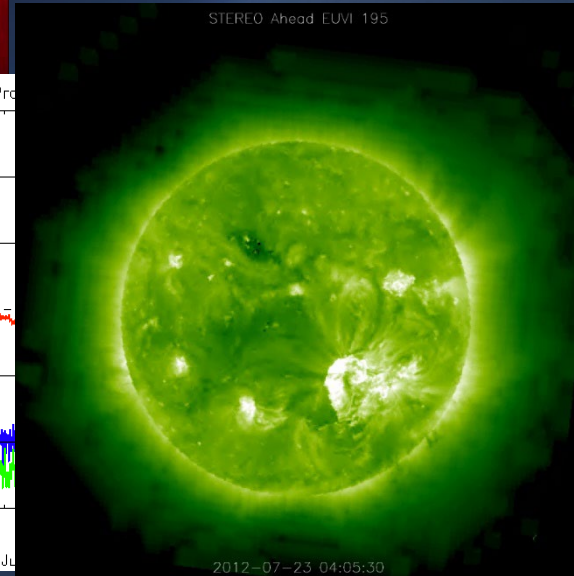
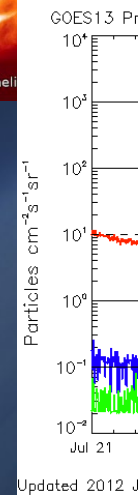
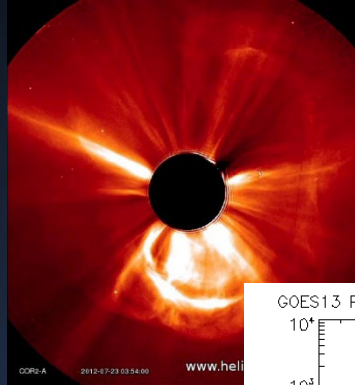
News Tech Spaceflight Science & Astronomy Search For Life

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Huge Solar Storm of 2012 Would Have Sparked Calamity on Earth

By Elizabeth Howell July 29, 2014 Science How a solar storm two years ago nearly caused a catastrophe on Earth

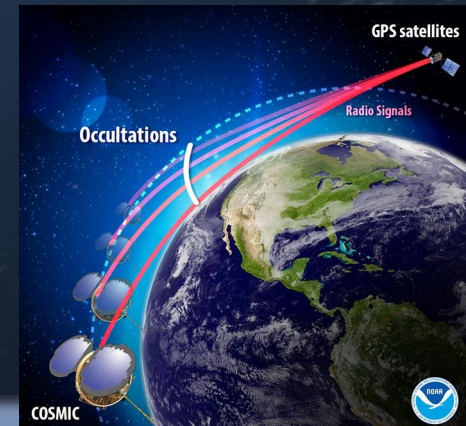
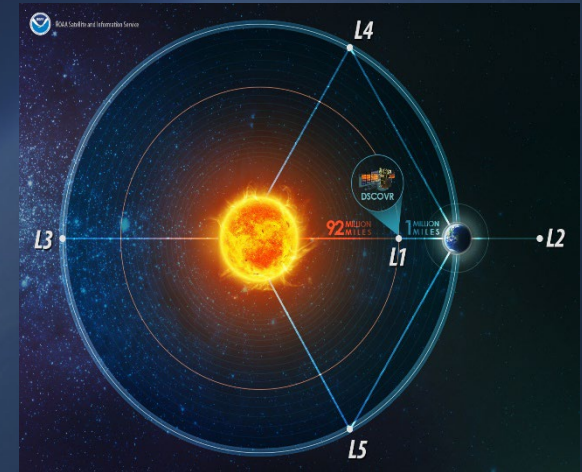
BY JASON SAMENOW July 23 at 3:48 pm



“Using a well-proven geomagnetic storm forecast model, we find the 23-24 July event would have produced a geomagnetic storm that was comparable to the largest events of the 20th Century.” *Baker et al. 2012*

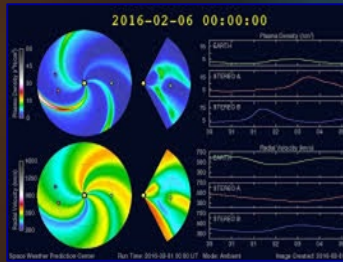
NOAA Response – Future observation commitments

- Future L1: Space Weather Follow On (SWFO) 2025; NOAA operational mission to fly coronagraph and solar wind monitor in rideshare with NASA Interstellar Mapping and Acceleration Probe (IMAP)
- European Space Agency (ESA) and NOAA partnership being explored for coordination (with ESA going to L5 and NOAA to L1)
- COSMIC-2A - six satellites in low-inclination orbits launched in June 2019
 - Providing ~8,000 radio occultation (RO) measurements daily
 - NOAA also acquiring commercial RO data operational use



Operational Space Weather Modeling at NOAA – A Sun-to-Earth Continuum

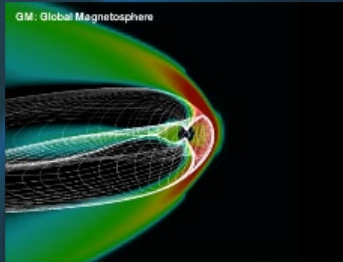
Operational 2011
Upgraded 2019



GMU/AFRL
WSA/Enlil

Predict and understand the structure of the solar wind as it propagates from the Sun to Earth

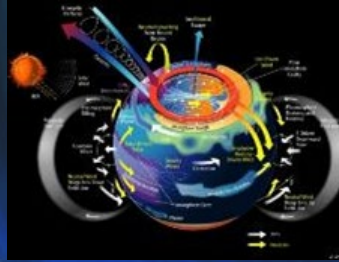
Operational 2016
Upgraded Feb 3
2021



U. Michigan
Geospace

Predict and understand the geomagnetic response to changes in solar wind; provide regional predictions of geomagnetic storms

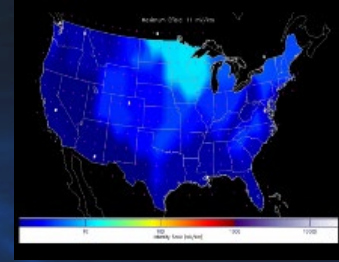
Operational
Transition Begins
March 5, 2021



NOAA/CIRES
WAM-IPE

Predict and understand details in the mesosphere, exosphere, and ionosphere, to understand links between the lower and upper atmosphere

3D Operational
Sept 2020



NOAA/USGS
E-field

Characterize and predict the regional electric field and the associated currents that impact electric power grids

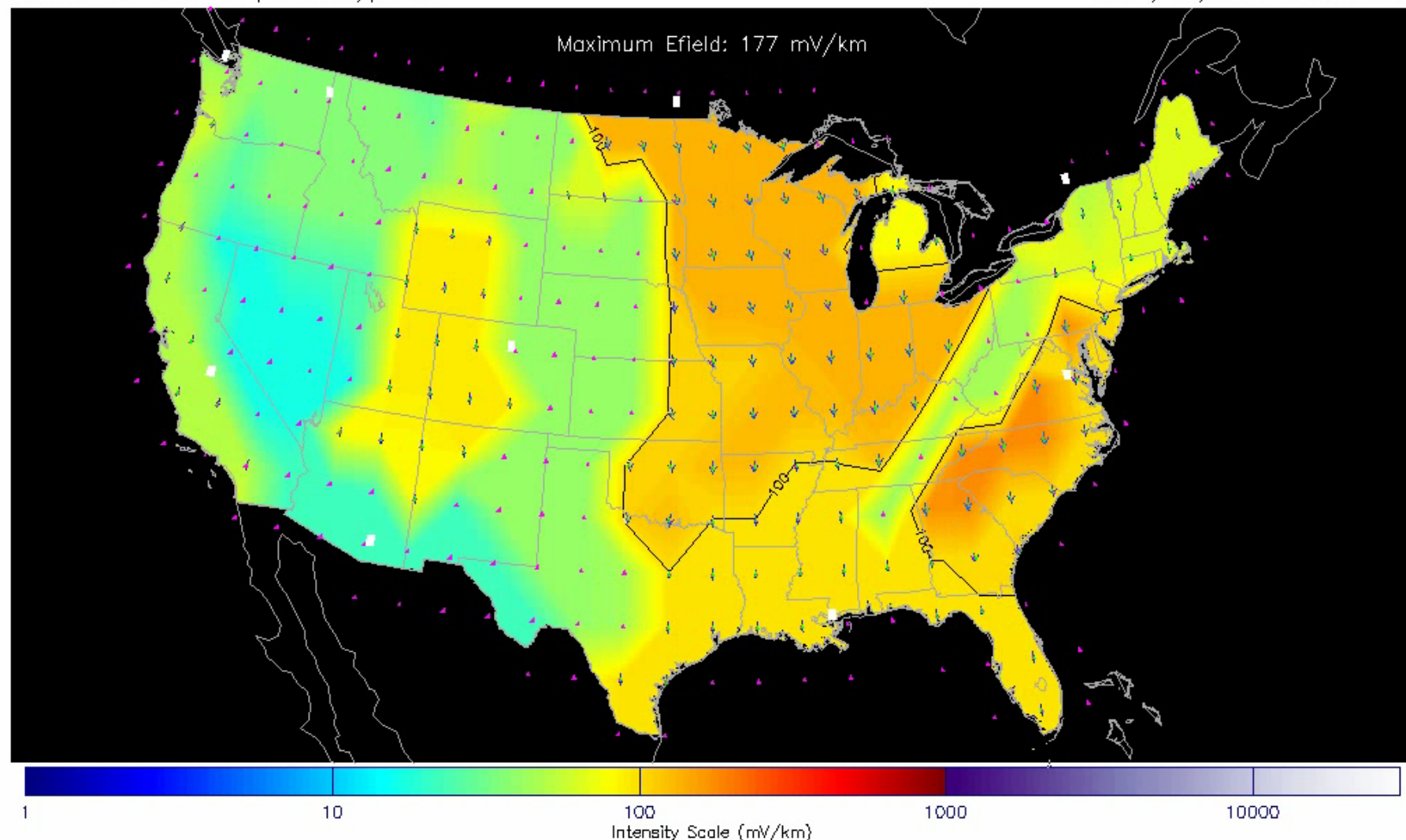
The space weather community working together on a modeling framework that captures critical domains of the Sun-Earth system, beginning at the Sun and ending at Earth's surface.

Supporting a space weather watch/warning paradigm similar to terrestrial weather.

Joint NOAA-USGS Geoelectric Field Model

Geoelectric Field Map Prototype V6

1989/03/13 01:29:30UTC



One-minute averaged values — 2×2 degree grid

Map Creation Time: Simulation UTC

Number of Stations Reporting: 9

Energy Sector

In response to new government directives, grid owners must:

- Develop plans and implement operator action in response to geomagnetic storms
- Perform vulnerability assessments and develop corrective actions as necessary to address the threats

DOE conducting pilot demo to test neutral blocking devices (to block geomagnetically induced currents) at the power grid of the federally owned Tennessee Valley Authority (TVA)

FEMA CONOPS for Space Weather

Outlines the necessary actions departments and agencies should take to prepare for, and respond to, a notification of an impending space weather event



IS-66: Preparing the Nation for Space Weather Events Independent Study course is available at FEMA Emergency Management Institute as of 9/19/2022

FEMA | Emergency Management Institute

Enter Search Term(s): Search

IS-66: Preparing the Nation for Space Weather Events

Enter Keyword(s) or Course Code Search IS

Course Date
9/19/2022

Course Overview
The Preparing the Nation for Space Weather Events Independent Study course will cover the lessons necessary to a greater understanding of space weather and its impacts, strengthen understanding of space weather events; the potential impacts from those events; and the roles of the Federal Government as well as the local and jurisdictional Emergency Manager in preparing for and mitigating such impacts.

Prerequisites
None

CEUs:
0.2

Course Length:
2 hours

TAKE THIS COURSE
[Interactive Web Based Course](#)

TAKE FINAL EXAM
Please note that the program now requires a fema sid to be used instead of your ssn. If you do not have a sid, [register for one here](#).
[Take Final Exam Online](#)

NOTICES
Test questions are scrambled to protect test integrity

Navigation Links:
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IS Course List
Lista de cursos de español
EMI Student Portal
Register for a FEMA SID
Critical Infrastructure Security and Resilience
Curriculum
Frequently Asked Questions

<https://training.fema.gov/is/courseoverview.aspx?code=IS-66&lang=en>

July 2019 – National Threat and Hazard Identification and Risk Assessment (THIRA)

Table 1: Threats and Hazards of Concern Identified for the 2019 National THIRA^{8,9}

Threat/Hazard Type	Threat/Hazard	Area/Region
Natural	Plausible Concurrent Operations ¹⁰	Nationwide
	Earthquake	Washington, Oregon, California, Idaho
		600,000 sq. km in the Midwest/East Galveston, Texas to the Midwest
	Hurricane	Fort Lauderdale, Florida to Alabama
		Hawaii
	Pandemic	Nationwide
	Space Weather	Nationwide



White House Office of Science and Technology Policy leads development of national policy

Oct 2015: National Space Weather Strategy and Action Plan

Oct 2016: Executive Order 13744 of October 13, 2016: *Coordinating Efforts To Prepare the Nation for Space Weather Events*

Mar 2019: Update to National Space Weather Strategy and Action Plan

- Executive Order on Coordinating National Resilience to Electromagnetic Pulses



NATIONAL SPACE WEATHER STRATEGY AND ACTION PLAN

Product of the
SPACE WEATHER OPERATIONS, RESEARCH, and MITIGATION
WORKING GROUP
SPACE WEATHER, SECURITY, and HAZARDS SUBCOMMITTEE
COMMITTEE ON HOMELAND and NATIONAL SECURITY
of the
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

March 2019

NATIONAL SPACE WEATHER STRATEGY

PRODUCT OF THE
National Science and Technology Council



October 2015

Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow Act or the PROSWIFT Act

– To help implement the priorities established in the National Space Weather Strategy and Action Plan

Passed by Congress by unanimous consent and signed by President on October 21, 2020



- Codifies many actions in National Strategy and Action Plan
 - Develop a strategy for coordinated observation of space weather
 - Develop formal mechanisms to transition research to operations
 - Support grants for multidisciplinary science centers that advance solar and space physics research
- Creates new Space Weather Advisory Group (non-gov only)

Questions



NOAA **National Weather Service** **Space Weather Prediction Center**

THE NATION'S
OFFICIAL SOURCE
OF SPACE WEATHER
ALERTS AND WARNINGS

