Severe Space Weather and Emergency Preparedness

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Credit: Christian Harris

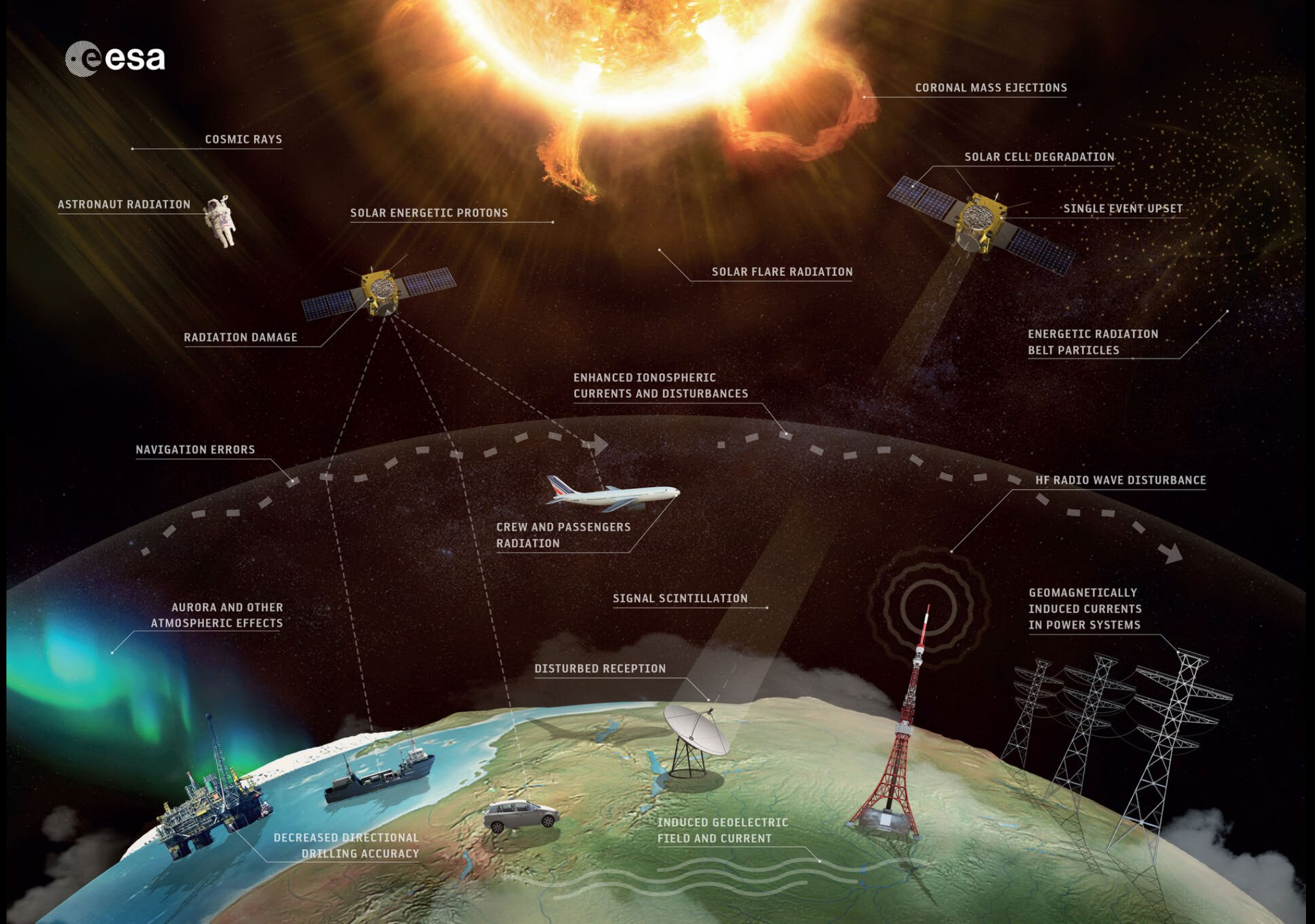
Educational Objectives

- Participants will be able to:
  - Recognize conditions in space environment known as space weather
  - Summarize solar cycle and changes in severe space weather risk
  - Identify healthcare-specific impacts of severe space weather

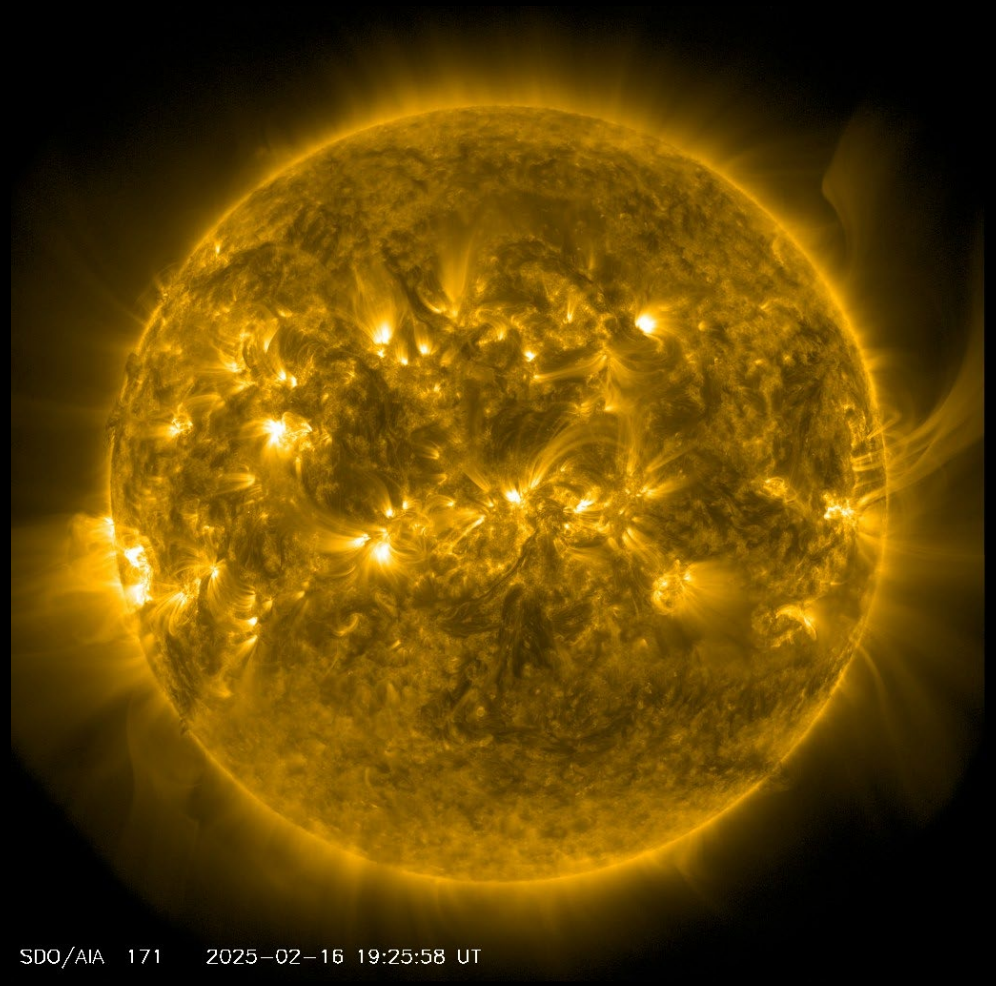
What is Space Weather?

- Conditions on the Sun and in space that can influence performance and reliability of space and ground-based technological systems

Credit: NOAA


esa
CORONAL MASS EJECTIONS
COSMIC RAYS
SOLAR CELL DEGRADATION
ASTRONAUT RADIATION
SINGLE EVENT UPSET
SOLAR ENERGETIC PROTONS
SOLAR FLARE RADIATION
RADIATION DAMAGE
ENERGETIC RADIATION
BELT PARTICLES
ENHANCED IONOSPHERIC
CURRENTS AND DISTURBANCES
NAVIGATION ERRORS
HF RADIO WAVE DISTURBANCE
CREW AND PASSENGERS
RADIATION
AURORA AND OTHER
ATMOSPHERIC EFFECTS
SIGNAL SCINTILLATION
GEOMAGNETICALLY
INDUCED CURRENTS
IN POWER SYSTEMS
DISTURBED RECEPTION
DECREASED DIRECTIONAL
DRILLING ACCURACY
INDUCED GEOELECTRIC
FIELD AND CURRENT

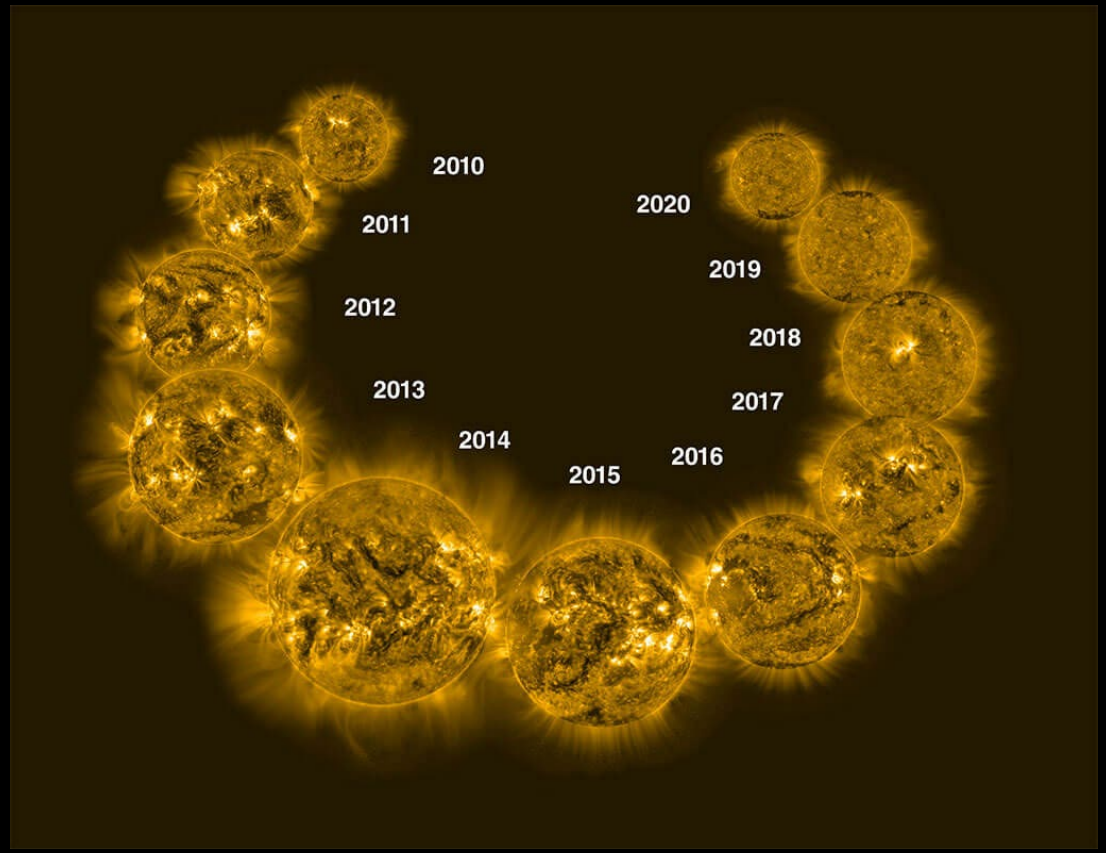
Origin of Space Weather



Credit: NASA Solar Dynamic Observatory

- Sun as an active star
  - Plasma
  - Nuclear fusion
  - Strong electrical and magnetic fields
- Solar activity as a source of space weather on Earth
  - Solar flares
  - Coronal mass ejections
  - High speed streams
  - Solar energetic particle (SEP) events

Solar Cycle



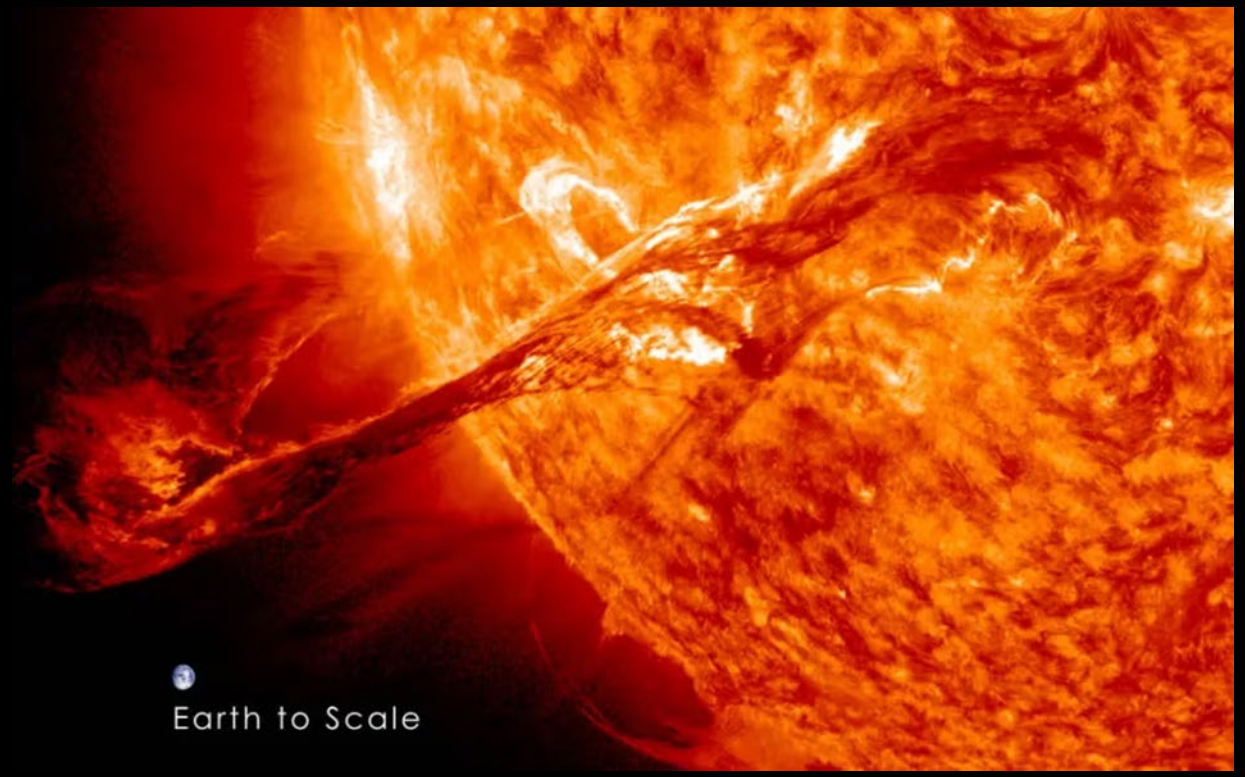
- Sun’s magnetic field is dynamic
- Poles reverse every 11 years
- Solar activity peaks at solar maximum
  - Sunspot number
  - Frequency and severity of events
  - Higher risk of severe space weather

Credit: ESA

Sunspots

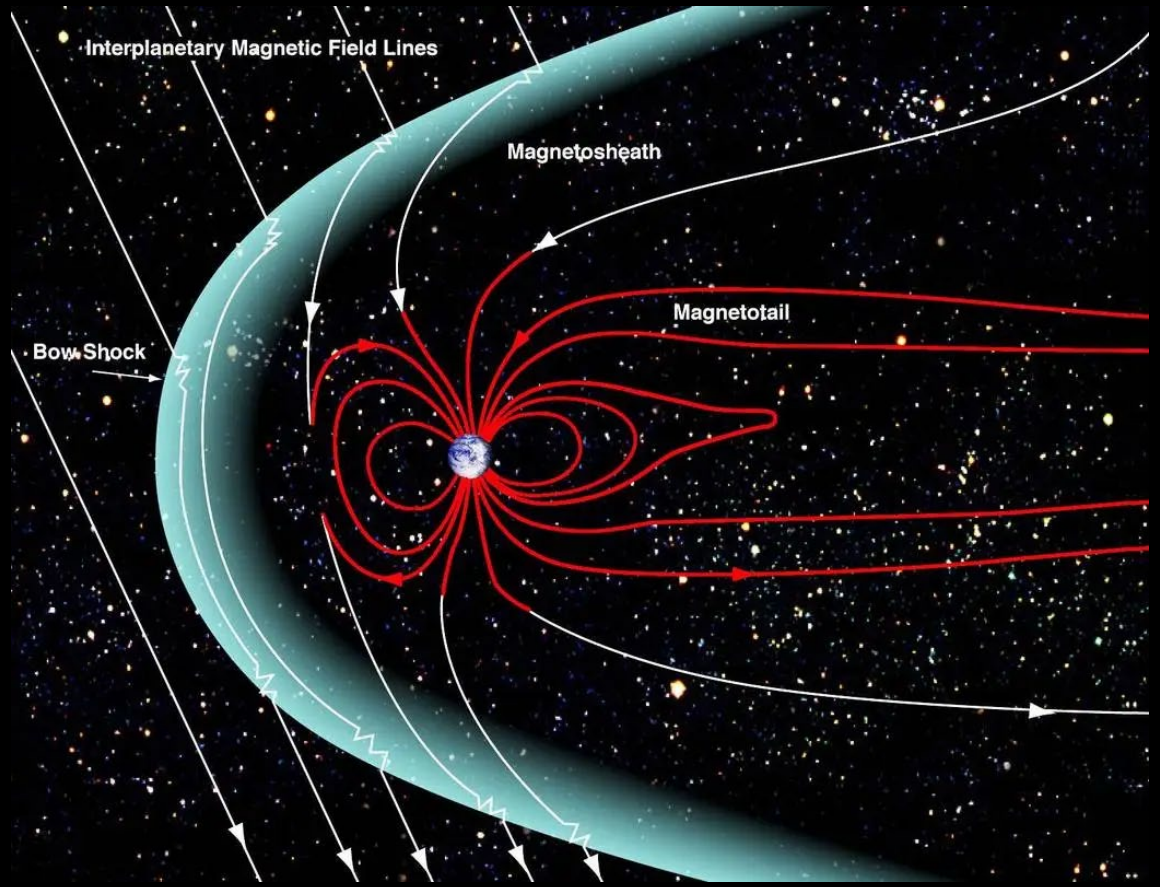
- Areas of strong magnetic field
- Increase near solar maximum
- Active reconfiguration of magnetic field
  - Solar flares
  - Coronal mass ejections

Coronal Mass Ejections



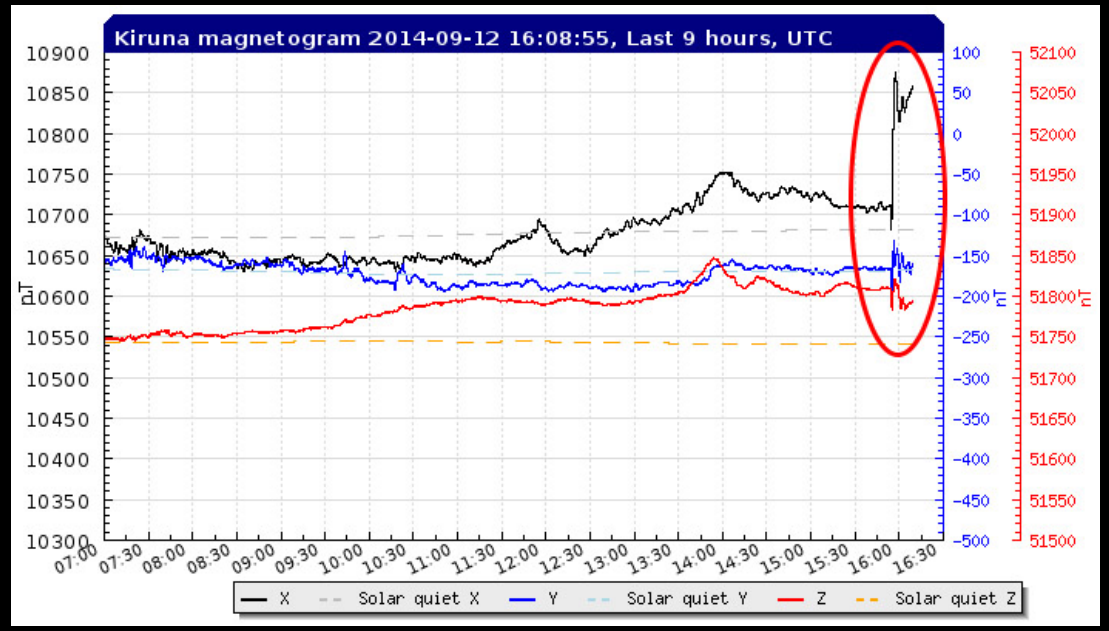
- Also known as CME
- Eruption of magnetized ionized gas
- Carry embedded magnetic field
- May be Earth-directed
- Earth effects:
  - Geomagnetic sudden impulse (EMP)
  - Geomagnetic storm

Earth’s Magnetosphere



- Magnetic field formed by solid-liquid Earth’s core
- Dipole field
- Interacts with solar wind
  - Deflection of energetic particles
  - Absorption of solar radiation
  - Geomagnetic storms

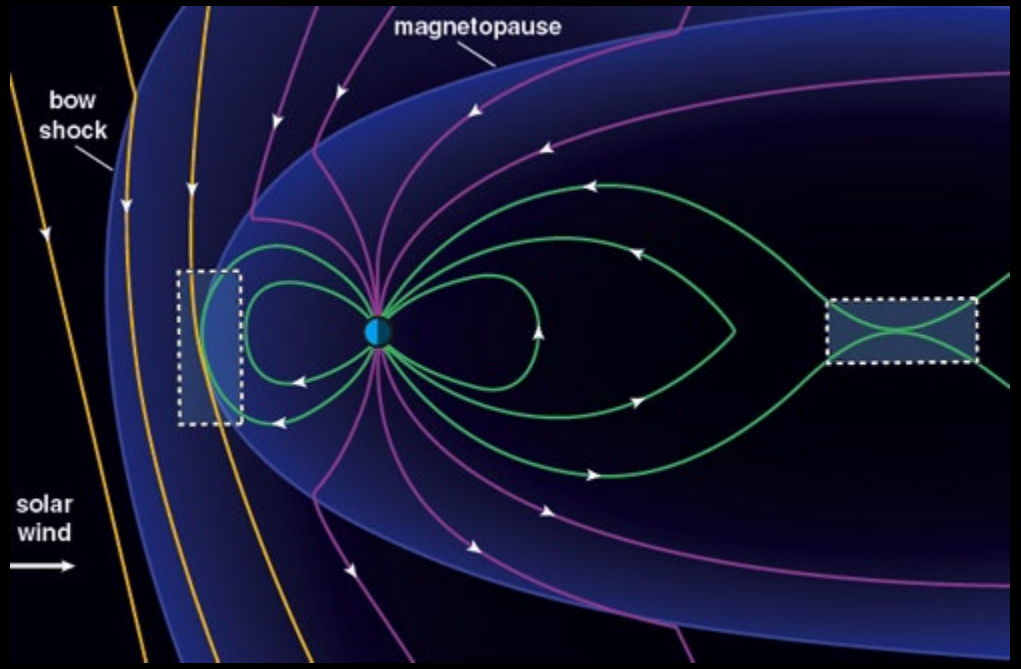
Geomagnetic Sudden Impulse



- Initial impact of CME
- Sudden compression of the magnetosphere
- Rapid change in Earth's magnetic field

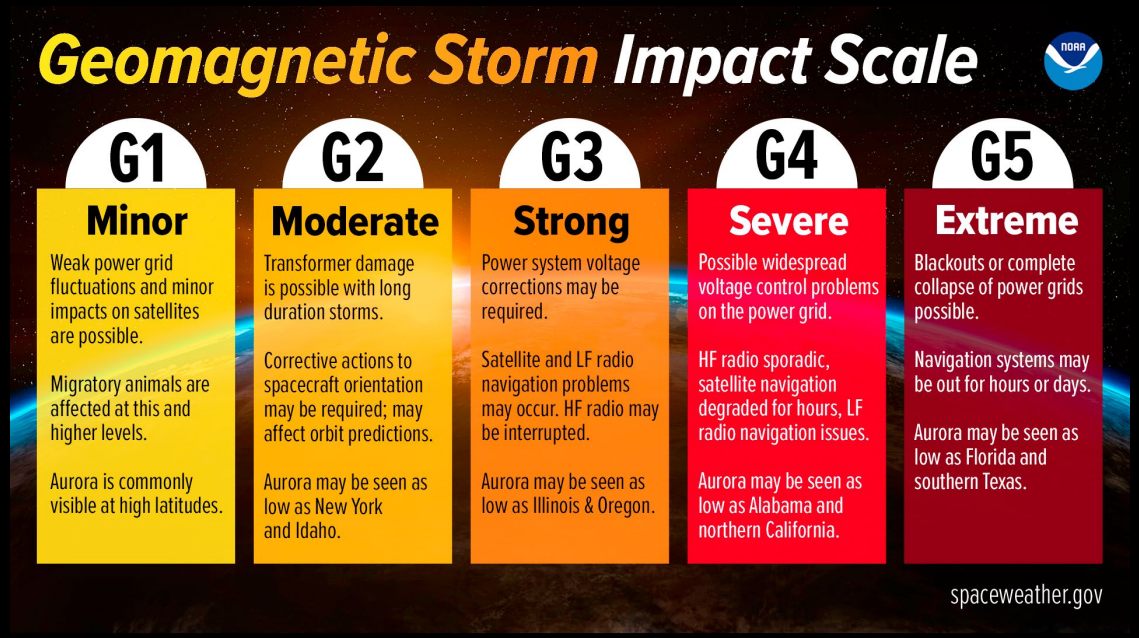
Credit: SpaceWeatherLive

Solar Wind Interaction



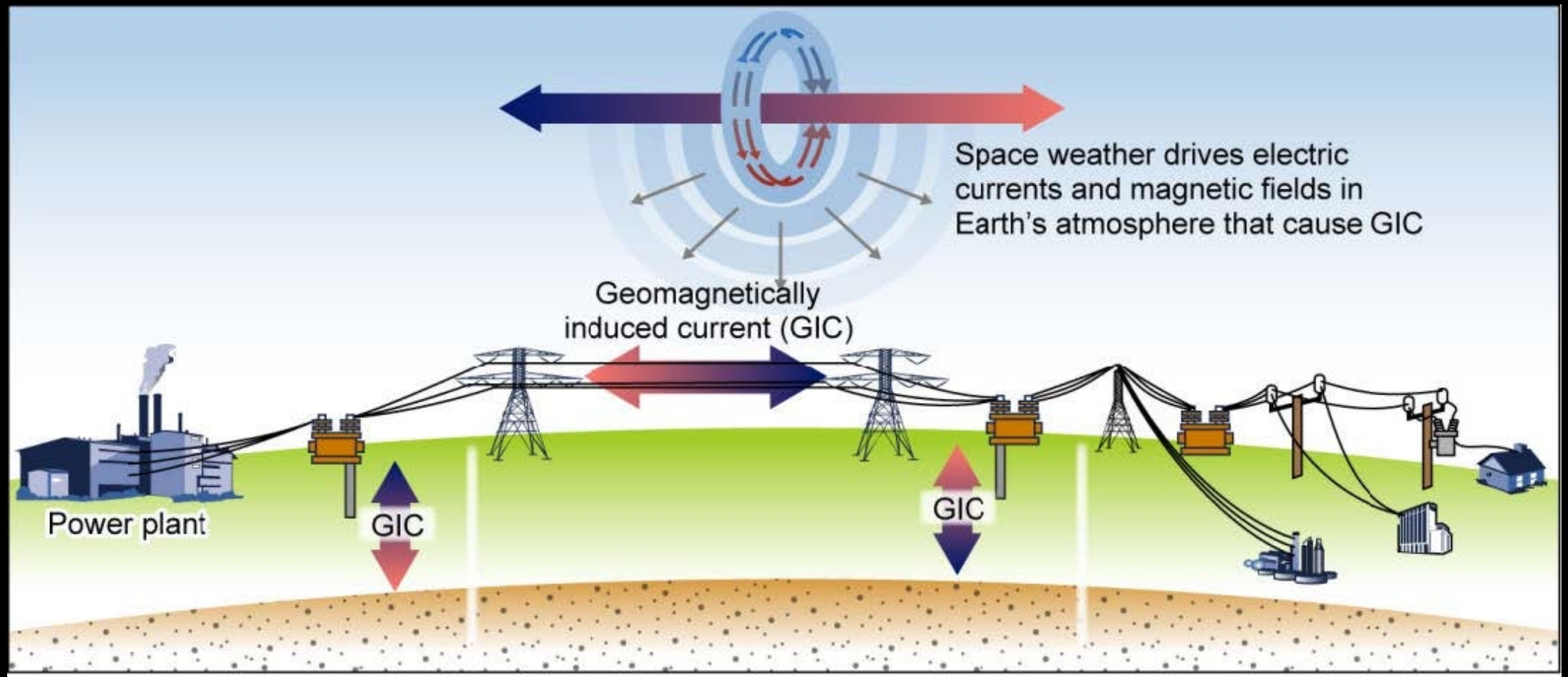
- Reconnecting magnetic field lines
  - Solar wind – day side
  - Magnetosphere – night side
- Strong magnetic field can cause significant disturbance
- Magnetic field of the CME can’t be predicted ahead of time

Geomagnetic Storms



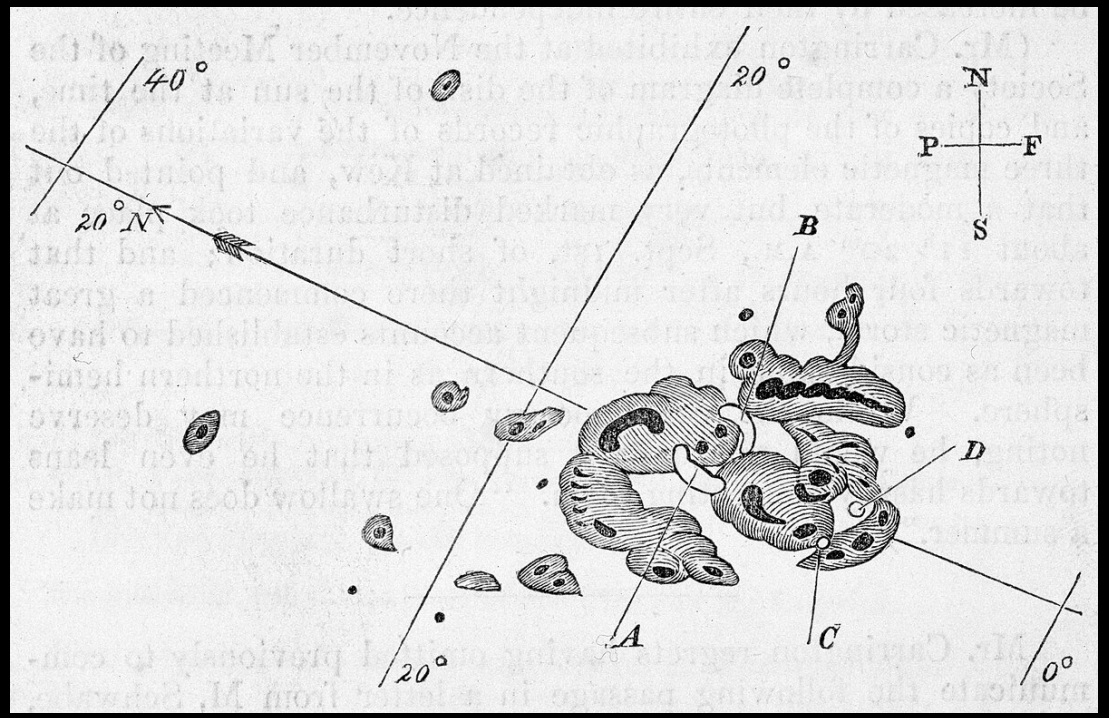
- Disturbance of Earth's magnetic field
- G-scale to describe severity
- May last for a couple of days
- Generate strong currents
  - Atmosphere
  - Ground

Geomagnetically Induced Currents (GICs)



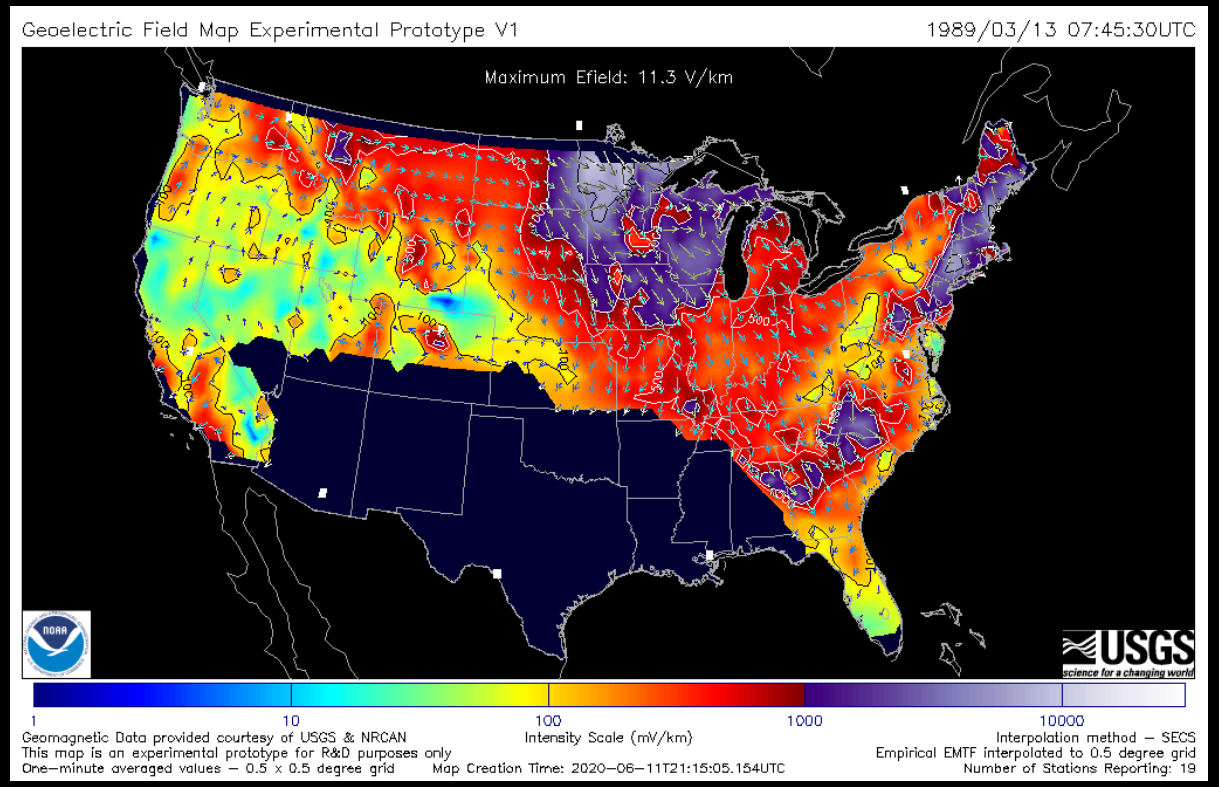
Sources: GAO (presentation); Art Explosion (images). | GAO-19-98

Carrington Event



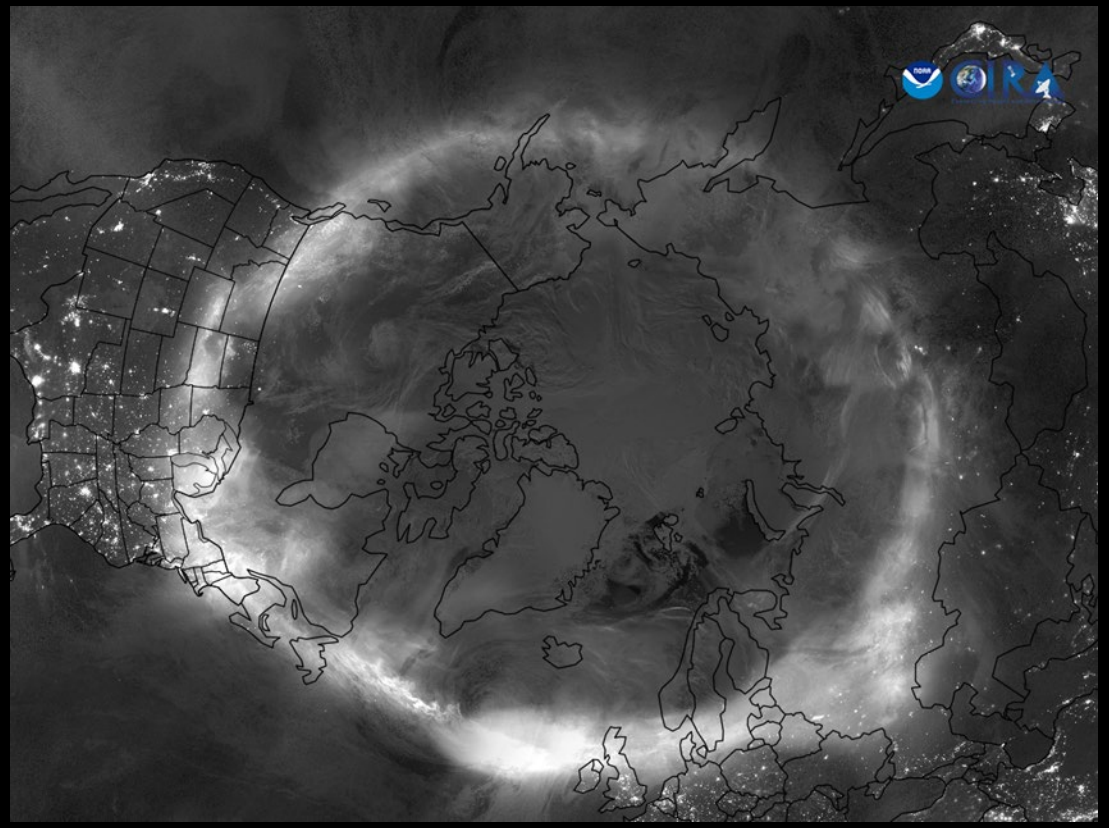
- Solar flare observed
  - September 01, 1859
- CME arrival in 17.6 hours
- Geomagnetic storm on September 1-2, 1859
- Aurora seen Cuba, Hawaii, and Colombia
- GICs observed in telegraph lines

Hydro-Quebec, 1989



- Solar flares
  - March 10, 1989
  - March 12, 1989
- CME arrival:
  - March 13, 1989 at 1:27 UTC
  - March 13, 1989 at 07:43 UTC
- Hydro-Quebec grid collapsed
  - 90 sec of the second CME arrival
- Power outage lasted 9 hours
- Peak storm Dst
  - March 13 at 2:00 UTC

May 10-11 Gannon Storm



- New Zealand
  - Grid emergency declared
  - Several power lines taken out
  - No service disruption
- UK
  - GICs up to 50 A
- Alberta, Canada
  - GICs up to 170 A
  - Some tripping
  - No loss in service
- Sweden
  - Severe disturbances in Sweden-Denmark lines

Historical Comparison of May 2024 Solar Storms

WHAT: How did the G5 Geomagnetic Storm Compare to Other Major Events?

Index	MAY 2024	OCT 2003	MAR 1989	MAY 1921	SEP 1859
Disturbance Storm Index (nT)	-412	-383	-589	~ -907	~-1200
A_p-Index	271	204	246	NA	NA

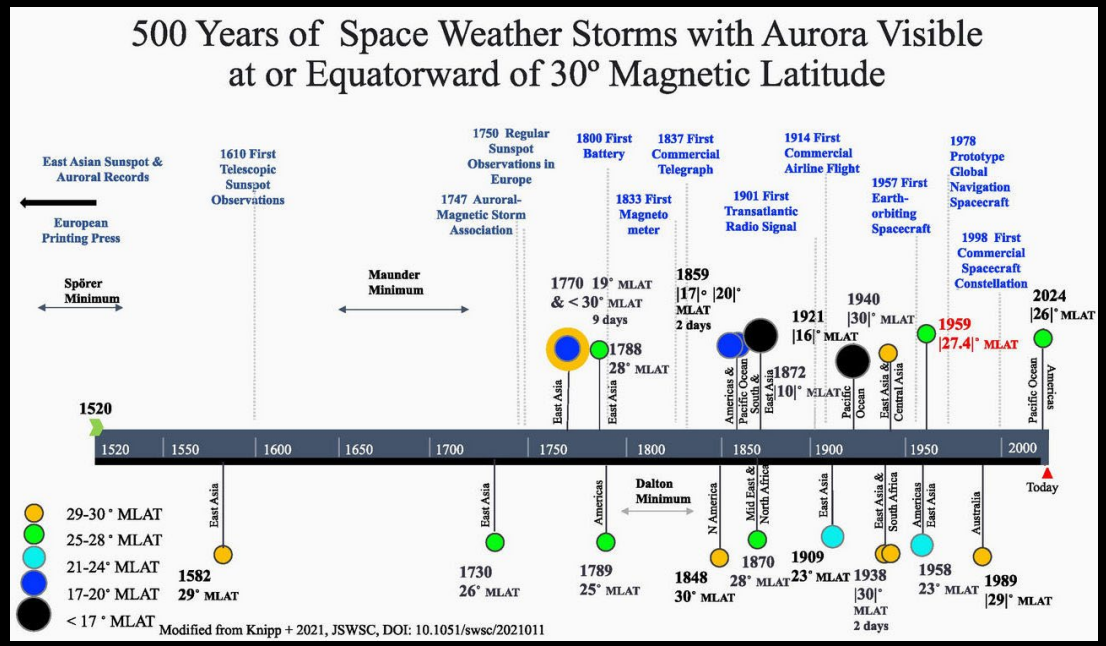
Loveland Pass, Colorado, 5/10/24. Credit: Dan McManus, SWPC.

Boulder, Colorado, 5/10/24. Credit: Jon Lash, SWPC.

Disturbance Storm Index (Dst): An index of magnetic activity derived from a network of near-equatorial geomagnetic observatories that measures the intensity in space of the ring of westward current around Earth (higher negative values generally correlate with stronger storms)

A_p-Index: The average from eight daily values gives the A_p-index of a certain day (every 3-hour K-value - or measure of geomagnetic activity - is converted into a linear scale). Days with higher geomagnetic activity have a higher daily A_p-value.

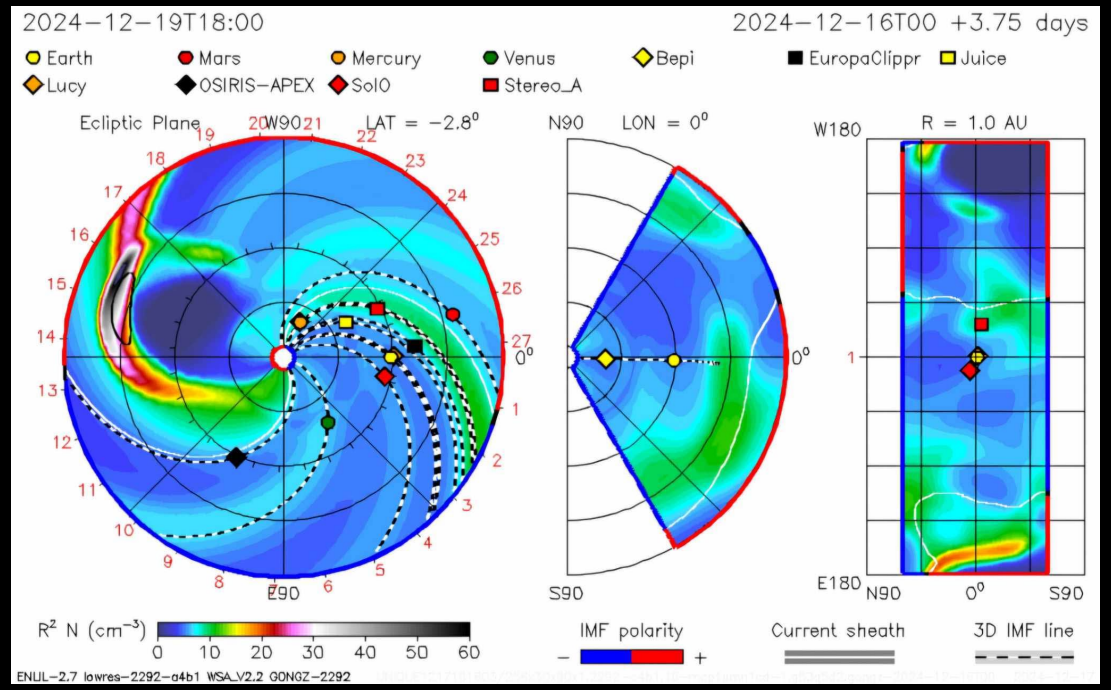
Storm Recurrence Risk



- May 10-11 Gannon Storm
  - 1 in 13 years – intensity
  - 1 in 41 years – duration
- HydroQuebec event
  - 1 in 50 years
- Carrington event
  - 1 in 500 years

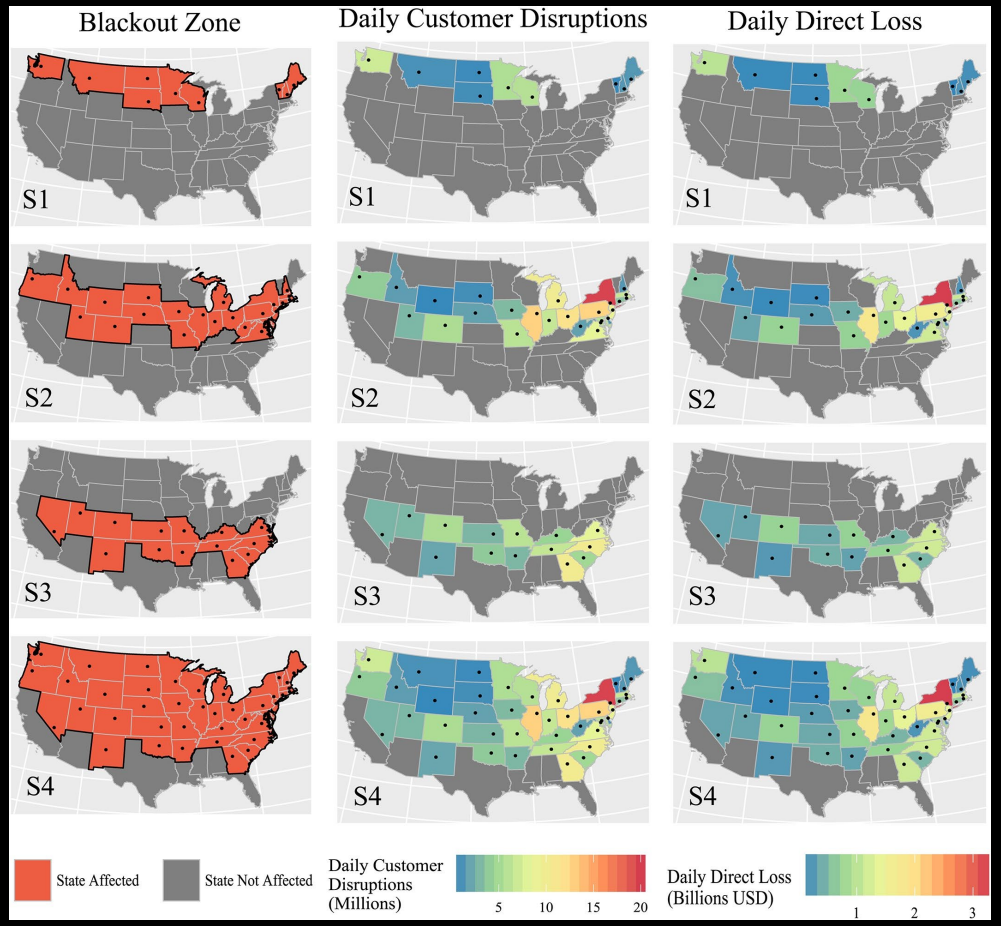
Elvidge & Themens, 2025

Recent Carrington-class events



- August 4, 1972
  - Arrival in 14.6 hours
  - Significant GSI
  - AT&T outage between IL and IA
  - Grid disturbances in Canada and USA
- July 23, 2012 solar flare and CME
  - Side event (west limb)
  - Near miss
  - Arrival in 20.78 hours
- December 17, 2024
  - Far-sided event
  - Speed over 3000 km/s

Severe Space Weather Impact



- Equipment damage
  - EHV transformers
  - Replacement time 6-16 months
- Infrastructure and supply chain disruption
- Direct and indirect loss
  - $7 to $48.5 billion per day

Oughton et al, 2017

Power Grid Impacts and Mitigation

- Vulnerabilities
  - High-voltage power lines
    - East-west lines
  - Ground conduction
  - Transformers
    - Waveform distortions
    - Heating
    - Permanent damage
  - Protection relays
    - Line tripping
- Mitigation strategies
  - Transformer resilience
  - Grid reconfiguration
  - GIC detection and blocking

Infrastructure at Risk

- Lead time:
  - CME detection: 15 hours to 3 days
  - CME impact: 30 min to 1 hour
- Power outage
  - Local impacts
    - Hospital/facility operations
    - Households
  - Regional impacts
    - Utilities
    - Communications

Space Weather Preparedness

- International collaboration
  - Space weather operational centers
  - Research to Operations to Research
- NOAA Space Weather Prediction Center (SWPC)
  - Space weather monitoring
  - Watches, Warnings, Alerts
  - Notifications for industries
- FEMA training
  - Space weather training module
- Local/Regional preparedness

Are We Prepared?

- Facility power outage plan
  - Operations affected
  - Power backup (generators, fuel)
  - Other utilities affects
  - Staff communications
- Regional plan
  - Coordination across healthcare
  - Community support
  - Infrastructure communications

Resources

- Space Weather Prediction Center
  - https://www.swpc.noaa.gov/
- National Weather Service
  - https://www.weather.gov/safety/space-before
- FEMA
  - https://emilms.fema.gov/is_0066/