NASA Space Weather Event Response & Vulnerability

Introduction to Space Weather

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Febuary 24 2026

Imagine that you…

Are an American farmer on May 10th, 2024.

The skies are clear, and you are preparing to plant your crops using a GPS operated planter. You suddenly notice that your GPS system is not working properly for all your machines, and you do not have the ability to plant your crops properly without them. You can no longer work today. But it's a beautiful day…why is this happening?

This was the reality for farmers across America on May 10th, 2024, and it resulted in an estimated $500 million loss. What was the cause? Space weather.

What Is Space Weather?

"Space Weather refers to variations in the space environment between the sun and Earth (and throughout the solar system) that can affect technologies in space and on Earth. Space weather is primarily driven by solar storm phenomenon that include coronal mass ejections, solar flares, solar particle events and solar wind. These phenomena can occur in various regions on the sun's surface, but only Earth directed solar storms are potential drivers of space weather events on Earth."
-NOAA Space Weather Prediction Center

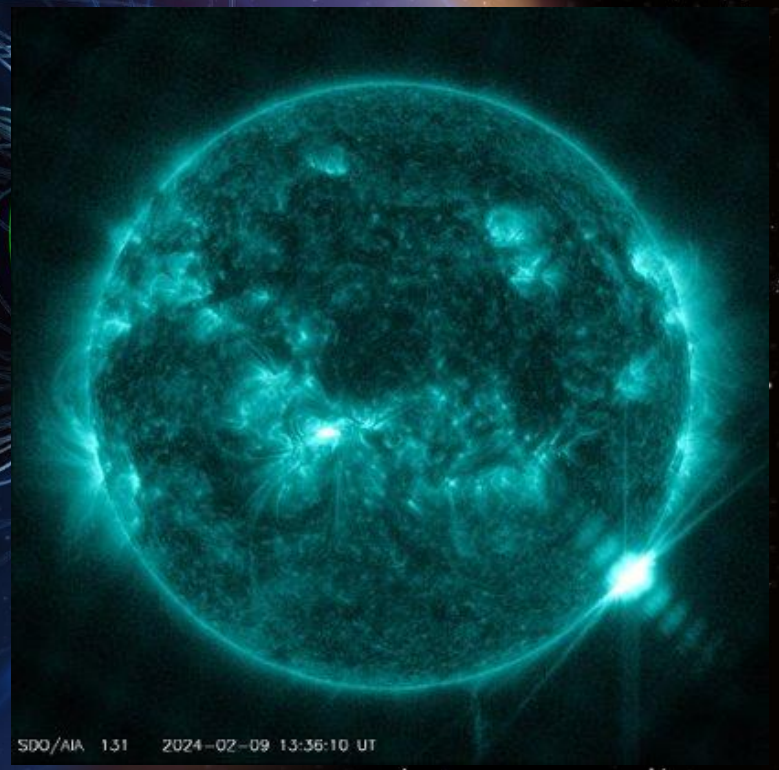
Space weather is a chain of complex interacting systems across different spatiotemporal scales.

Coronal Signatures

1. Solar Flares
2. Filaments/Prominences
3. Coronal Holes

Coronal Signatures

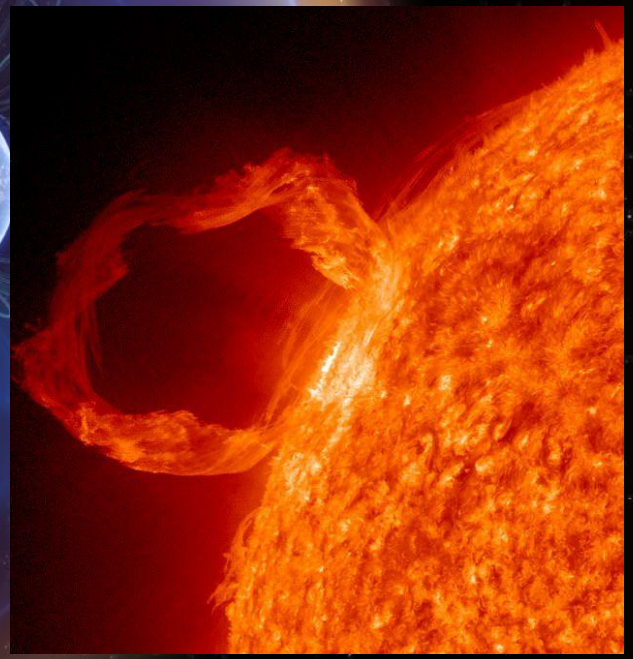
1 Solar Flares



- Bursts of electromagnetic energy lasting minutes to hours
- Can produce strong X-rays, Extreme Ultraviolet (EUV) and radio emissions, and solar energetic particles
- Can degrade or block high frequency radio waves
- Solar energetic particles can cause a radiation hazard

Coronal Signatures

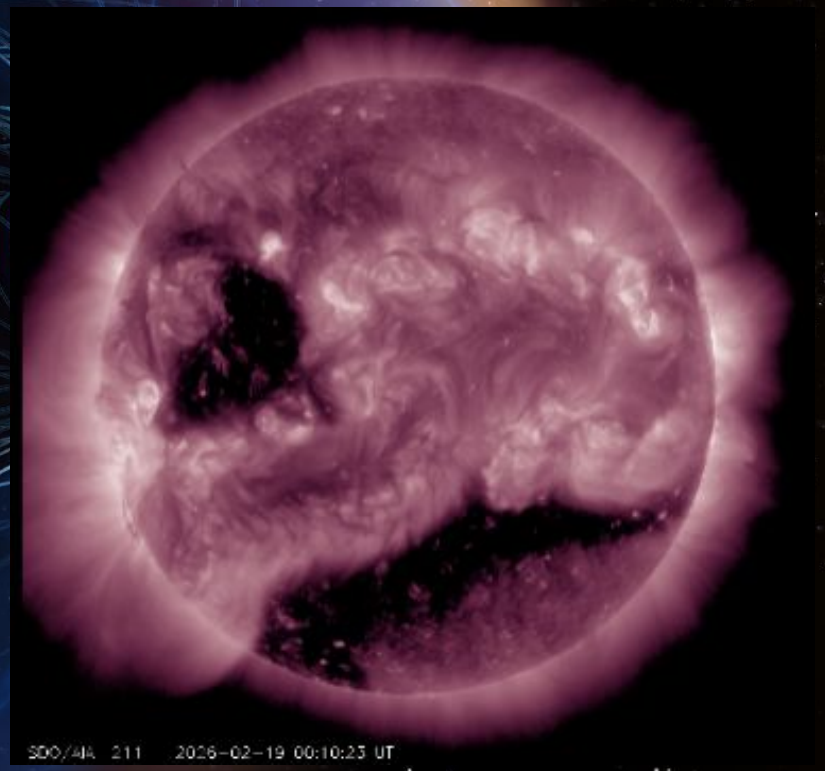
2 Filaments/Prominences



- Loops of cool, dense plasma hovering above the Sun's surface
- Are called filaments when seen on the Earth facing disk (appear as dark lines)
- Are called prominences when seen along the limb (appear as bright loops)
- Can become unstable and erupt into the corona.

Coronal Signatures

3 Coronal Holes



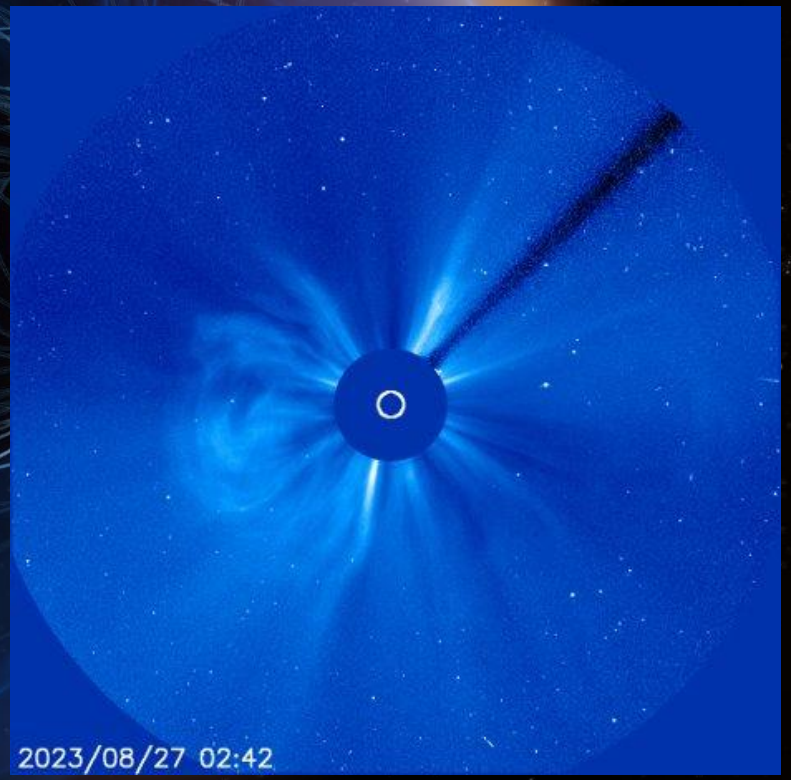
- Patches on the Sun with “open” field lines that don’t immediately connect back to the Sun’s surface.
- In these areas the constant stream of particles called the solar wind is uncaged and is free to stream much faster.
- Coronal hole are cooler and less dense than the surround areas, making them appear darker in certain wavelengths.

Interplanetary Signatures

1. Coronal Mass Ejections (CMEs)
2. Solar Energetic Particles (SEPs)

Interplanetary Signatures

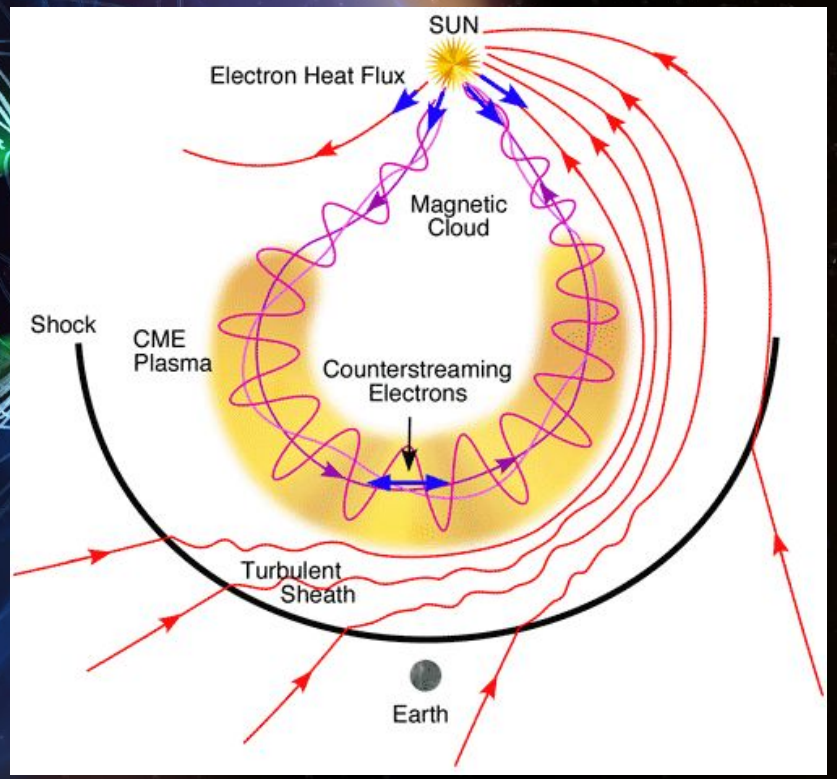
1 Coronal Mass Ejections (CMEs)



- Bubbles of plasma and magnetic field that typically travel between 500-700km/s
- Observed using a coronagraph that blocks out the light of the Sun like an eclipse
- Sometimes has a shock component that can drive solar energetic particles

Interplanetary Signatures

1 Coronal Mass Ejections (CMEs)



Internal flux rope:

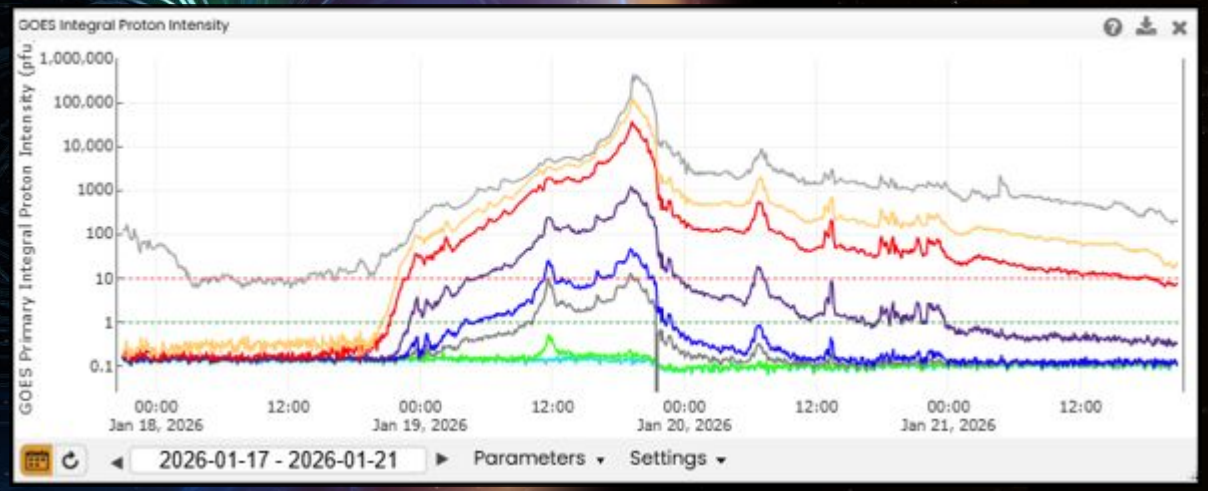
- Twisted rope of magnetic field and plasma within the CME
- The orientation of the flux rope affects the strength of a potential geomagnetic storm

Leading Shock:

- Can drive solar energetic particle events
- First detectable feature at missions/planets

Interplanetary Signatures

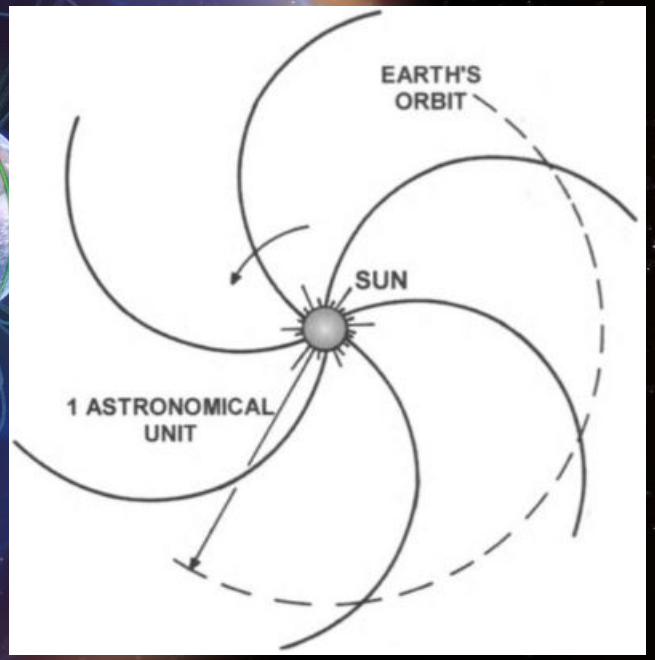
2 Solar Energetic Particles (SEPs)



- Solar Energetic Particle (SEP) events are an enhancement in the radiation environment, usually associated with flares and CMEs.
- SEPs can reach Earth on the timescale of minutes to hours following an eruption.

Interplanetary Signatures

2 Solar Energetic Particles (SEPs)



The Parker Spiral

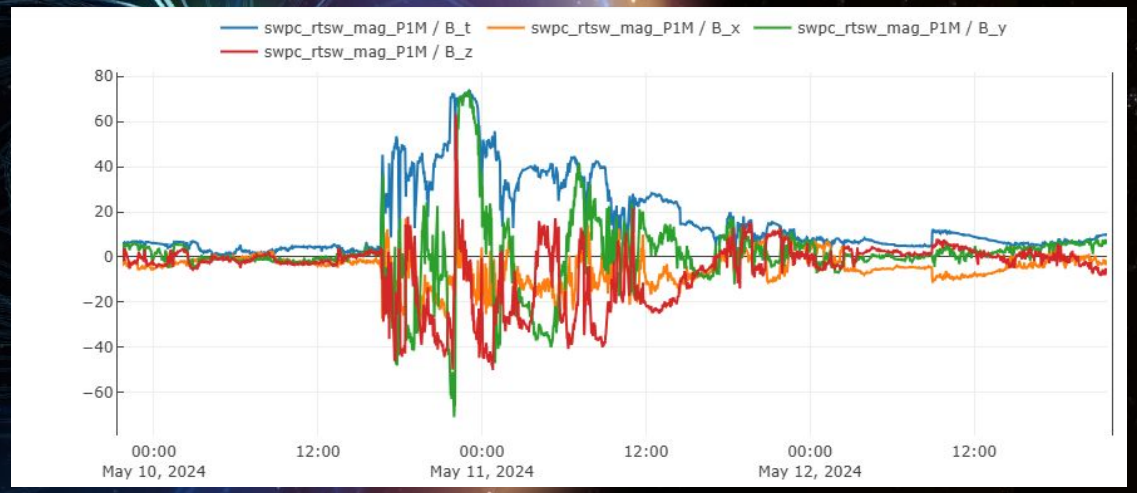
- Solar wind and magnetic field lines stream out from the Sun radially
- As the Sun rotates, these lines appear curved
- Missions/planets are more favorably connected to the Western portion of the Sun

Near Earth Environment

1. Interplanetary Shocks (IPS)
2. Geomagnetic Storms (GMS)
3. Magnetopause Crossing (MPC)
4. Radiation Belt Enhancement (RBE)
5. High Speed Stream (HSS)

Near Earth Environment

1 Interplanetary Shocks (IPS)



- The arrival of a CME or HSS can create a sharp disturbance in the near-Earth environment
- Magnetic field components, solar wind speed, temperature and density can be impacted
- Typically followed by the passage of a flux rope

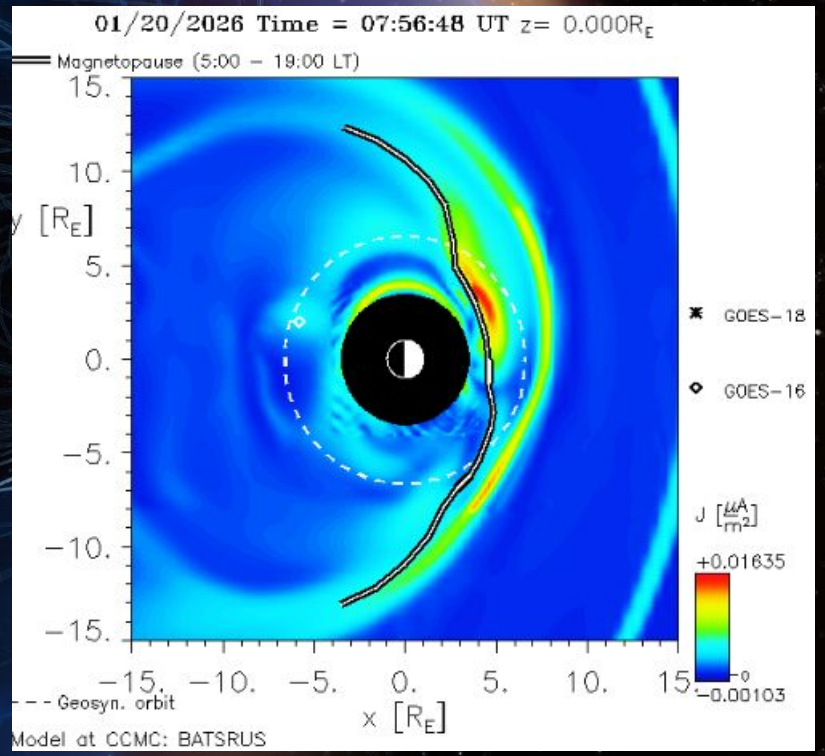
Near Earth Environment

2 Geomagnetic Storms (GMS)

- Magnetic reconnection caused by the magnetospheric compression deposits energy to the poles, producing auroras
- Create disturbances in the ionosphere, a dynamic layer of the upper atmosphere from ~30-600 mi from the Earth's surface, full of charged particles
- Changes in density and composition can impact the radio and GPS signals that travel through or bounce off the ionosphere

Near Earth Environment

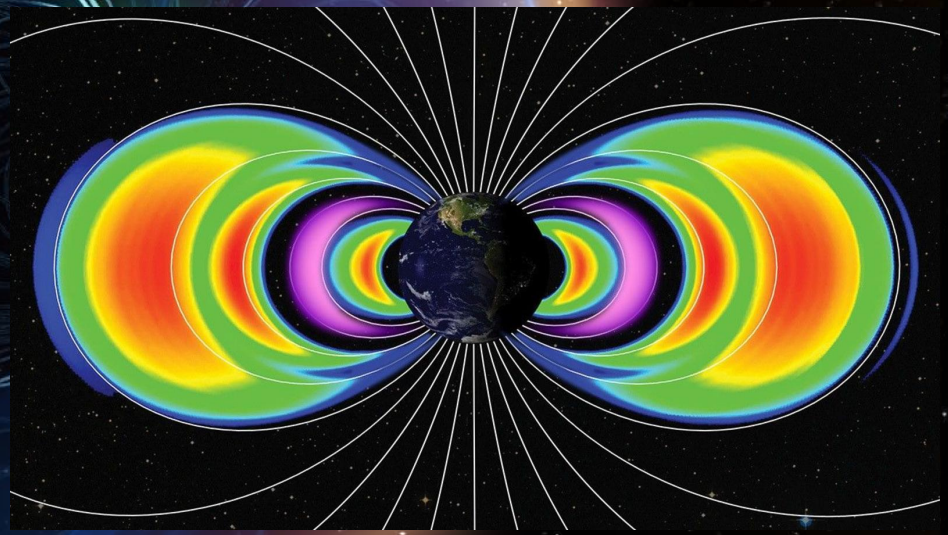
3 Magnetopause Crossing (MPC)



- When a CME or HSS arrives, the increased solar wind speeds and densities can compress Earth's magnetosphere
- This can result in increased drag on spacecraft which can result in additional heating or trajectory issues
- Can expose missions typically shielded by the magnetosphere to greater impacts from the arriving CME or HSS

Near Earth Environment

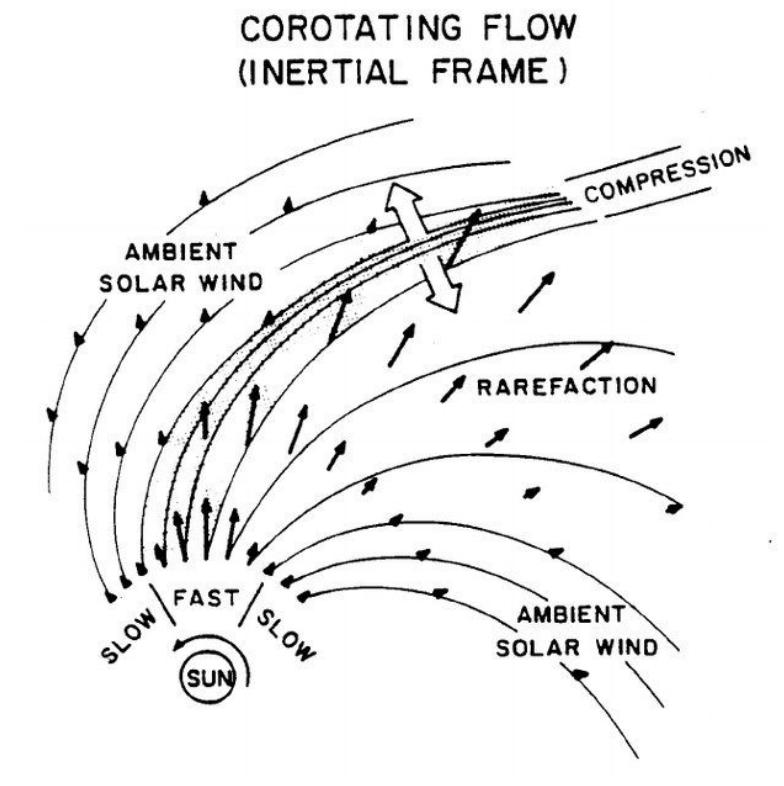
4 Radiation Belt Enhancement (RBE)



- The Van Allen radiation belt is a region around Earth where energetic particles get trapped
- Following the arrival of a CME or HSS, the radiation belt can become further enhanced
- This poses a threat to both human and robotic missions

Near Earth Environment

5 High Speed Stream (HSS)

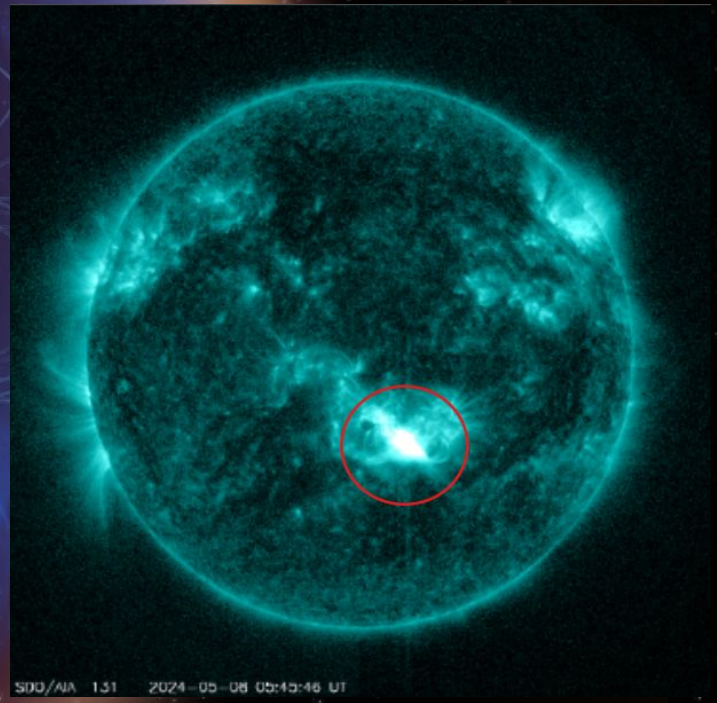


- When the fast solar wind emanating from a coronal hole “catches up” to the slow solar wind, it creates a compression region with an increased density and enhanced magnetic field
- This enhancement can arrive as an IPS signature and cause geomagnetic storming at Earth
- Following this co-rotating interaction region (CIR) increased solar wind speeds are observed
- This can enhance the radiation belt

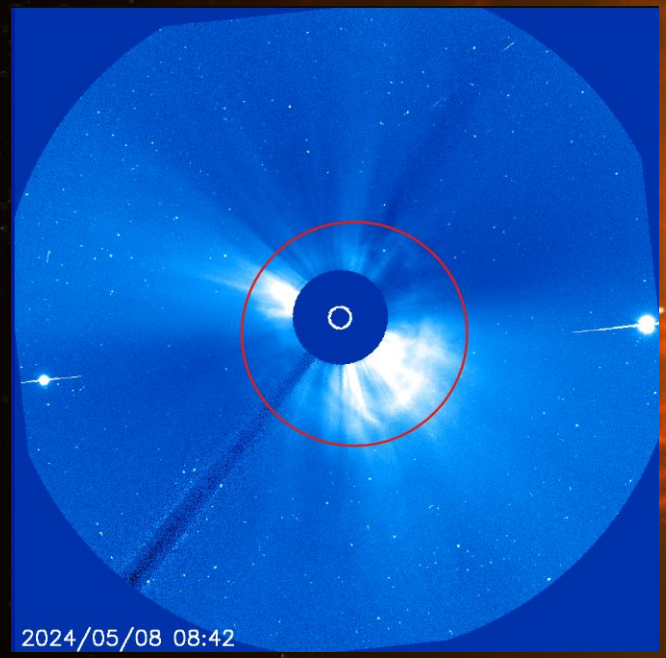
So What Happened in May 2024?

Solar Flares

From May 7th – May 10th , seven X-class flares and 66 M-class flares were recorded



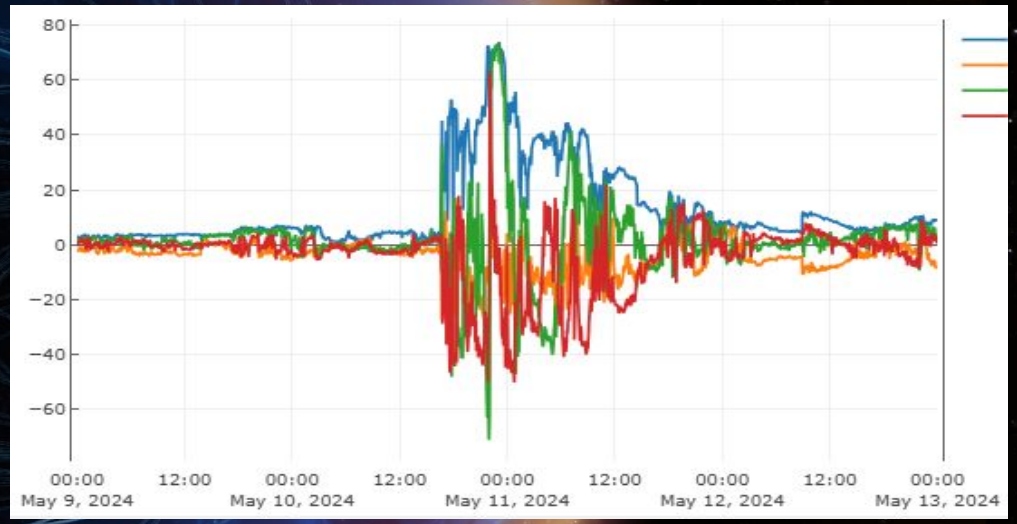
CMEs



At least 7 large, fast CMEs were directed towards Earth over the period

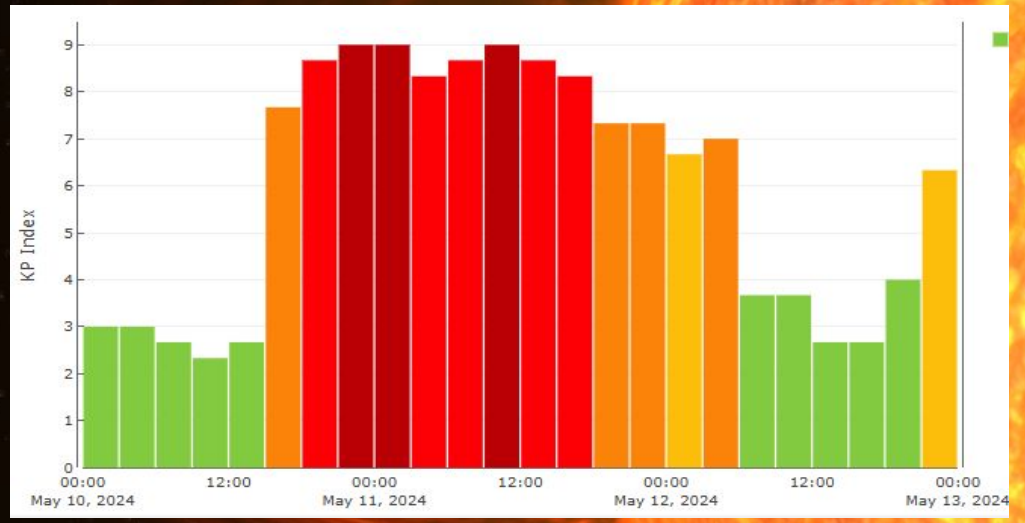
So What Happened in May 2024?

IPS



A very intense IPS was observed as these CMEs arrived at Earth. The orientation was just right for high impact.

GMS



A severe, long duration geomagnetic storm was reported as a result of this arrival.

So What Happened in May 2024?

This geomagnetic storming is what knocked out the GPS guidance systems on American farming equipment in May 2024.

Even more severe impacts were possible, but the knowledge or space weather events and impacts allowed industries to employ mitigation tactics to protect valuable infrastructure and assets.