Solar Cycle 25
Lessons Learned for Amateur Radio

Dr. Tamitha Skov WX6SWW

Dayton Hamvention Antenna Forum
16 May 2025

Special thanks to Dr. Terry Griffin and Janelle Shank, the AMPERE Science Data Center for providing data products derived from the Iridium Communications constellation (enabled by support from the National Science Foundation), and to the Google Research Team: Smith, J., Kast, A., Geraschenko, A. et al., for their work, “Mapping the ionosphere with millions of phones,” *Nature 635, 365–369 (2024). https://doi.org/10.1038/s41586-024-08072-x*

Space Weather Stakeholders – The list is growing

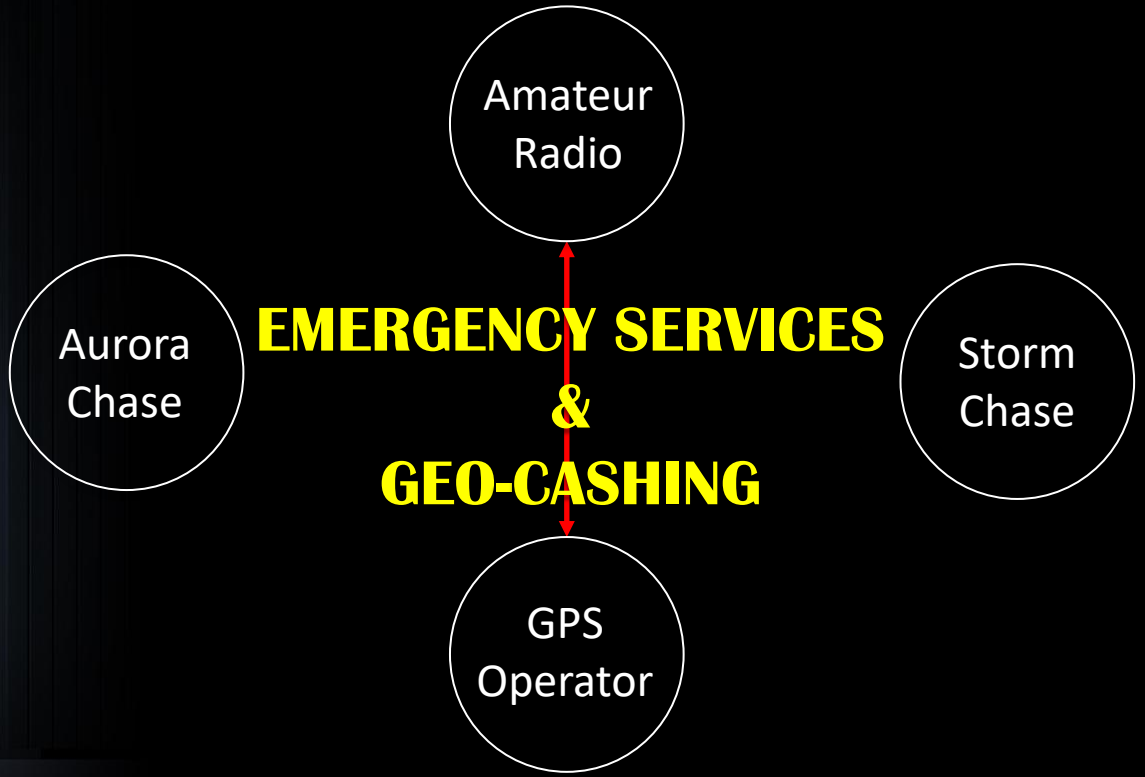
Space Weather Impacts on You– the list is growing

Not really much at all, just these little things…

INTERCONNECTED

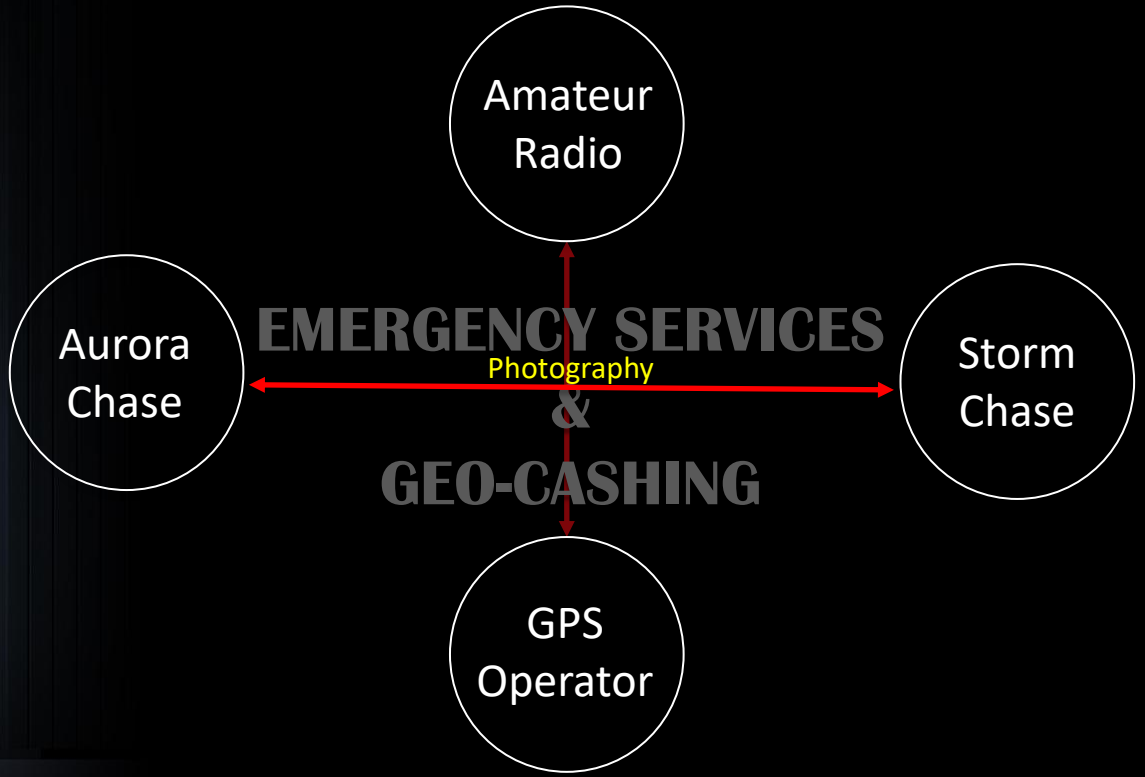
- Amateur Radio Communication
- Satellite Radio and Television
- Satellite Internet and Mobile Technologies & “The Internet of Things”
- Airline Communication and Transportation
- National Electric Utilities and Power Grids
- Emergency or Disaster Search, Rescue, and Relief Services
- GPS/GNSS navigation and Location-Based Services (LBS)
- Unmanned Aerial Vehicles (drones)
- Precision Agriculture
- Financial Markets & Precise Timing Applications
- Aurora Tourism
- Space Tourism
- Cloud based services, storage and operation, now including AI

Modern Technology Interconnects Communities



Forming a highly-skilled "Super Community" connected by expertise

Modern Technology Interconnects Communities



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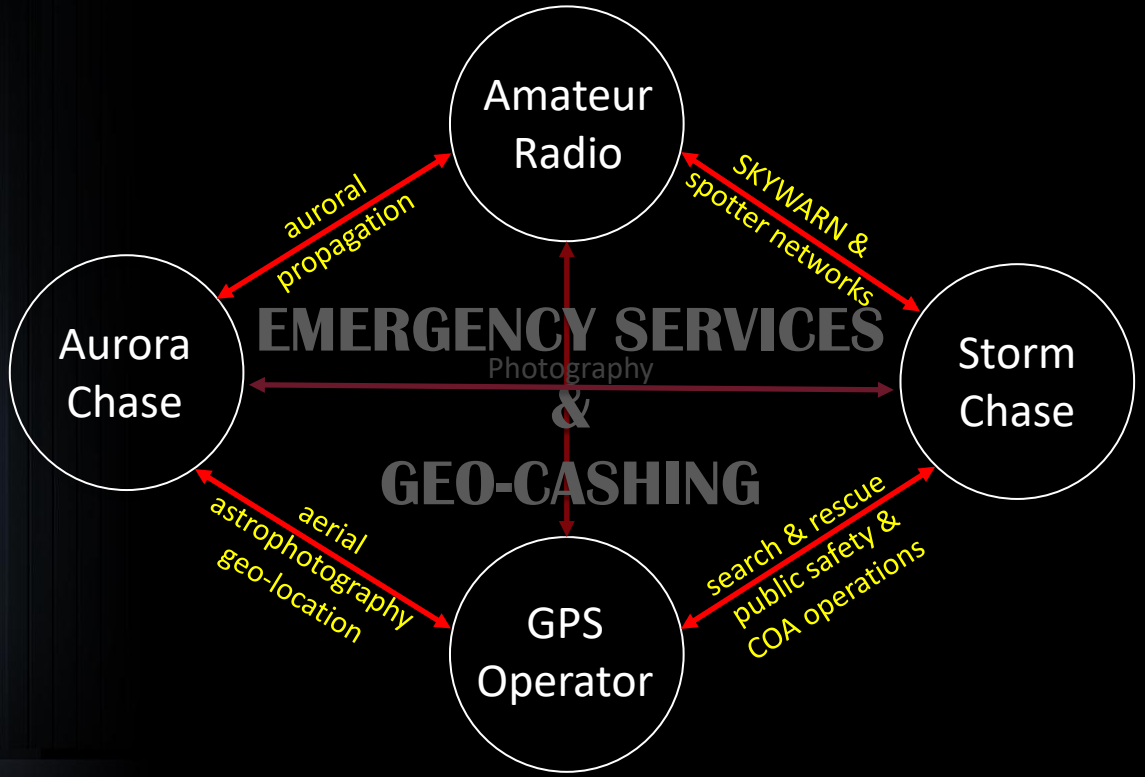

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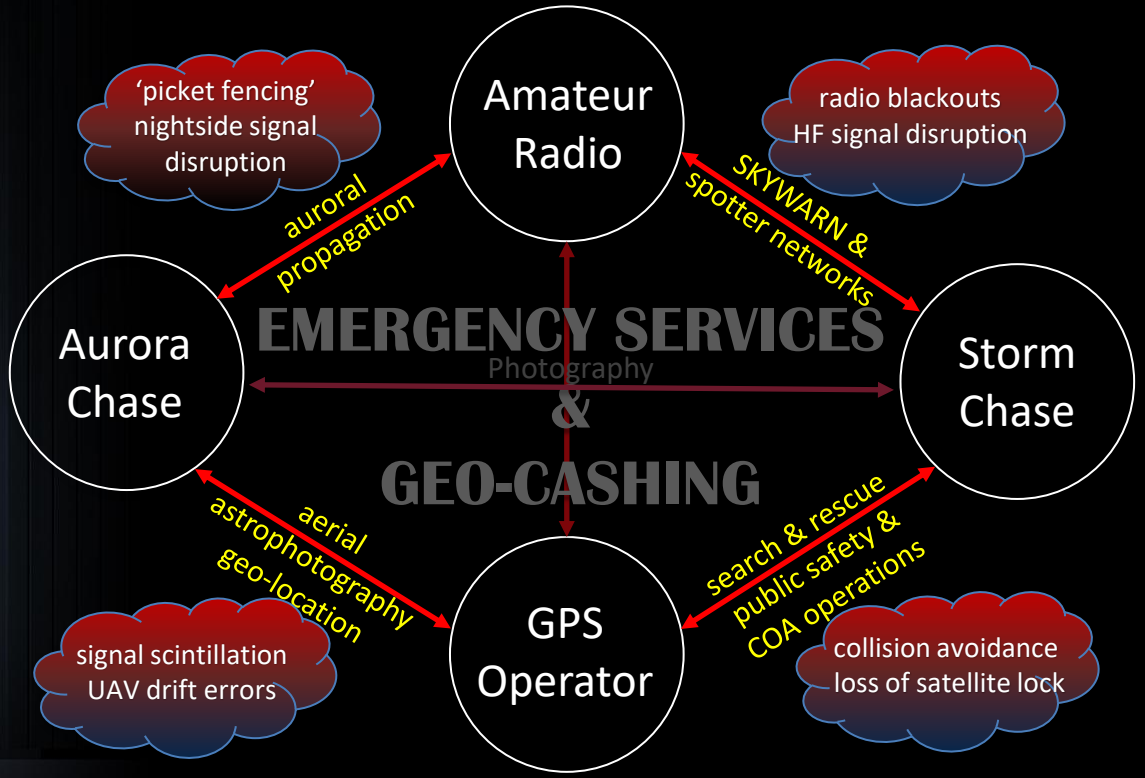
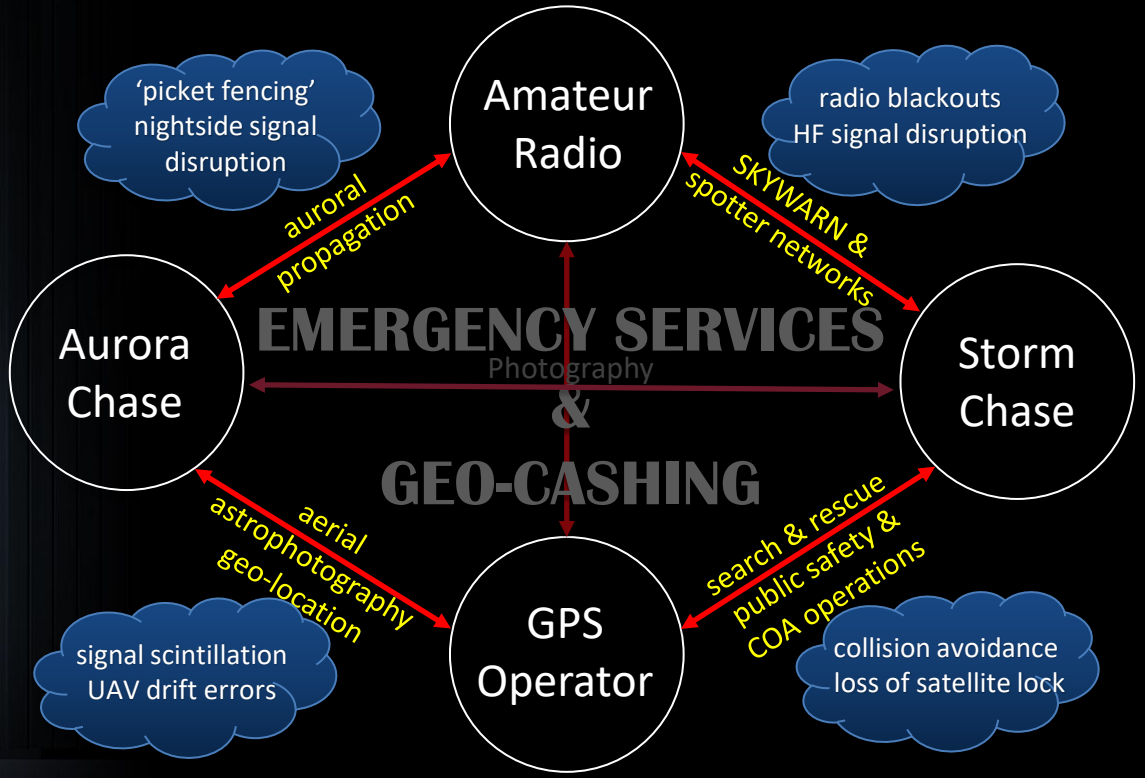


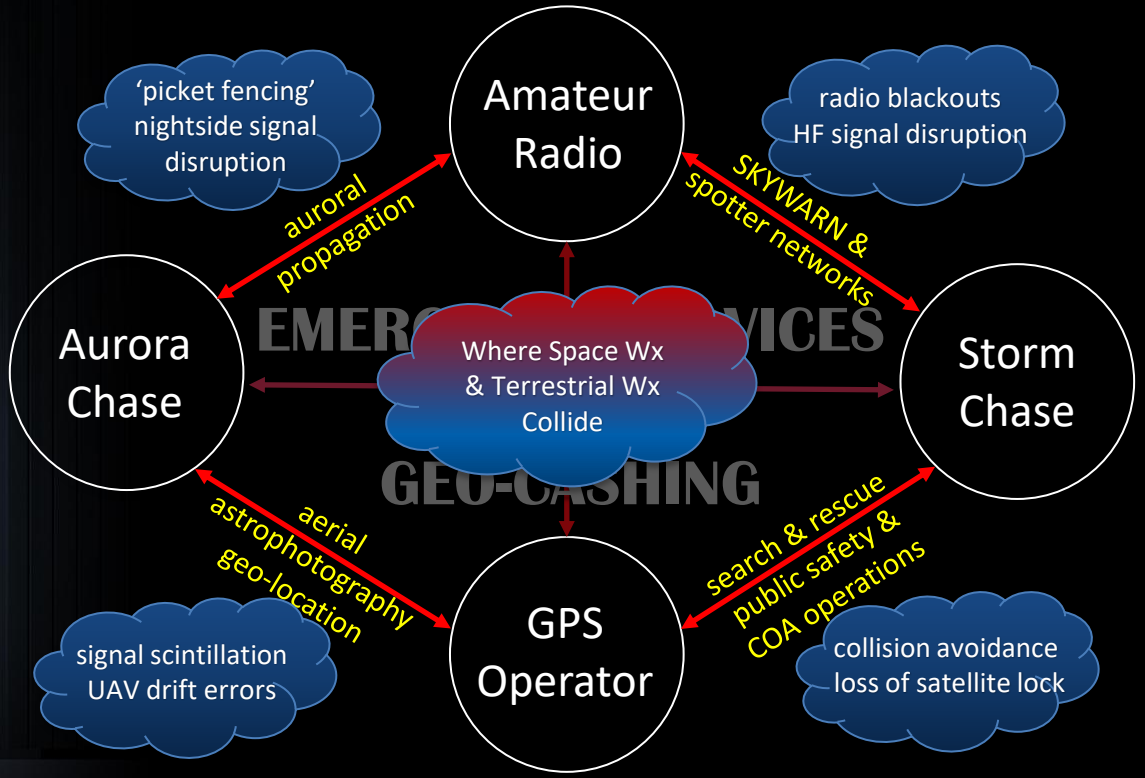
Forming a highly-skilled "Super Community" connected by expertise and weather

Space Weather Interconnects Communities



Forming a highly-skilled "Super Community" connected by expertise and weather

Space Weather Interconnects Communities



Forming a highly-skilled "Super Community" connected by expertise and weather

The Mobile Phone Camera Revolution

The public knows of space weather, but thanks to pop-culture, Super Storm events have taken on a new meaning

Cell phone camera CCDs sensitive enough to capture low-light events including Aurora

A Super Storm Event portrayed in Modern Space Weather

Pet names for a Super Storm Event Today:

- Mega-Flare
- Kill-Shot
- Micro-Nova
- Power Grid Destroyer
- Armageddon from the Sun
- God's Wrath
- Black Swan

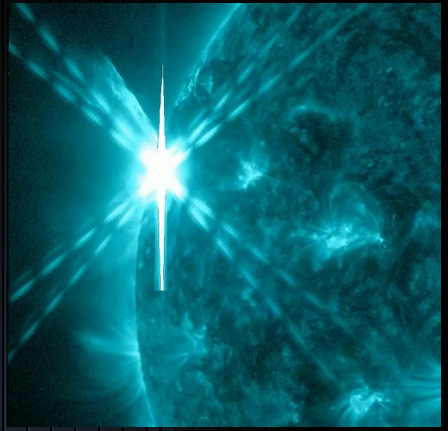
Basically, it is any space weather event that spells doomsday for Earth's weakening magnetic field, all our technology, and ultimately all life on Earth

Solar Attack (also called ***Solar Strike***) is a 2006 television film by CineTel Films and Lions Gate Entertainment, starring Mark Dacascos, Joanne Kelly and Louis Gossett Jr.

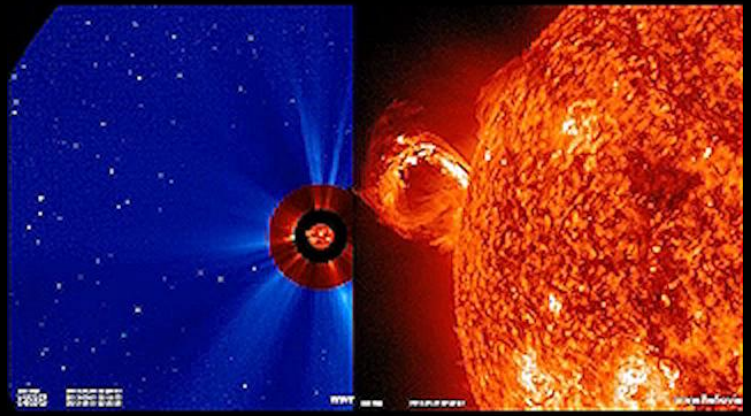
Solar Attack concerns large coronal mass ejections (CMEs) that cause the Earth's atmosphere to burn, potentially suffocating all life on Earth. All of this happens during a time of political tension between the United States and Russia. Disaster is eventually averted by the detonation of nuclear missiles at the poles, releasing vapor that extinguishes the burning methane caused by the CMEs.[1]

Four Basic Types of Solar Phenomena that Affect Earth

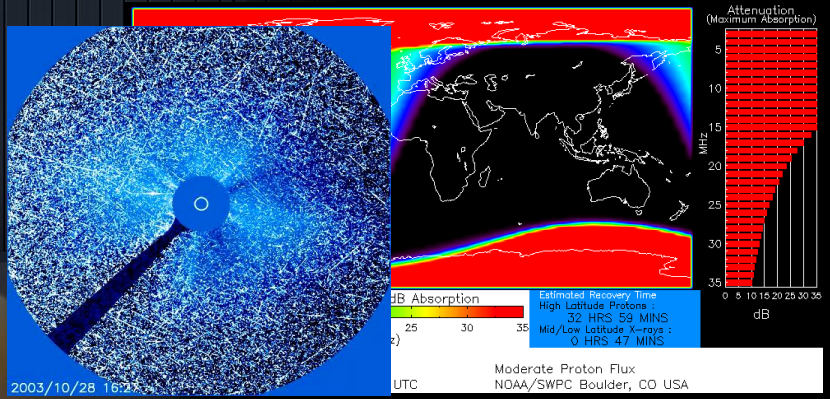
Solar Flares



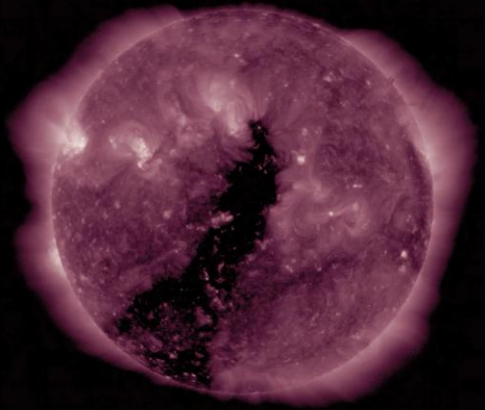
Solar Storms (a.k.a. CMEs)



Solar Radiation Storms (a.k.a. SEPs)

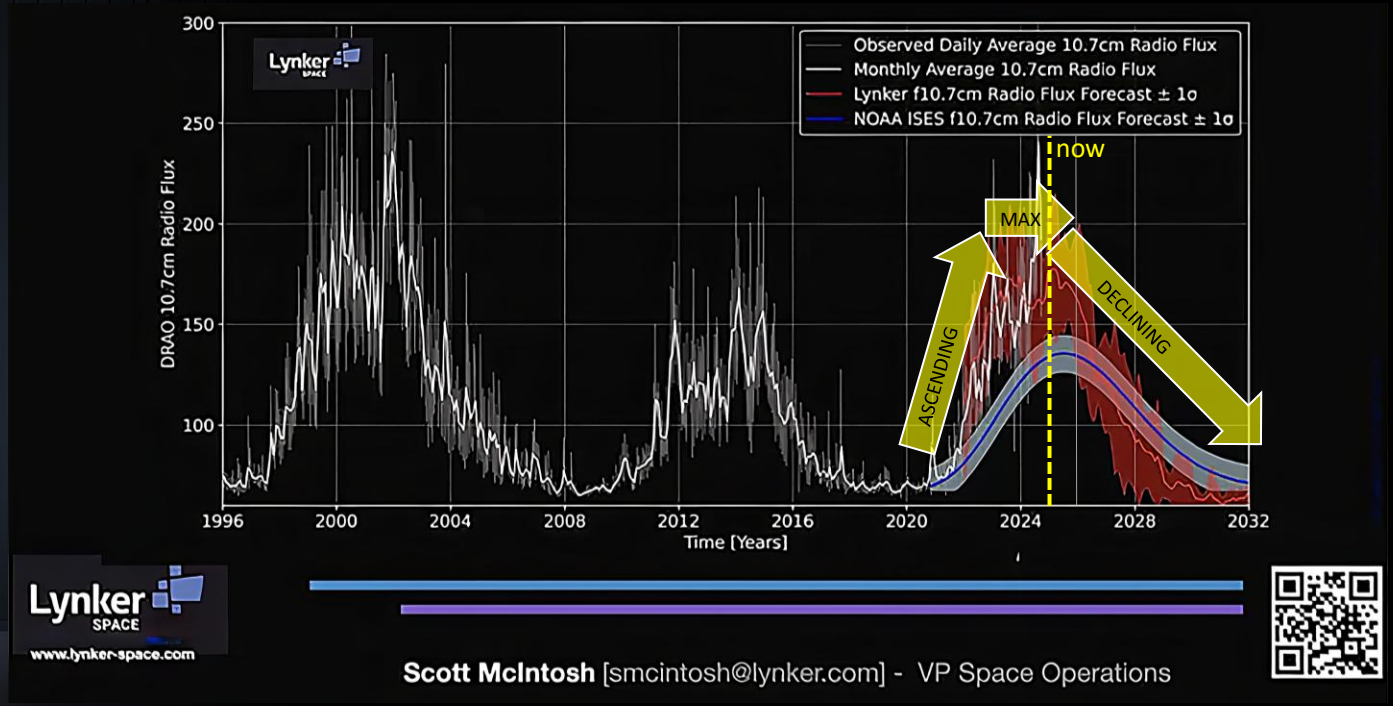


Coronal Holes (Fast Solar Wind)



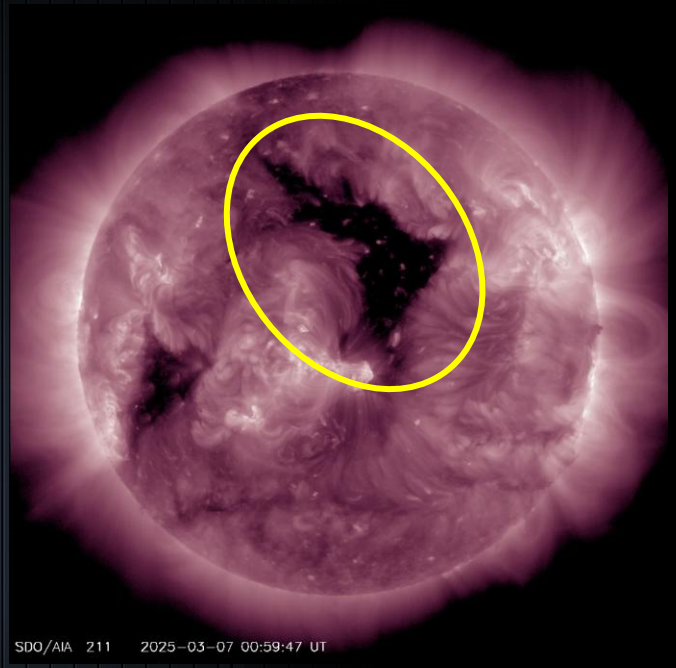
Solar Cycle 25: Where are We Now?

- Recent F10.7cm flux drop signals we have entered the declining phase
- Lynker-Space predictions show it dropping below 100 mid-to-late 2027

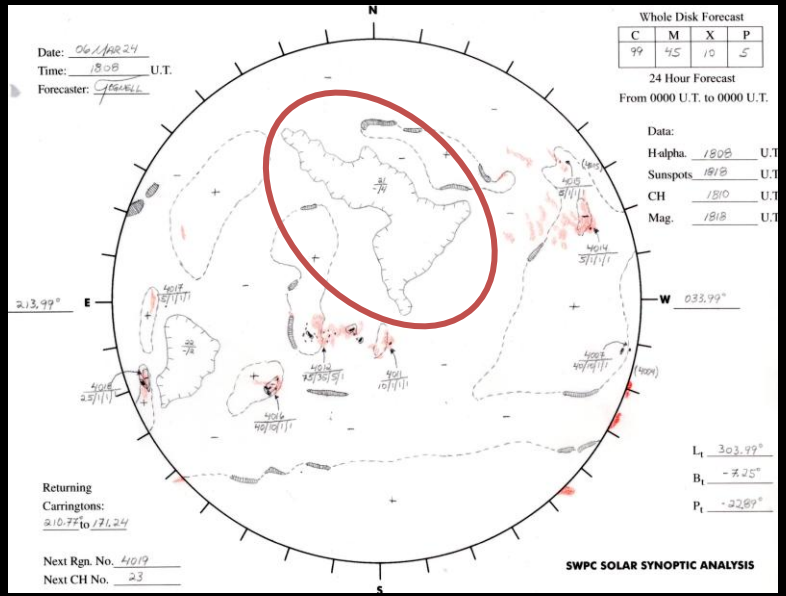


In the Declining Phase Coronal Holes Take Center Stage

SDO/AIA 211Å imagery

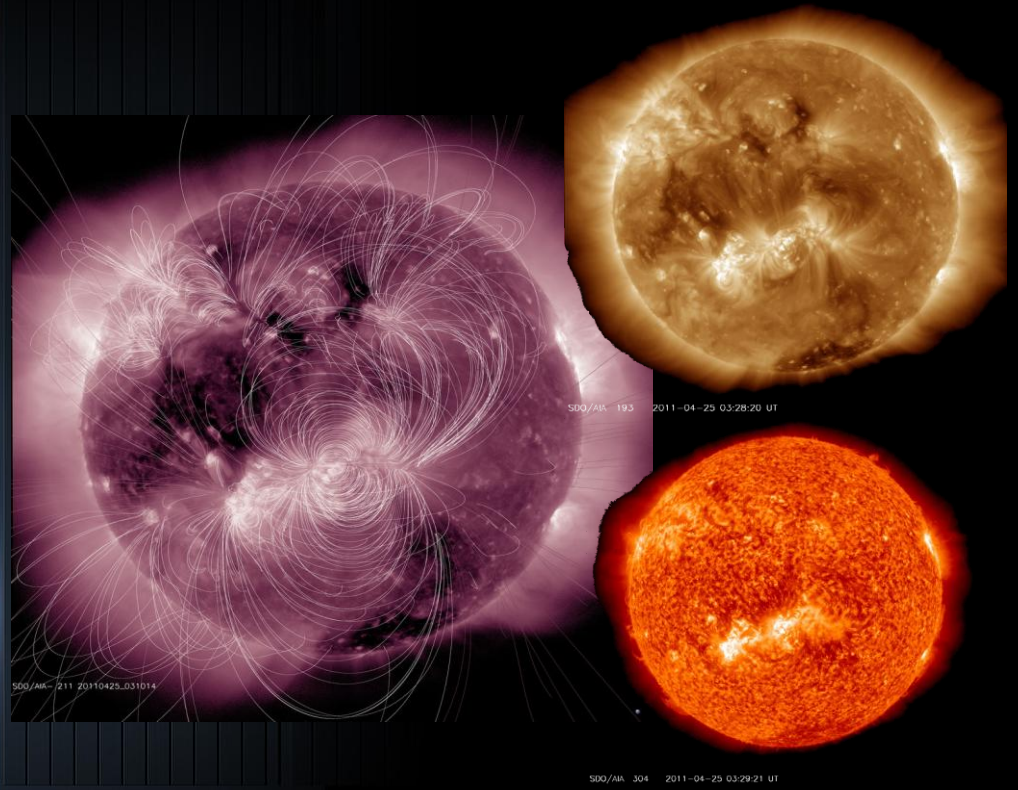


NOAA/SWPC Synoptic Chart



- The declining phase is when solar dynamics are the most complex
- A new dipole field competes with the remnants of the old

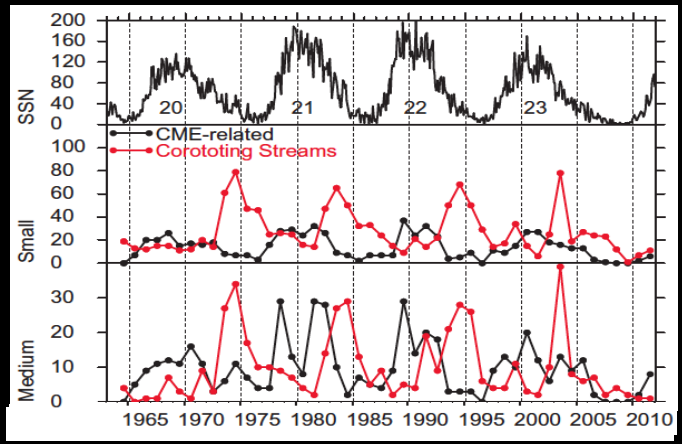
What Are Coronal Holes?

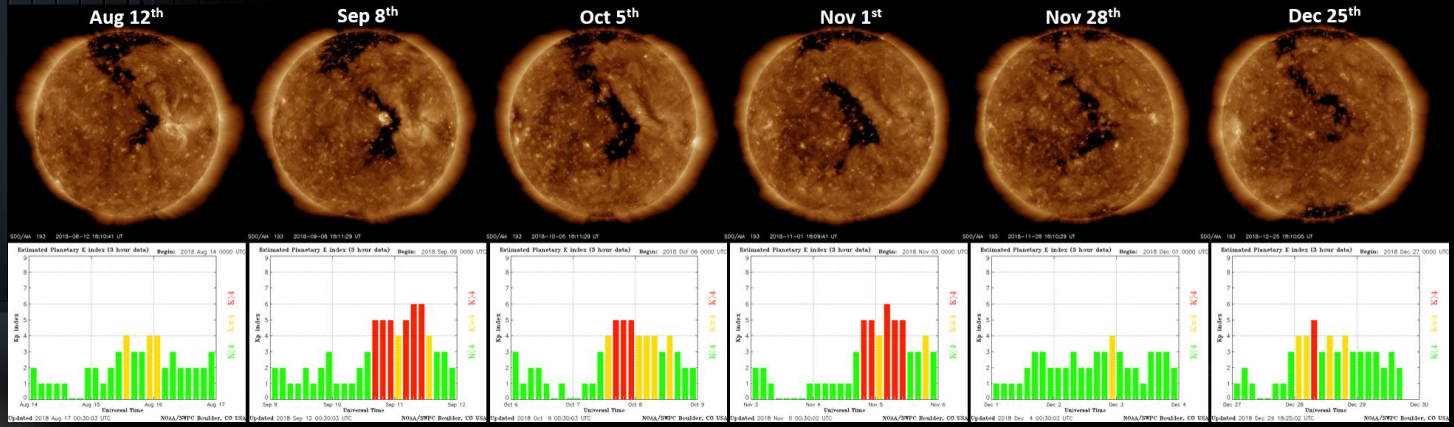


- Coronal holes appear as dark areas on the solar surface in specific frequencies of EUV and X-ray
- They have a lower density and temperature compared with the surrounding corona
- They correspond to regions of open magnetic field and fast solar wind
- In the declining phase they become “trans-equatorial”

Coronal Holes Drive Recurrent Storms

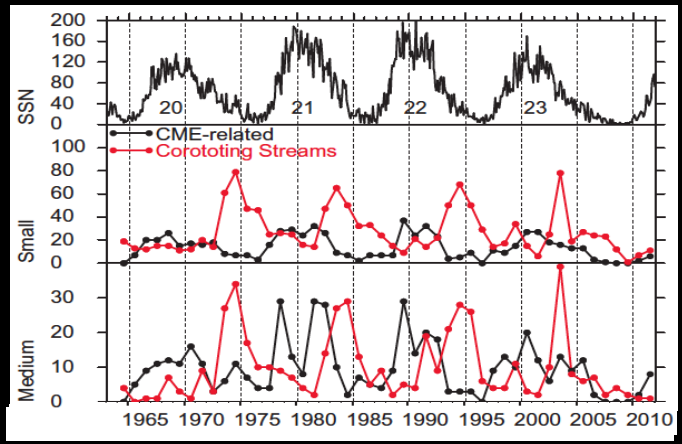
- Geomagnetic storm activity always peaks during the declining phase
- This is when the incidence of fast wind streams at Earth from coronal holes increases dramatically
- This cycle will have faster high-speed streams than Cycle 24

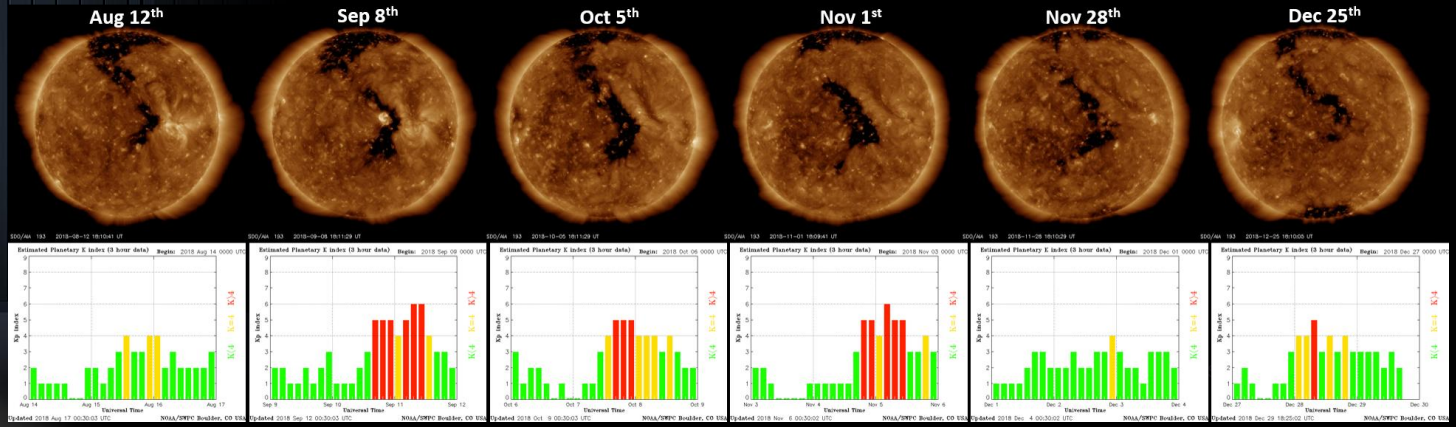




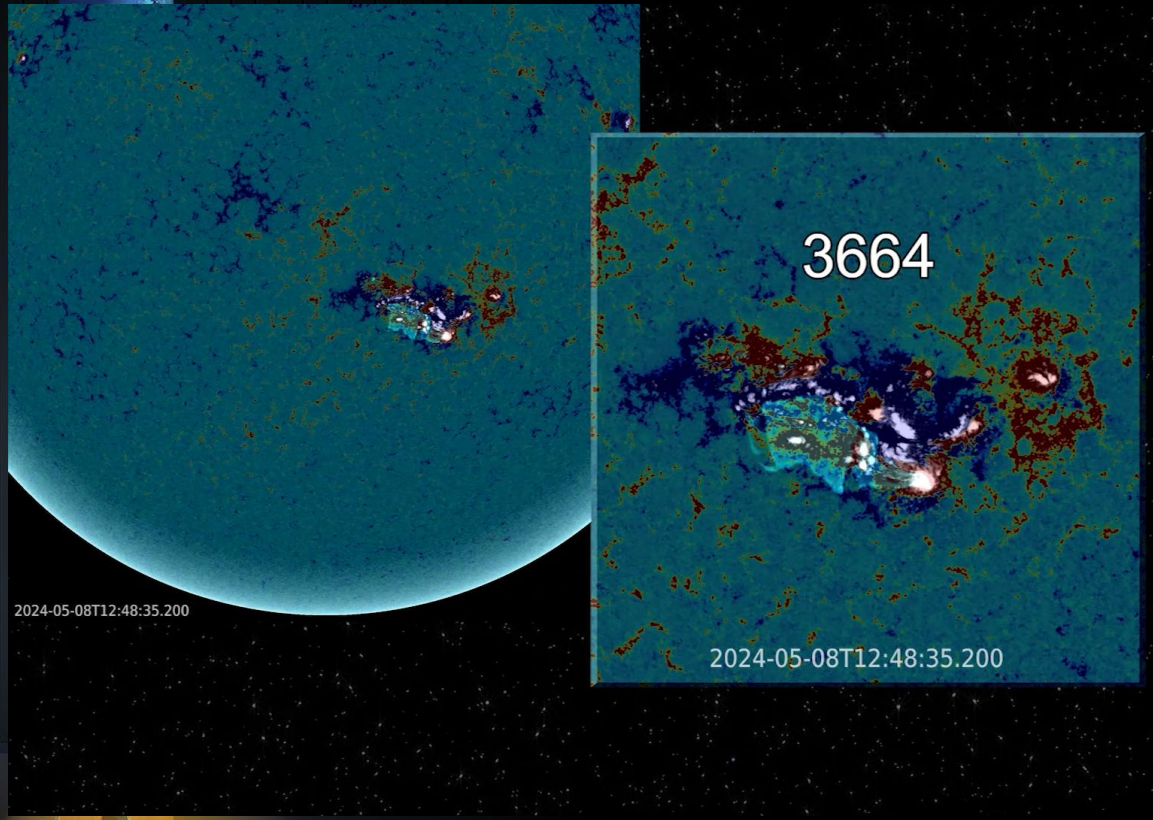
Coronal Holes Drive Recurrent Storms

- In the declining phase space weather becomes more predictable
- Every 27 days old patterns return due to ”persistent” coronal holes
- For radio propagation, knowing *what kind* of fast wind is crucial for propagation
- This depends upon the season & sector polarity *(from CTU: Storm times S.N.A.P)*





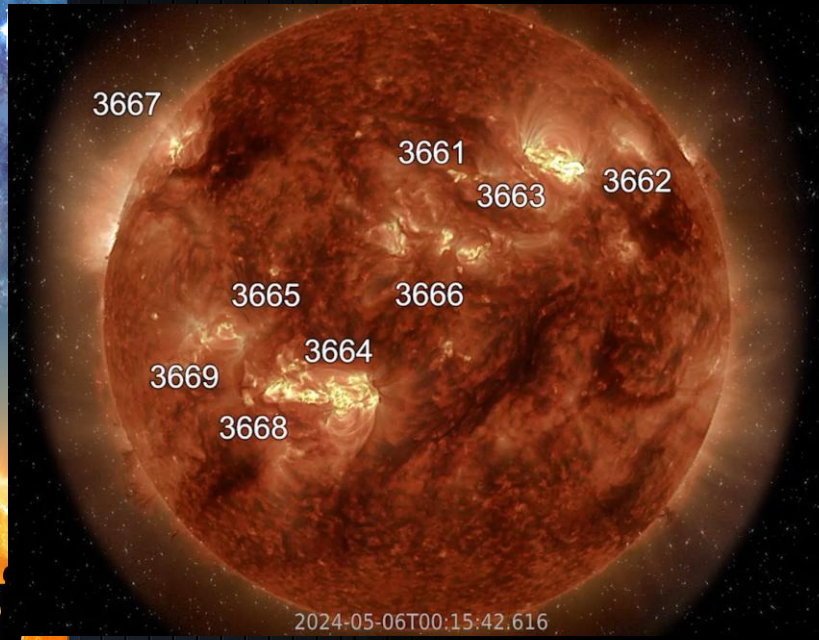
Super Storm Producer Region 3664 in May 2024

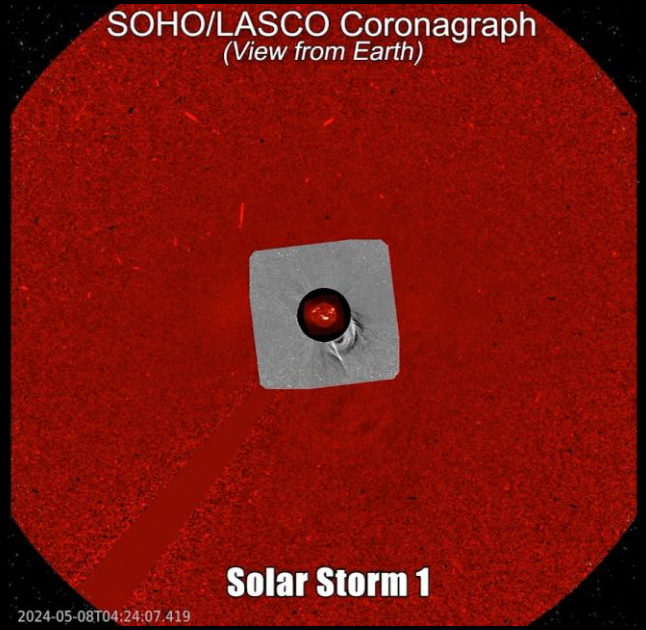


Evolution of Region 3644

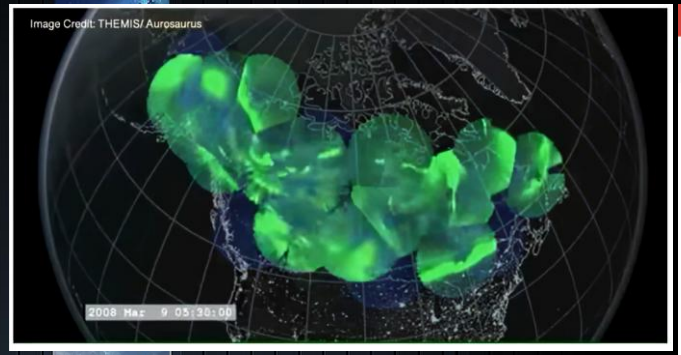
- Merging of THREE regions
- Fired 10 X-class flares *(including the largest of this cycle)*
- Caused G5-level “super storm” *(largest since 2005)*
- By contrast no G5-level storms occurred in Solar Cycle 24

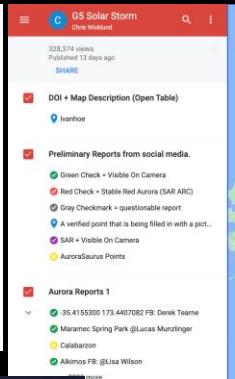
The G5 “Gannon Storm” Caused by at least 7 CMEs

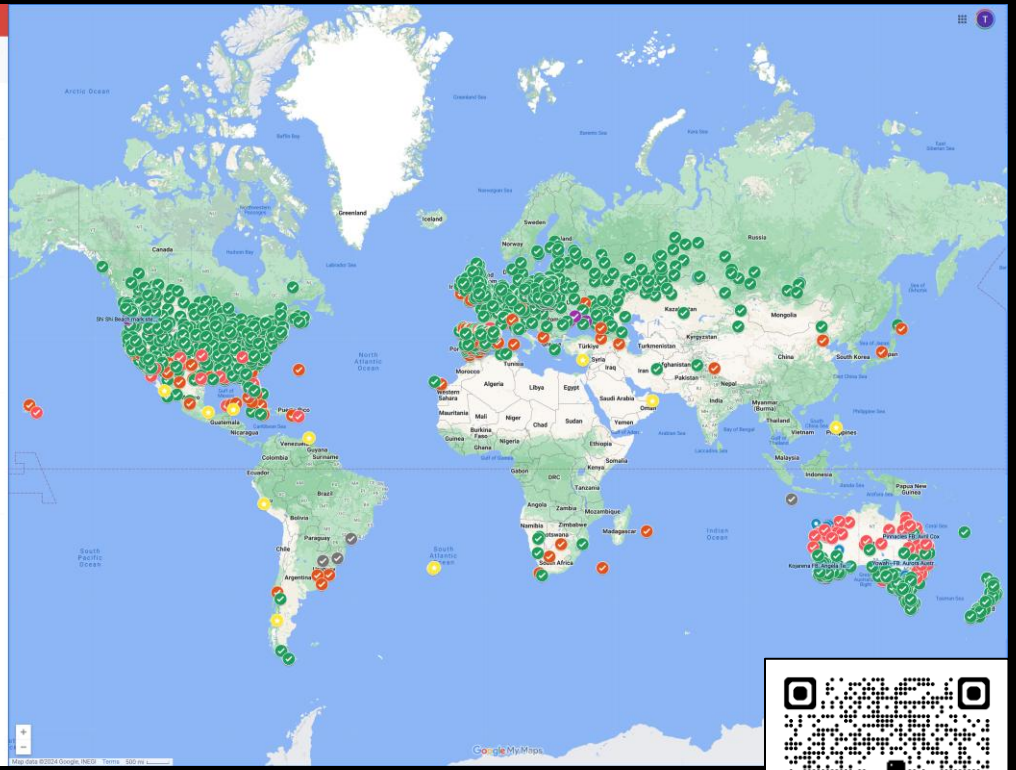


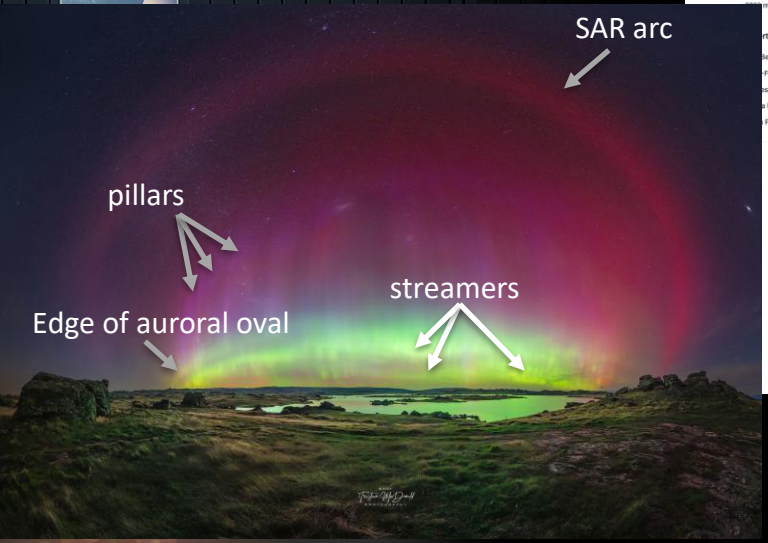


Aurora during “Gannon Storm” was Visually Disruptive

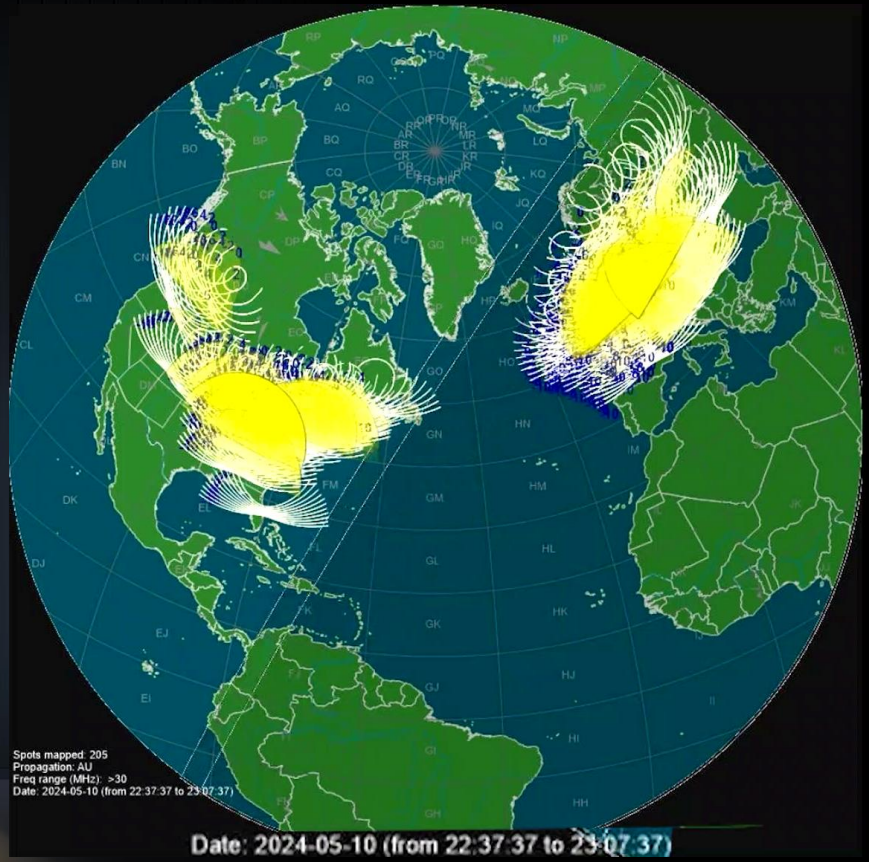








CONUS Auroral Propagation as far South as Florida



Credit: G7IZU/G7RAU (Live MUF V7)

- Live MUF V7 conics show locations of anecdotal reports of auroral propagation during May 10 – 11, 2024
- The horizontal wings of the conics indicate the latitudes at which auroral scatter in the HF range becomes possible
- But what “kind” of aurora is responsible?

Gannon Storm Disrupted Precision Farming

JOHN DEERE | LANDMARK IMPLEMENT

Geomagnetic Storm Signals - May 2024

Friday, May 10 - 5:00pm Update:

We are seeing GPS issues across our e
other levels of GPS. We are currently tr

machine is receiving from the base sta
accuracy will still likely be reduced due to the storms.

We apologize for the inconvenience.

posted on Saturday, May 11, 2024 in News/Blog

Saturday, May 11 - 9:00am Update:

Yesterday, we sent out a text message advising customers to turn off their RTK and use a grace period of SF2 or SF3. We believe that the SF2 and SF3 accuracy is also extremely compromised as well due to this storm. Due to the way the RTK network works, the base stations were sending out corrections that have been affected by the geomagnetic storm and were causing drastic shifts in the field and even some

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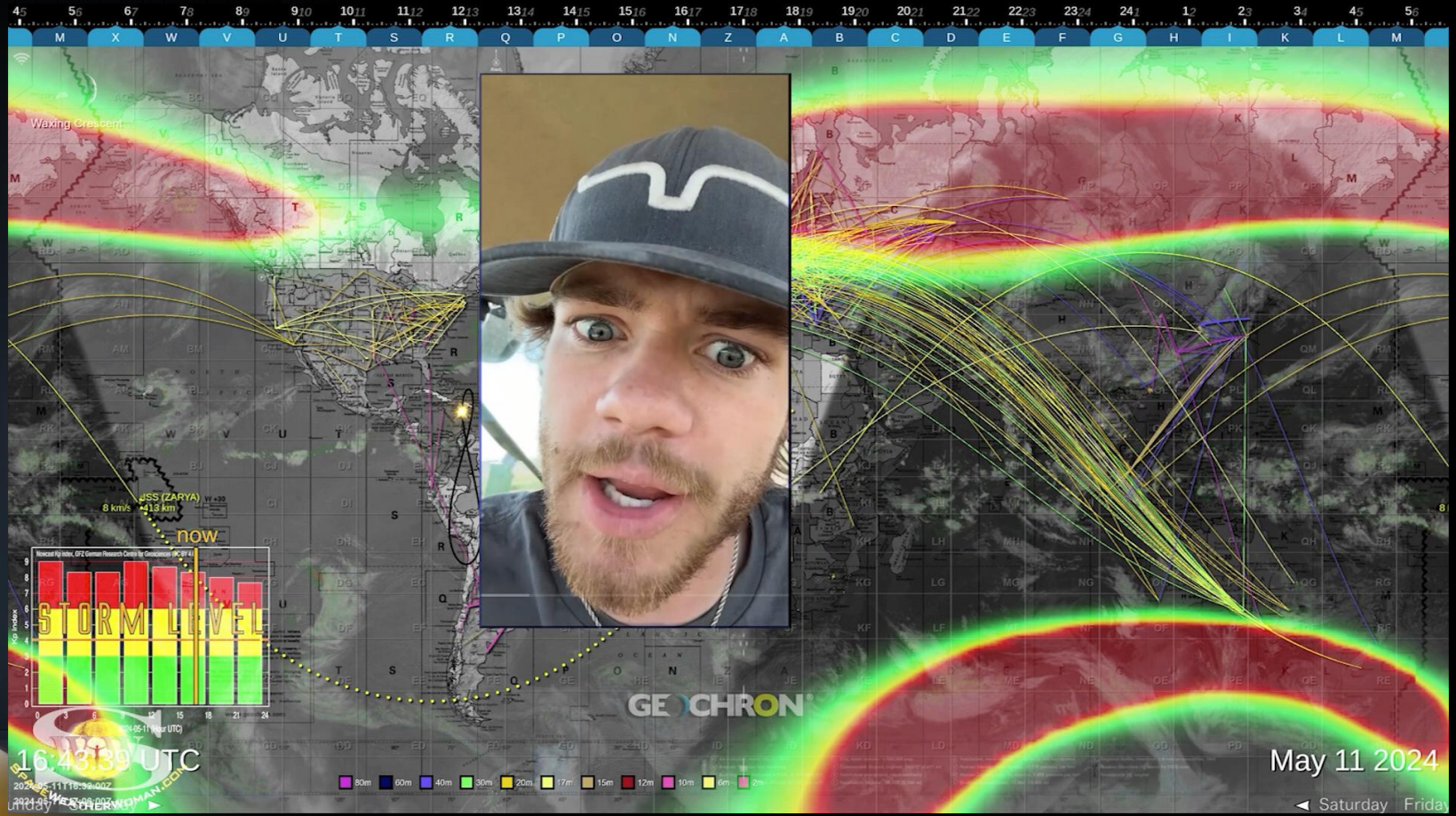
situation at hand is definitely not ideal.

When you head back into these fields to side dress, spray, cultivate, harvest, etc. over the next several months, we expect that the rows won't be where the AutoPath lines think they are. This will only affect the fields that are planted during times of reduced accuracy. It is most likely going to be difficult - if not impossible - to make AutoPath work in these fields as the inaccuracy is most likely inconsistent.

https://landmarkimp.com/news/news/blog/geomagnetic-storm-affecting-gps-signals--may-2024/

Impacts of the “Gannon” G5 Storm were Widespread



Gannon Storm Disrupted Precision Farming

AGRICULTUREDIVE Deep Dive Events Press Releases

Crops Meat Dairy

Geomagnetic storm s navigation systems

The massive solar storm that splashed the nort farming operations at the peak of planting seas

Published May 15, 2024

By S.L. Fuller and Sarah Zimmerman

The northern lights fill the sky with green ribbons of electrical charged particles over the barn and pastures at Greaney's Turkey Farm in Mercer, Maine on May 11, 2024. *Michael Seamans via Getty Images*

AGRICULTUREDIVE Deep Dive Events Press Releases Topics

While the solar storm is considered a one-off event, it raises questions about the future reliability and security of agriculture technology as farmers increasingly adopt digital solutions, according to Curt Covington, senior director of institution credit at AgAmerica Lending. The event could also deter some farmers from adopting technology down the line.

"If anything came from this, it's the importance of being proactive in protecting our food system and having a response plan in place to avoid large-scale disruption," Covington said in an email to Agriculture Dive.

Editor's note: This story has been updated to include comments from AgAmerica Lending.

https://www.engadget.com/the-geomagnetic-storm-is-a-nightmare-for-farmers-relying-on-precision-agriculture-tech-180252016.html

Gannon Storm Disrupted Precision Farming

News & Events

6 MIN READ

What NASA Is Learning from the Biggest Geomagnetic Storm in 20 Years

Storm Consequences

The Gannon storm had effects on and off our planet.

On the ground, some high-voltage lines tripped, transformers overheated, and GPS-guided tractors veered off-course in the Midwestern U.S., further disrupting planting that had already been delayed by heavy rains that spring.

"Not all farms were affected, but those that were lost on average about $17,000 per farm," said Terry Griffin, a professor of Agricultural Economics at Kansas State University. "It's not catastrophic, but they'll miss it."

In the air, the threat of higher radiation exposure, as well as communication and navigation losses, forced trans-Atlantic flights to change course.

https://science.nasa.gov/science-research/heliophysics/what-nasa-is-learning-from-the-biggest-geomagnetic-storm-in-20-years/

Multiple Storms in 2024 Disrupted Precision Farming

spaceweather.com

News and information about the Sun-Earth environment

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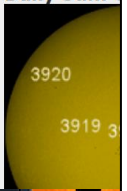
Current Conditions

Solar wind
speed: **467.8** km/sec
density: **1.74** protons/cm^3
more data: ACE, DSCOVR
Updated: Today at 1147 UT

X-ray Solar Flares
6-hr max: **C2** 1947 UT Dec09
24-hr: **C8** 1612 UT Dec09
explanation | more data
Updated: Toda

Daily Sun: (



What's up in space

Monday, Dec.

This is an AI Free Zone! Text created by Large Language Models is spreading rapidly across the Internet. It's well-written, but frequently inaccurate. If you find a mistake on Spaceweather.com, rest assured it was made by a real human being.

IMPULSIVE X-CLASS SOLAR FLARE: Sunspot 3912 erupted on Dec. 8th (0906 UT), producing an X2-class solar flare and a shortwave radio blackout over southern Africa. The explosion hurled a CME into space, but it will not hit Earth. **Solar flare alerts:** SMS Text

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May 10th wasn't the end of it. Tractors went off-course again during the autumnal storms of Oct. 6th and 10th.

Ramstad was helping her cousins defoliate sugar beets on Oct. 6th when her tractor started acting up: "As the aurora activity began, my GPS was off by close to a foot. Twice while on Autosteer, the tractor danced a row to the left, to the right — and then the defoliator was off a row, so I had to loop around and start over. By nightfall, there was no controlling the Autosteer."

Indiana farmer Michael Spencer had a similar experience: "This fall was the first time I was able to see the aurora. My hair was standing on end from the beauty, however, it did make the John Deere tech dance. When the storms were strongest around Oct. 7th, my tractor's Autosteer system would 'jump the line'--meaning, the tractor would make a quick jolt left or right and I would have to manually reset."

https://spaceweather.com/archive.php?view=1&day=09&month=12&year=2024

Solar activity poses a growing problem for farm-tech. During big solar storms, a layer of Earth's atmosphere called "the ionosphere" fills with bubbles, waves, and turbulence, which severely distort radio signals from GPS satellites. Sometimes tractors and harvesters can't lock on, which stops them in their tracks. Or the signal may be garbled, causing them to juke back and forth.

Crooked rows in Iowa caused by a solar storm.

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Multiple Storms in 2024 Disrupted Precision Farming

Machinery

Home / Farm Management / Precision Agric

KANSAS STATE UNIVERSITY | Agricultural Economics

Receive weekly email updates

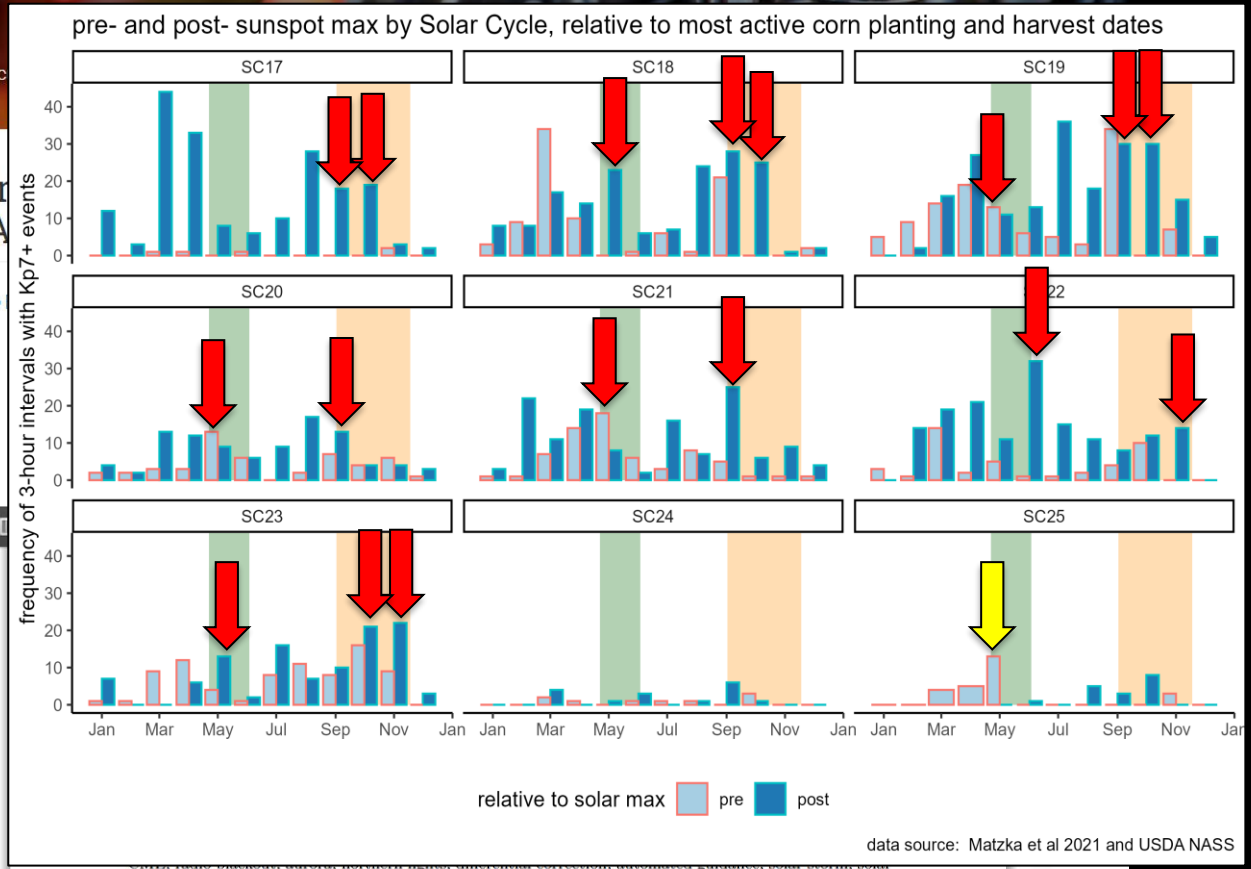
K-State College of Agriculture Links

AgKansitions and Kansas LandLink
Agronomy
Animal Science
Kansas Ag Mediation Service (KAMS)

Extension Agent Link

Farm Management

- Land Buying & Valuing
- Land Rental Rates
- Farm Profitability
- Precision Agriculture
- Finance & Business Planning



particle events, agricultural technology, digital agriculture, automated section control

https://doi.org/10.5281/zenodo.14976490

https://www.agmanager.info/management-finance/precision-agriculture/impact-gannon-storm-corn-production-across-midwestern-usa

New Insights Due to the Super Community Mindset

Global data aggregation is getting easier thanks to a growing number of citizen-driven partnerships in the public and in industry

Google Research | Who we are | Research areas | Our work | Programs & events | Careers | Blog

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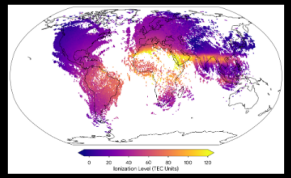
Mapping the ionosphere with the power of Android

November 13, 2024 · Anton Kast and Jamie Smith, Staff Software Engineers, Google Research



We can now understand the ionosphere better thanks to aggregat
measurements from millions of Android phones.

The ionosphere is a swirling sea of charged particles that lies in Earth's upper atmosphere. The ions accumulate wh
radiation collides with atmospheric gas molecules, knocking off some of their electrons. Variations in the free electr
across the ionosphere are one of the largest sources of error in satellite navigation systems such as the Global Pos
(GPS). Spatial and temporal fluctuations in the ionosphere's plasma based on the season, time of day, and geograp
such as distance from the equator, affect the trajectory of satellite signals and interfere with GPS location accuracy
disruptions to satellite communication and navigation systems are caused by bursts of radiation from solar storms
May 2024, which produced spectacular aurorae across both the northern and southern hemispheres.

In a new study published today in *Nature*, we report the use of aggregated sensor measurements from millions of A
to map the ionosphere at a level of accuracy that matches — or, in some parts of the world, far exceeds — that of c
monitoring infrastructure. Although each mobile phone on its own provides noisy readings, we demonstrate that a
crowdsourced network of aggregated signals can act as a highly sensitive scientific instrument. Most importantly, w
accomplish this while maintaining important privacy protections — without identifying any contributing individual d
approach yields particular benefits in regions including India, Southeast Asia, and central Africa, where monitoring

NSF | AMPERE | iridium | JOHNS HOPKINS APPLIED PHYSICS LABORATORY

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AMPERE-NEXT Data Processing Now Valid

An error noted previously has been corrected and all on-line data are valid. The on-line data are fine for scientific work. New calibrations and improved inversions are coming soon! Please reach out to the team for any questions.

AMPERE

Active
Magnetosphere and
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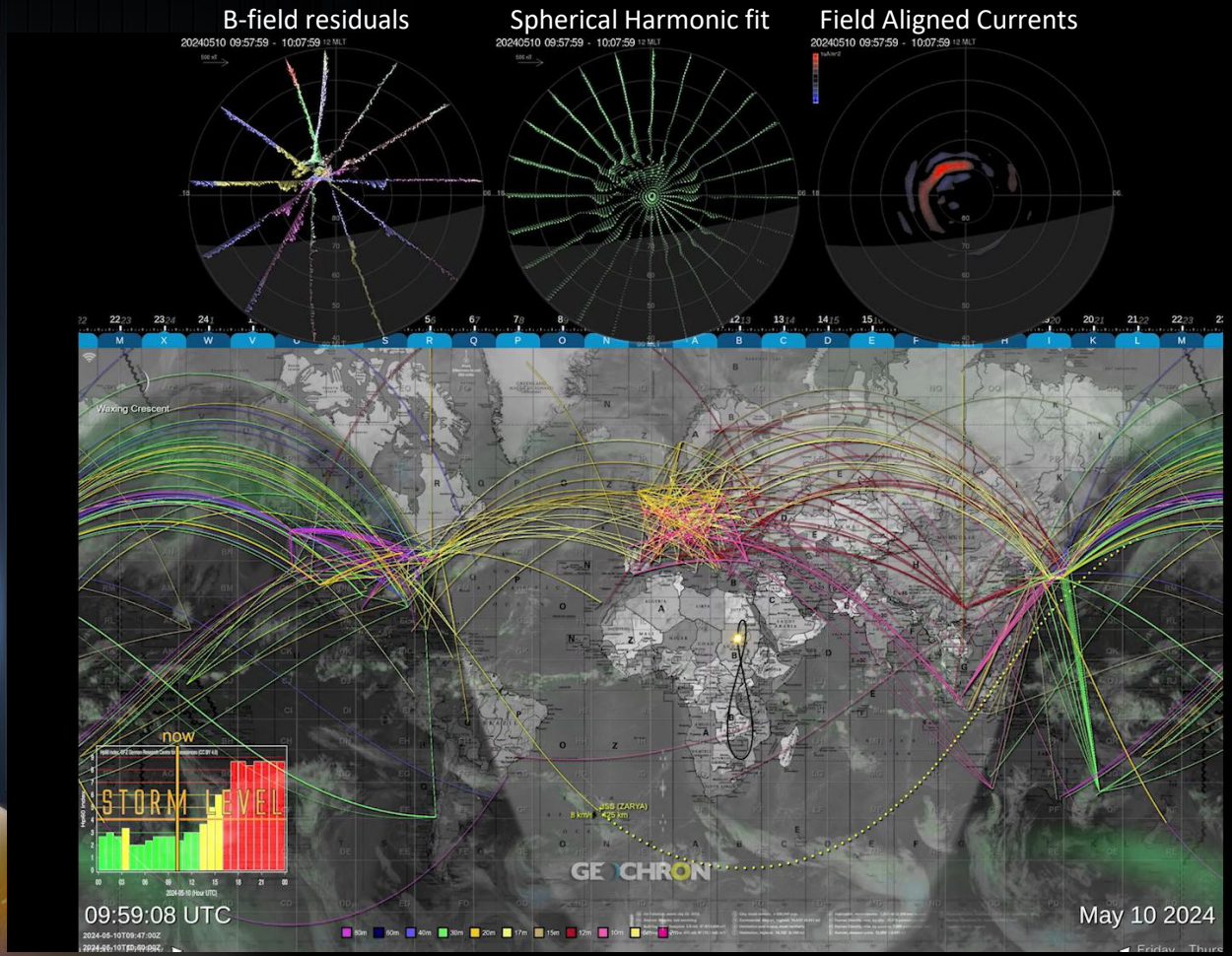
Radio Impacts of the “Gannon Storm” were Widespread



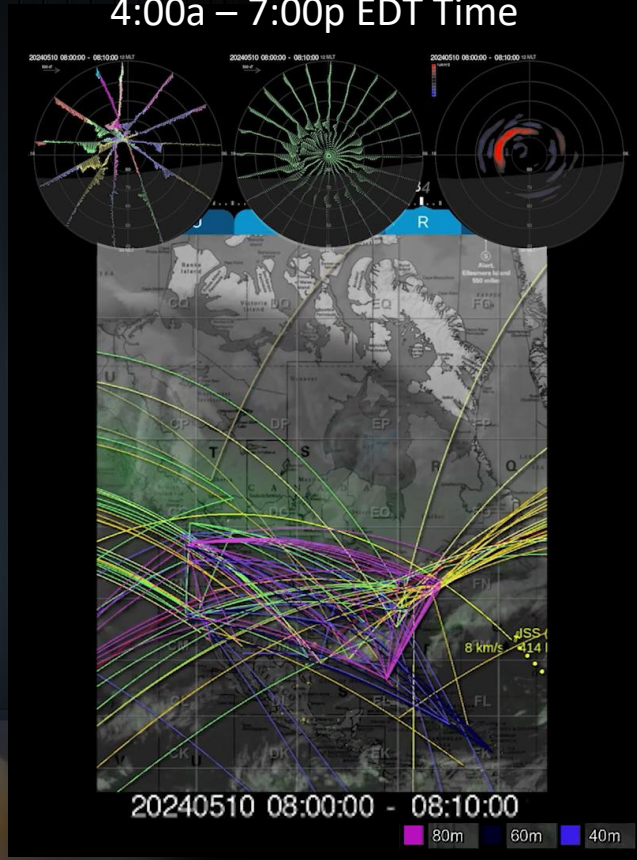
IRIDIUM/AMPERE

GEOCHRON

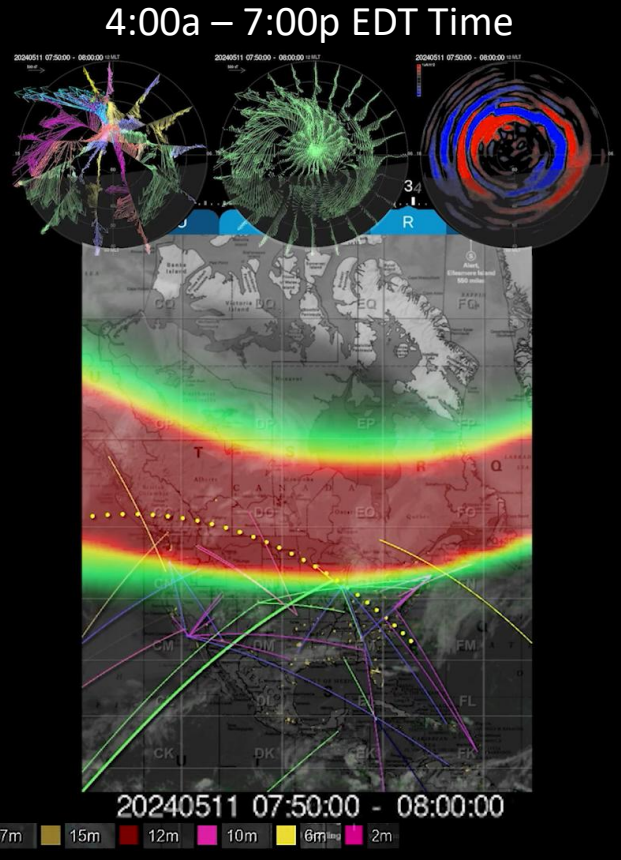
- HF/UHF radio contacts (PSK reporter)
- Ovation Prime (SWPC auroral forecast)
- Hp60 Index

Radio Impacts of the “Gannon Storm” were Widespread

10 May 2024 Pre-Storm
4:00a – 7:00p EDT Time



11 May 2024 Mid-Storm
4:00a – 7:00p EDT Time

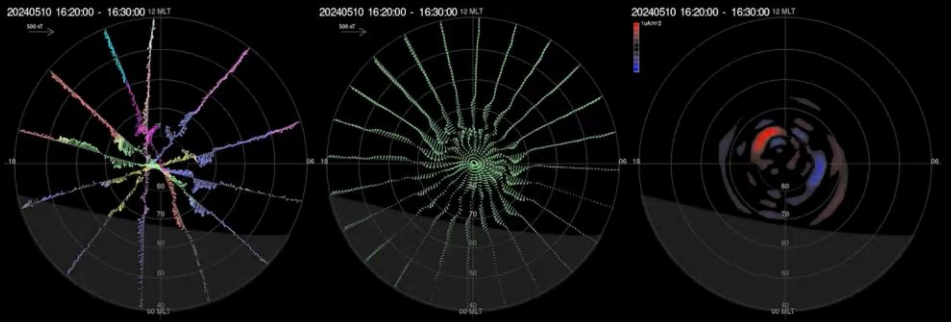


Ionospheric Dynamics in the CONUS During Storm Onset

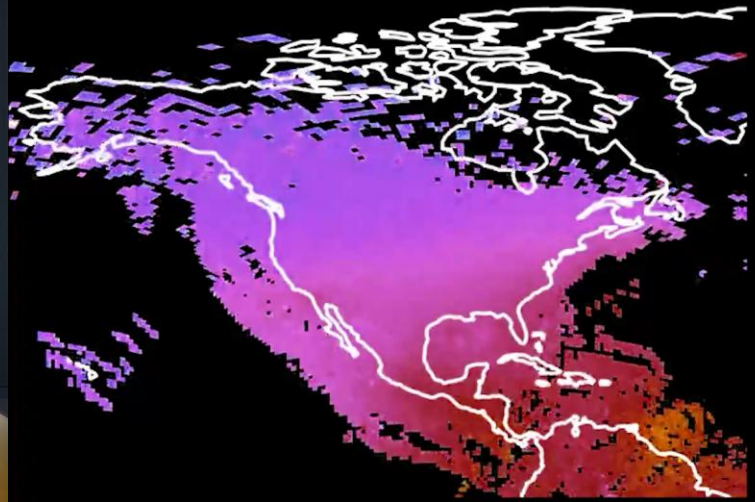
B-field residuals

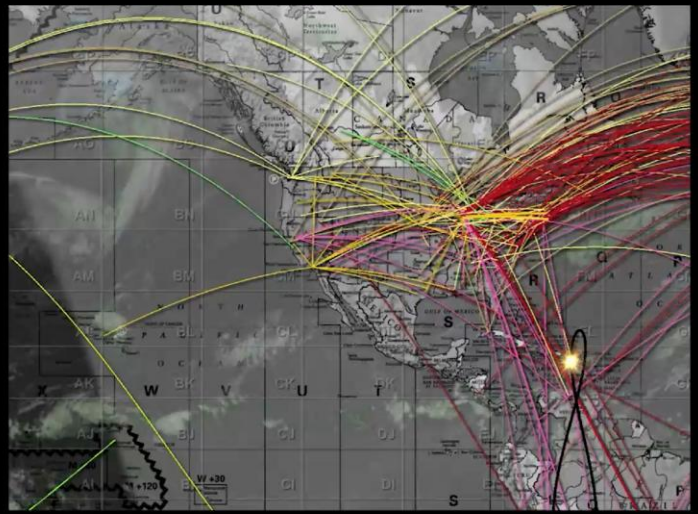
Spherical Harmonic fit

Field Aligned Currents



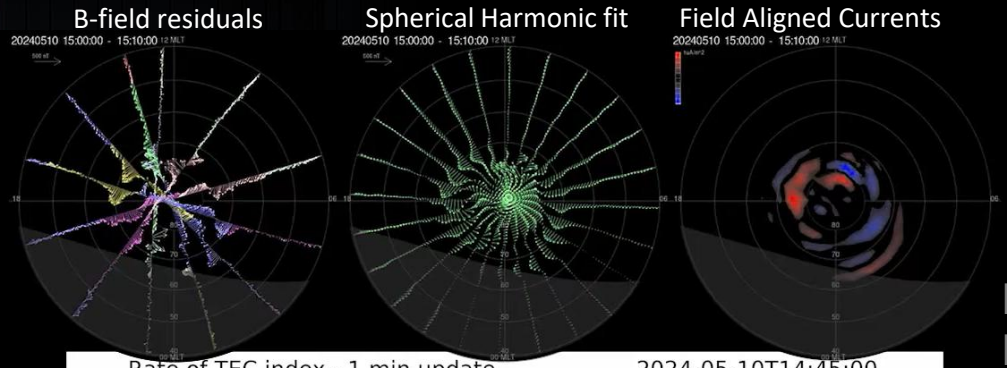
IRIDIUM/AMPERE



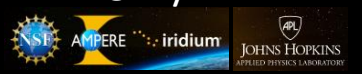


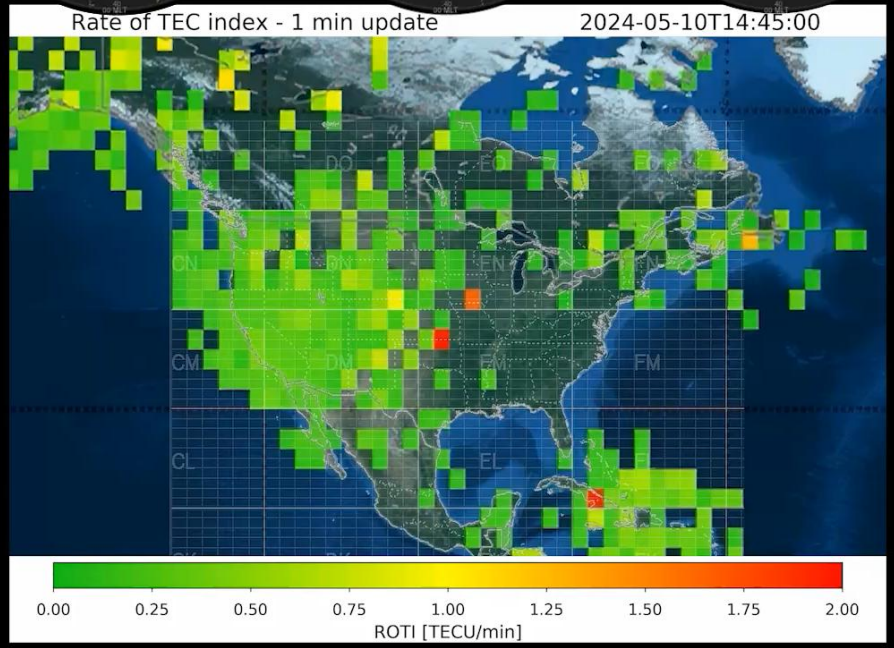
20240510 16:20:00 - 16:30:00

“ROTI in the Red” in the CONUS During Storm Onset



IRIDIUM/AMPERE

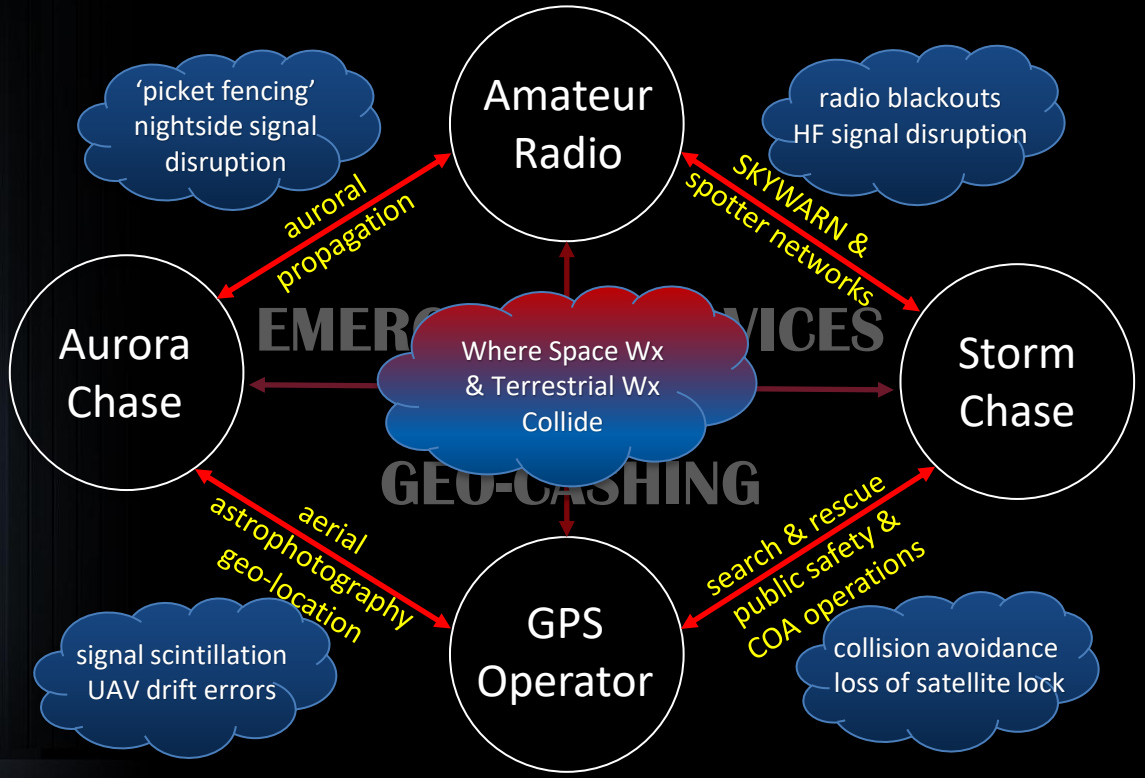




Ionosphere Monitoring and Prediction Center (IMPC)

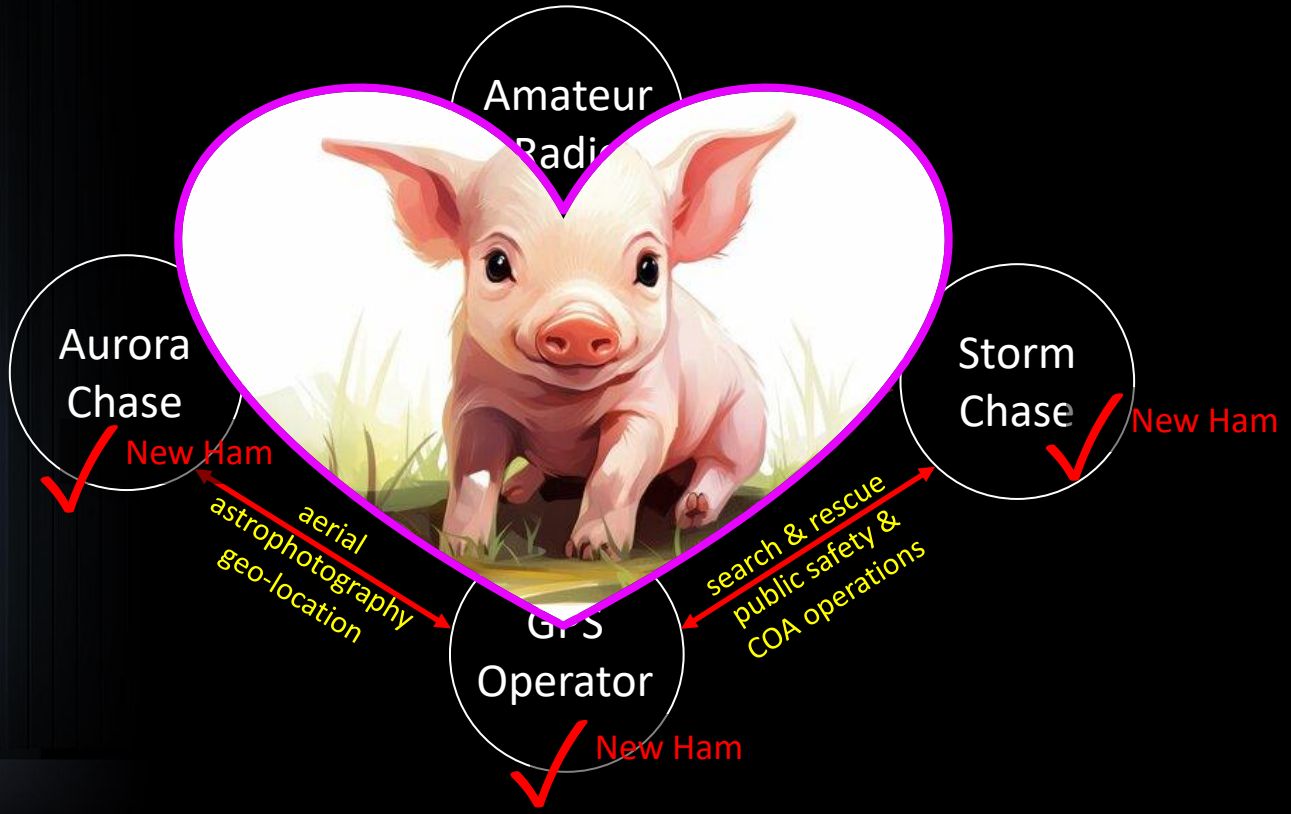
- ROTI: Rate of Change of TEC Index (real-time data)
- Indicates high-risk zones for GPS scintillation (often due to TIDs)
- Note strong auroral oval dynamics in AMPERE followed by intensifications in ROTI
- Overlay of amateur radio Maidenhead grid squares facilitates amateur collaboration

Reciprocity in the Super Community



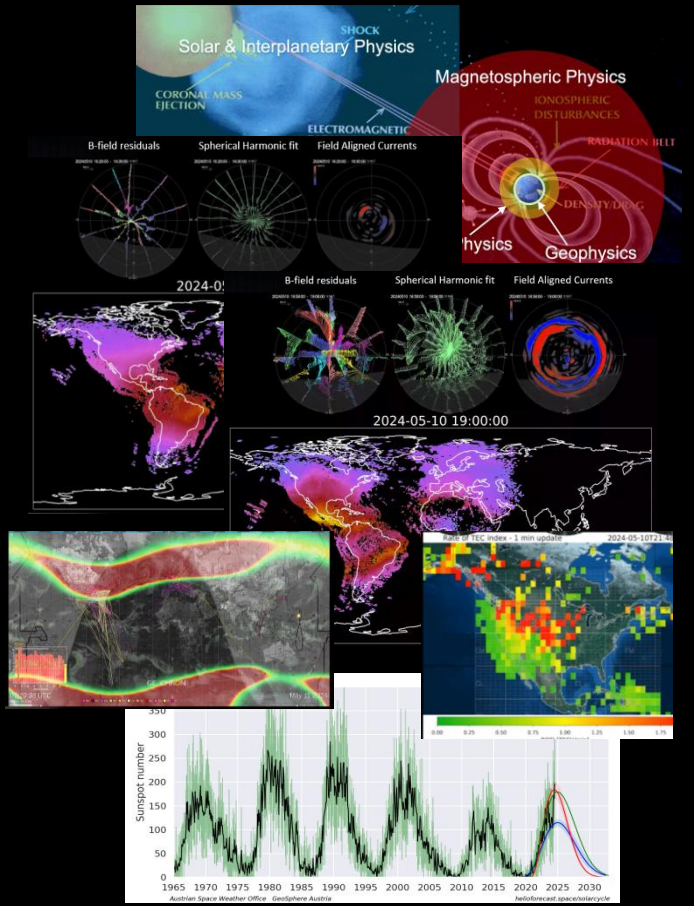
Amateur Radio Operators are the 'Over the Horizon' & Early Detection Arm of this Super Community

Space Weather Interconnects Communities



Summary

- The May 2025 “Gannon” Storm was the largest in 20 years and it opened eyes to new susceptibilities
- We are now entering the declining phase when activity increases but F10.7 flux drops
- Cycle 25 will continue to outperform predictions
- Space weather impacted communities are a “Super Community” of expertise & experience
- Amateur Radio operators are the over-the-horizon and early detection arm of the Super Community
- Precision AG community is only one fast-growing field that will need guidance in the coming years
- You are the Elmers to the Precision AG community among others



Space Weather is 21st Century Weather

Space weather is like the weather in your own backyard just a little further up.

Help us shape the future:

Millersville University Space Weather and Environment Science (SWEN) program

https://www.millersville.edu/swen
POC: tamitha.skov@millersville.edu

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