Solar Weather and Cycle 25

A Revisit

Solar Weather and Cycle 25

- This is an edited version of a presentation from 2023
- The following has changed:
  - Several Topics have been clarified
  - History of Cycle 25 so far is reflected

Disclaimer

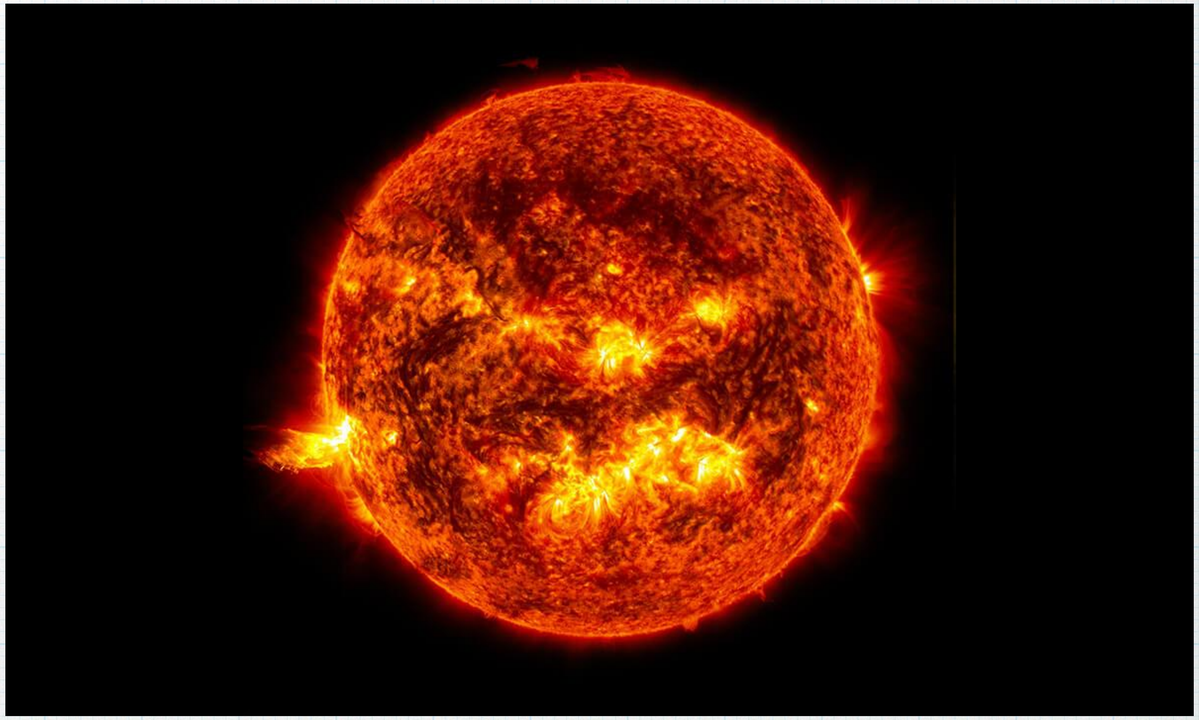
I am neither formally nor informally trained in solar physics or space weather. I’m just a ham who got interested in this stuff and started investigating. I’m just sharing what I’ve discovered.

Solar Weather and Propagation

- Solar behavior and weather
- Earth, its magnetic field, and ionosphere
- Interactions

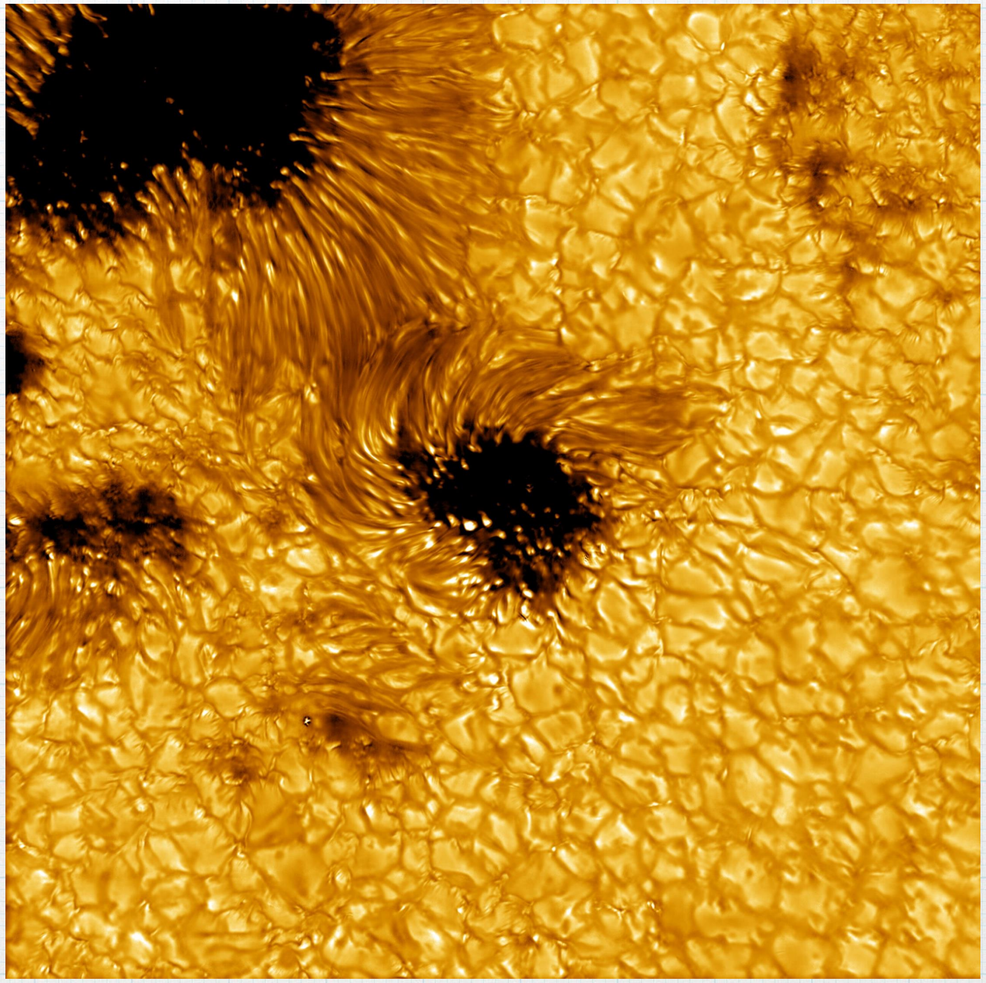
Our Sun

- G2 (”Yellow Dwarf”) star
- ~4.5 Billion years old
- Output: 385 x 10^{24} watts
- Magnetic cycle: 22 years
  - ‘Flips’ every 11 years



Solar Weather

- Sunspots: Regions of intense magnetic density
- Cooler than rest of surface
- Solar disturbance launch points

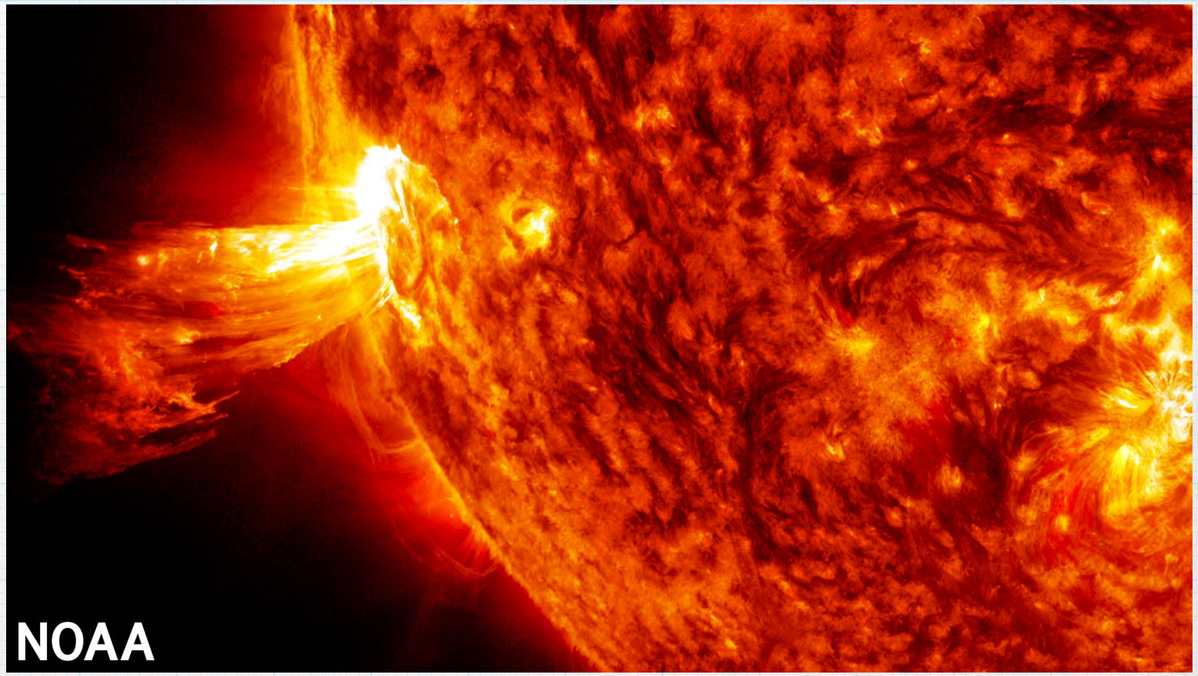


‘SN’ (‘SSN’) Number

- ‘SN’ (also referred to as ‘SSN’) would seem to indicate the number of visible sunspots on the sun’s surface, but it’s more complicated than that.
- SN consists of a sum of two scores:
  - 10 points for each sunspot ‘Group’
  - 1 point for each discrete sunspot
- Thus a single sunspot is 1 Group (10) plus 1, or SN = 11
- Rule of Thumb: SN / 15 = actual number of discrete visible sunspots

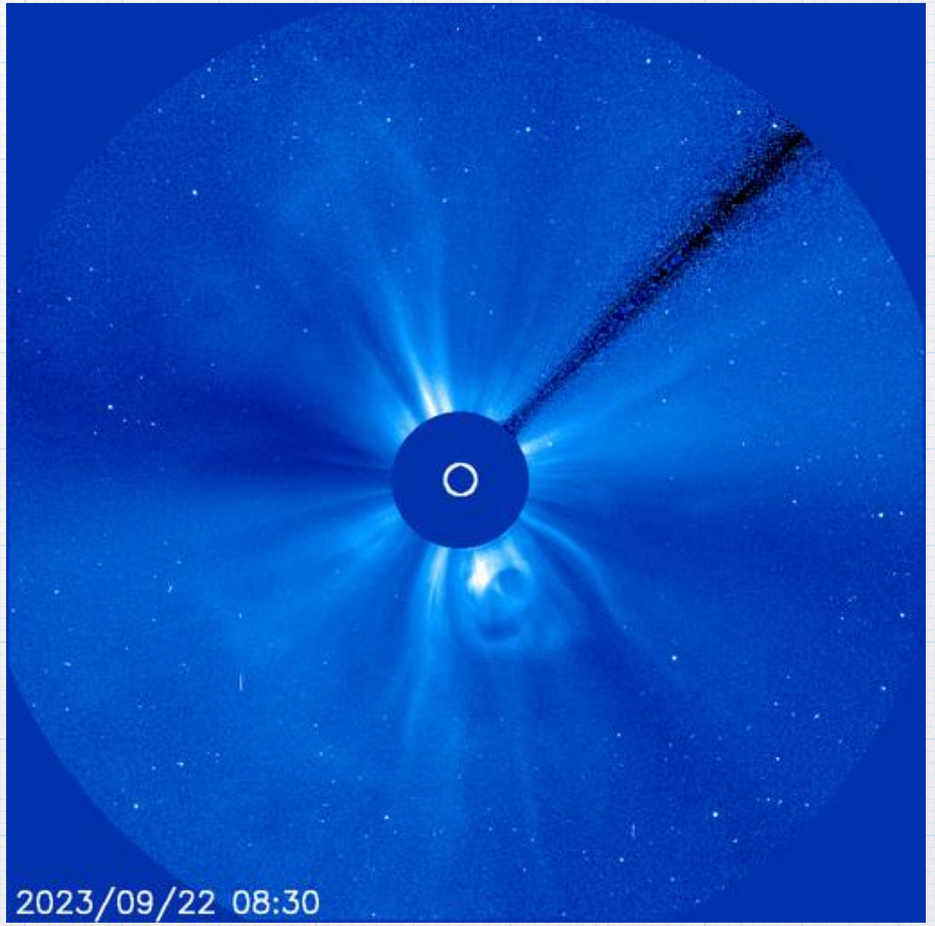
Solar Flares

- ‘Fractured’ magnetic lines
- Geomagnetic, Electromagnetic, and Particulate in nature
- Directed, and often miss the Earth



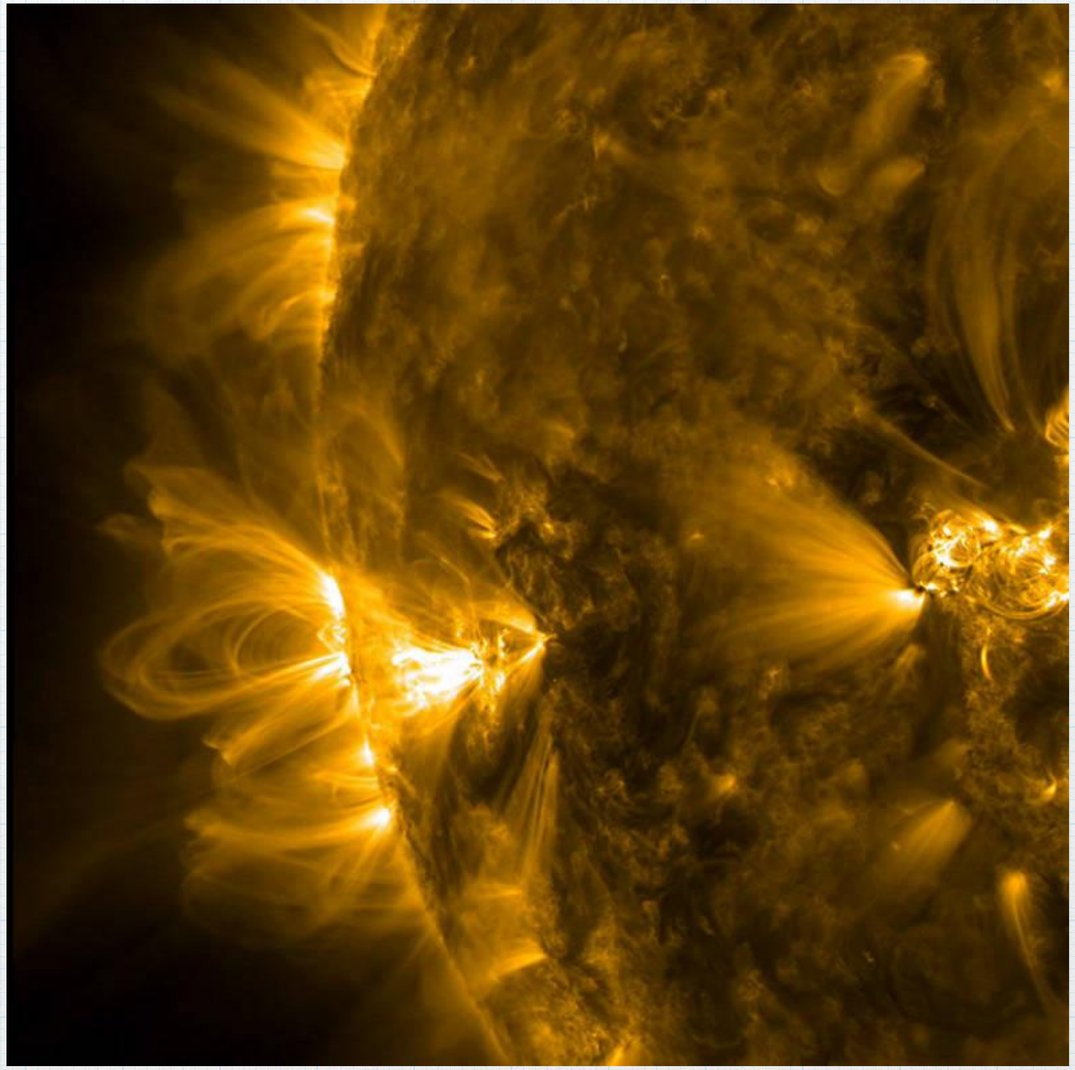
Coronal Mass Ejections (CMEs)

- Material ejected from the sun
- Mostly ionized Hydrogen and Helium
- Can cause major radio disturbances or blackouts if earth-directed



Coronal Loops

- Intense magnetic loops
- Fueled by intense currents
- 10^{16} - 10^{19} Amperes
- Can ‘snap’ and launch solar flares



X-Ray Flares

* Intense bursts of X-Ray radiation ‘leaking’ from sunspot areas
* If Earth-directed, they often cause radio blackouts

Solar Output

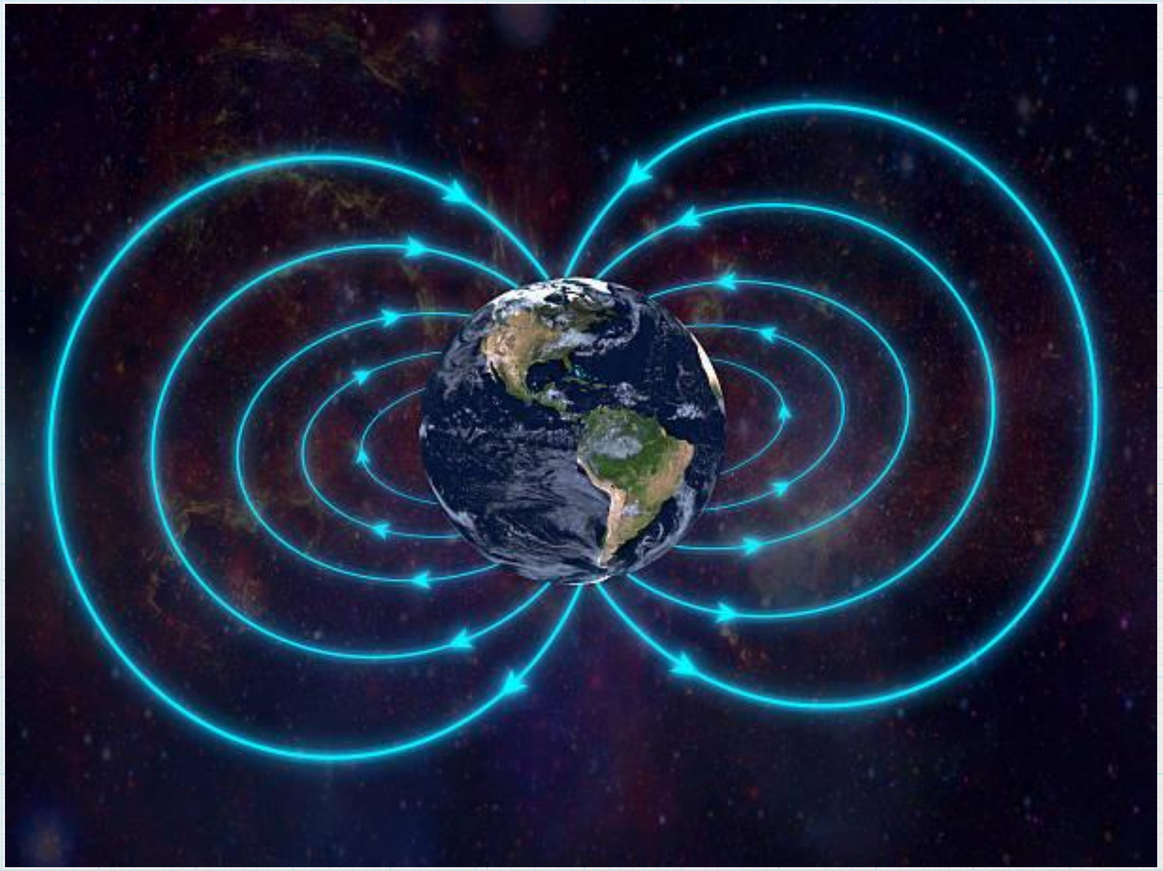
- Output of Sun reaching earth is in 3 general classes:
  - Electromagnetic
    - Visible / Invisible spectrum including IR, UV, X-Rays
  - Geomagnetic
    - Variable magnetic field of Sun, including storms
  - Particulate
    - Solar wind, CMEs, Solar flares

Earth

* Rocky planet, significant atmosphere and a formidable magnetic field
* Orbits the Sun at about 93 million miles distance

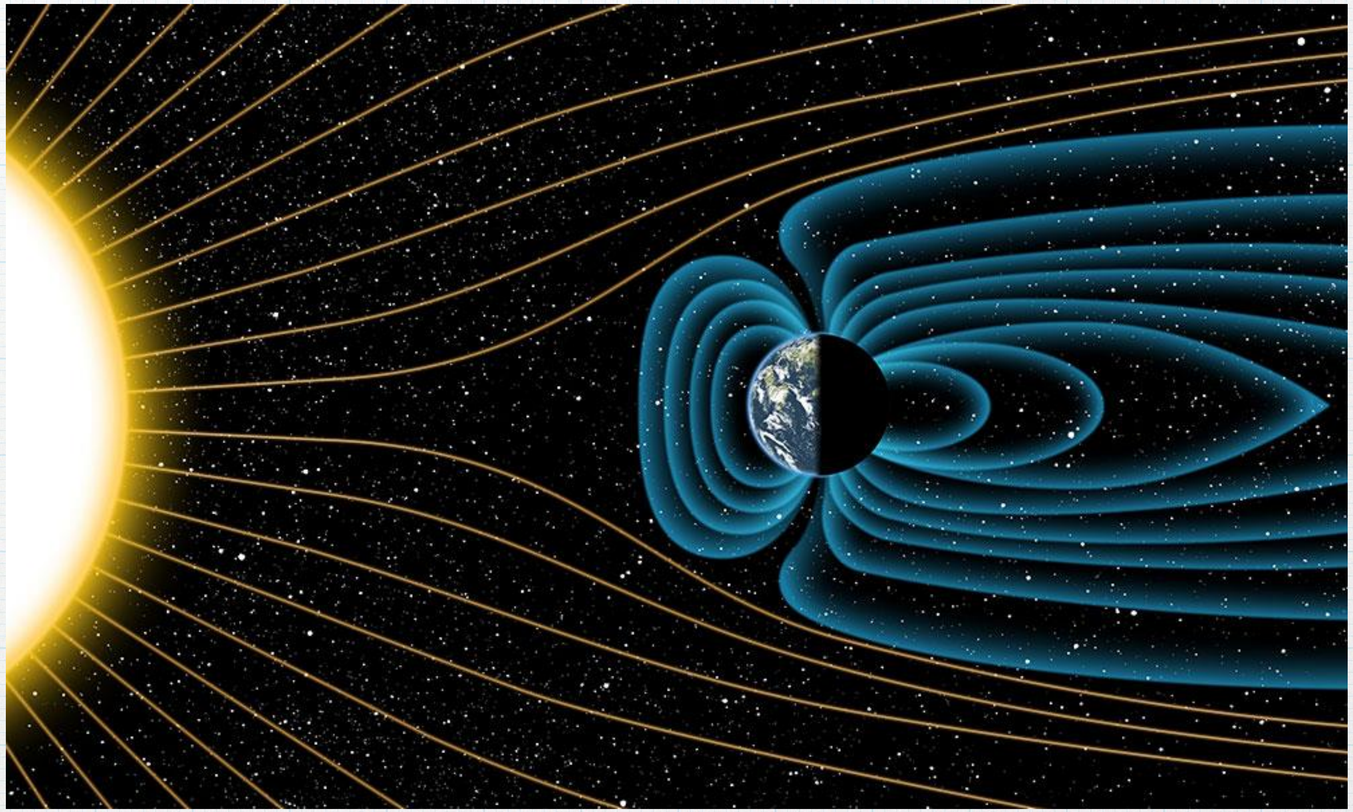
Magnetosphere

* Third Grade science class told us that Earth had a magnetic field much like a bar magnet…



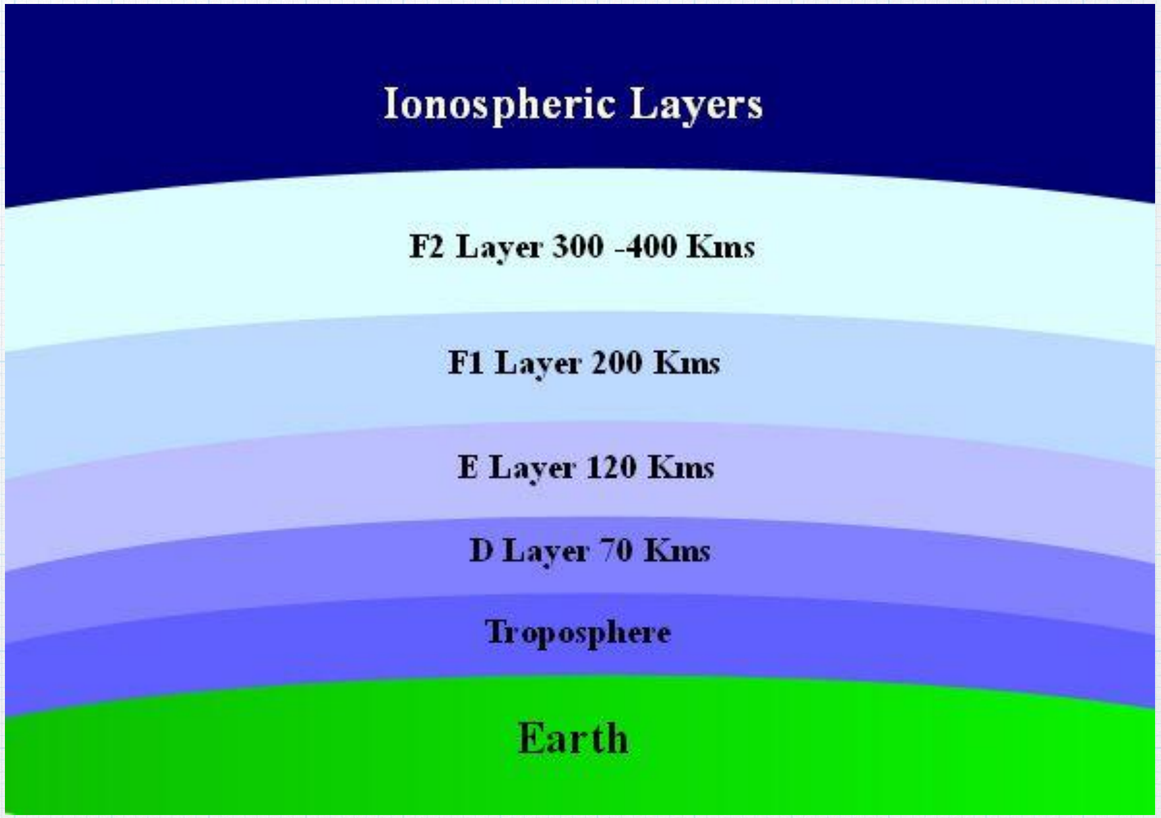
Magnetosphere

- However, the Solar Wind and Sun's magnetic field distort that significantly…

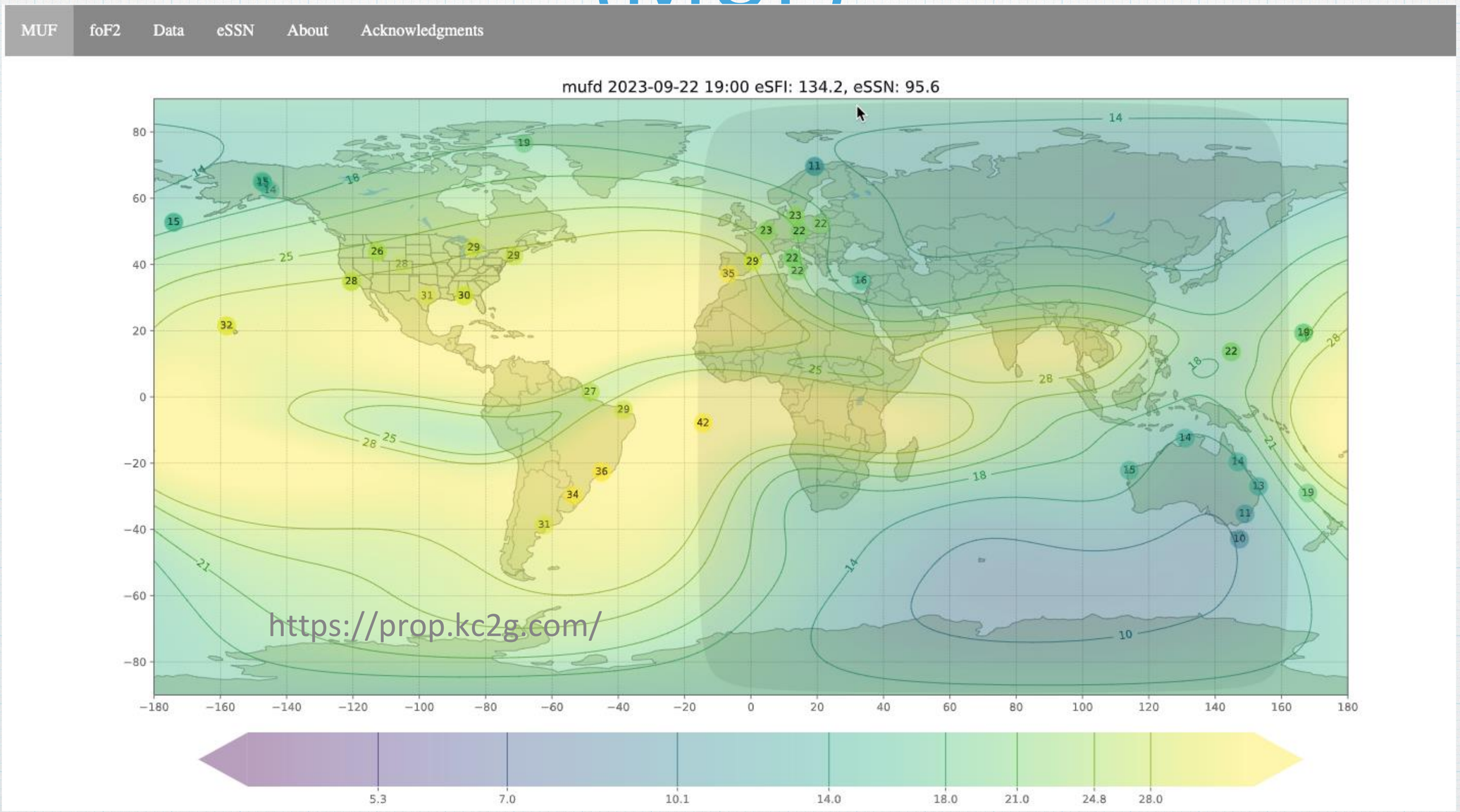


Ionosphere

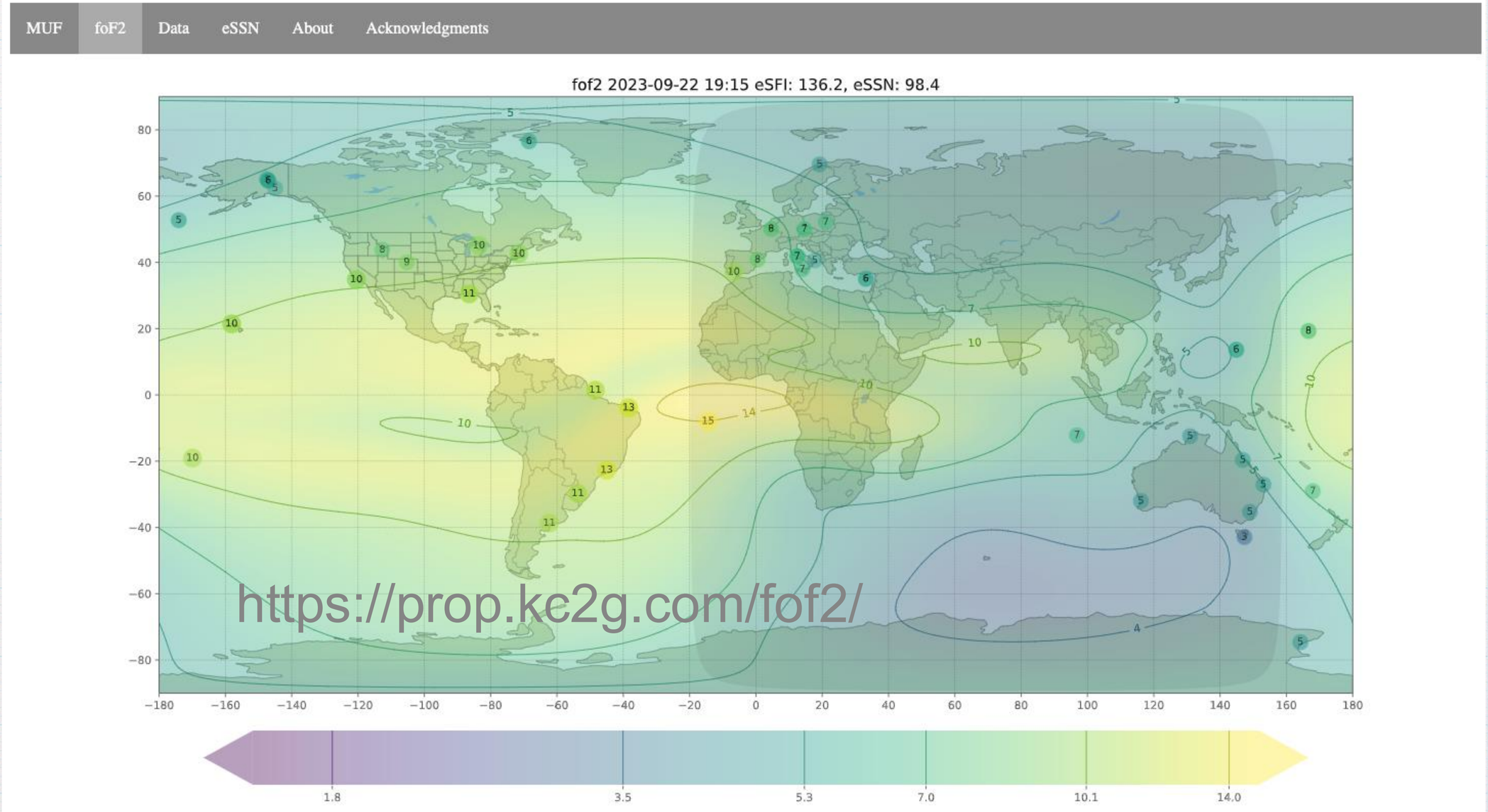
- ‘D’ Layer present in daylight only
  - Absorptive rather than Refractive
- ‘E’ Layer refracts MF, lower HF frequencies
- ‘E’, ‘F’ Layers 24 Hours



Maximum Useable Frequency (MUF)



Critical Frequency (NVIS)



Solar Flux Index (SFI)

- SFI :Measure of the sun’s radiative output, UV and X-Ray
- Indirectly measured via 10.7cm (2800 MHz) solar output
- Indicative of the thickness of the ionospheric layers
- Primary driver of MUF

k(Kp), a(Ap) indices

- ‘k’ Index measures geomagnetic variability
- Logarithmic in nature
- ‘Kp’ is Planetary Average
- ‘a’ Index is a linearized measure of the ‘k’ Index
- ‘Ap’ is a rolling time average

RELATIONSHIP BETWEEN KP INDEX AND A INDEX		
AP INDEX	KP INDEX	DESCRIPTION
0	0	Quiet
4	1	Quiet
7	2	Unsettled
15	3	Unsettled
27	4	Active
48	5	Minor storm
80	6	Major storm
132	7	Severe storm
208	8	Very major storm
400	9	Very major storm

‘G’ Rating for Geomagnetic Storms

* ‘K’ indices are Earth-based indicators
* ‘G’ Ratings are the strength of solar geomagnetic storms

Kp	G-scale	Auroral activity
0	G0	Quiet
1	G0	Quiet
2	G0	Quiet
3	G0	Unsettled
4	G0	Active
5	G1	Minor storm
6	G2	Moderate storm
7	G3	Strong storm
8	G4	Severe storm
9	G5	Extreme storm

’S’ Level Indicators

Scale	Description	Effect	**Physical measure** (Flux level of >= 10 MeV particles)	**Average Frequency** (1 cycle = 11 years)
S 5	**Extreme**	**Biological:** Unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** Satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. **Other systems:** Complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	**Severe**	**Biological:** Unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** May experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. **Other systems:** Blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	**Strong**	**Biological:** Radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** Single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. **Other systems:** Degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	**Moderate**	**Biological:** Passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk. **Satellite operations:** Infrequent single-event upsets possible. **Other systems:** Small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	**Minor**	**Biological:** None. **Satellite operations:** None. **Other systems:** Minor impacts on HF radio in the polar regions.	10	50 per cycle

Rating for X-Ray Flares

* X-Ray Flares are classified by letter rating
* Rated by brightness in the 1 - 8 angstrom range

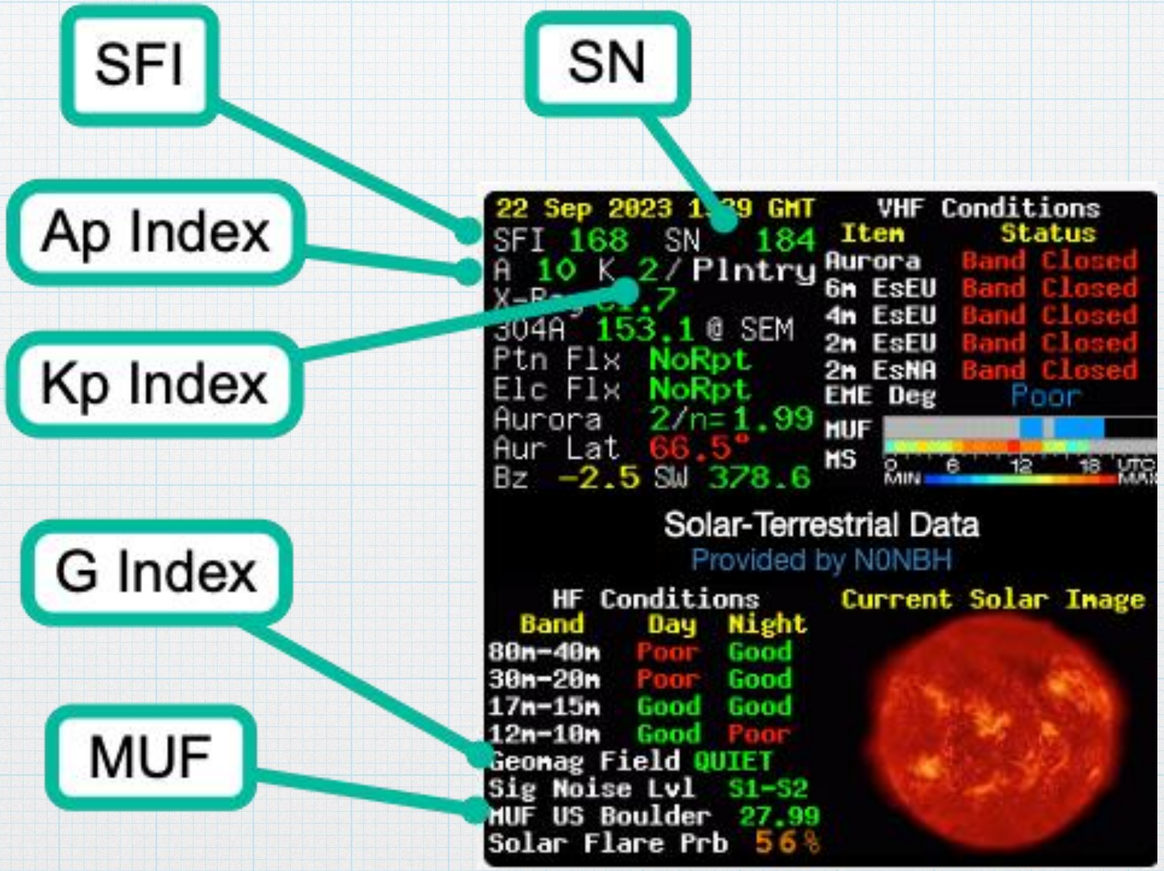
Flare Class	Measurement	Impact
A	Less that 10^{-7} W/m^2	None
B	10^{-7} - 10^{-6} W/m^2	Not typically impactful
C	10^{-6} - 10^{-5} W/m^2	Minor effects
M	10^{-5} - 10^{-4} W/m^2	Brief polar blackouts and minor radiation storms
X	> 10^{-4} W/m^2	Planet wide blackouts

What does all this mean?

Parameter	Domain	Ideal Value	“Good” Range	Comments
SN	Geomagnetic	200+	100+	More sunspots indicate more solar activity
SFI	Electromagnetic	300	150+	Higher SFI Means thicker ionosphere layers, higher MUF
K, Kp	Geomagnetic	0	<3	Less noise
A, Ap	Geomagnetic	0	<10	Less QRN, QSB
G	Geomagnetic	0	G1 or less	Less QRN, QSB
S	Particulate	S1	S2 or less	Better Propagation, less band noise

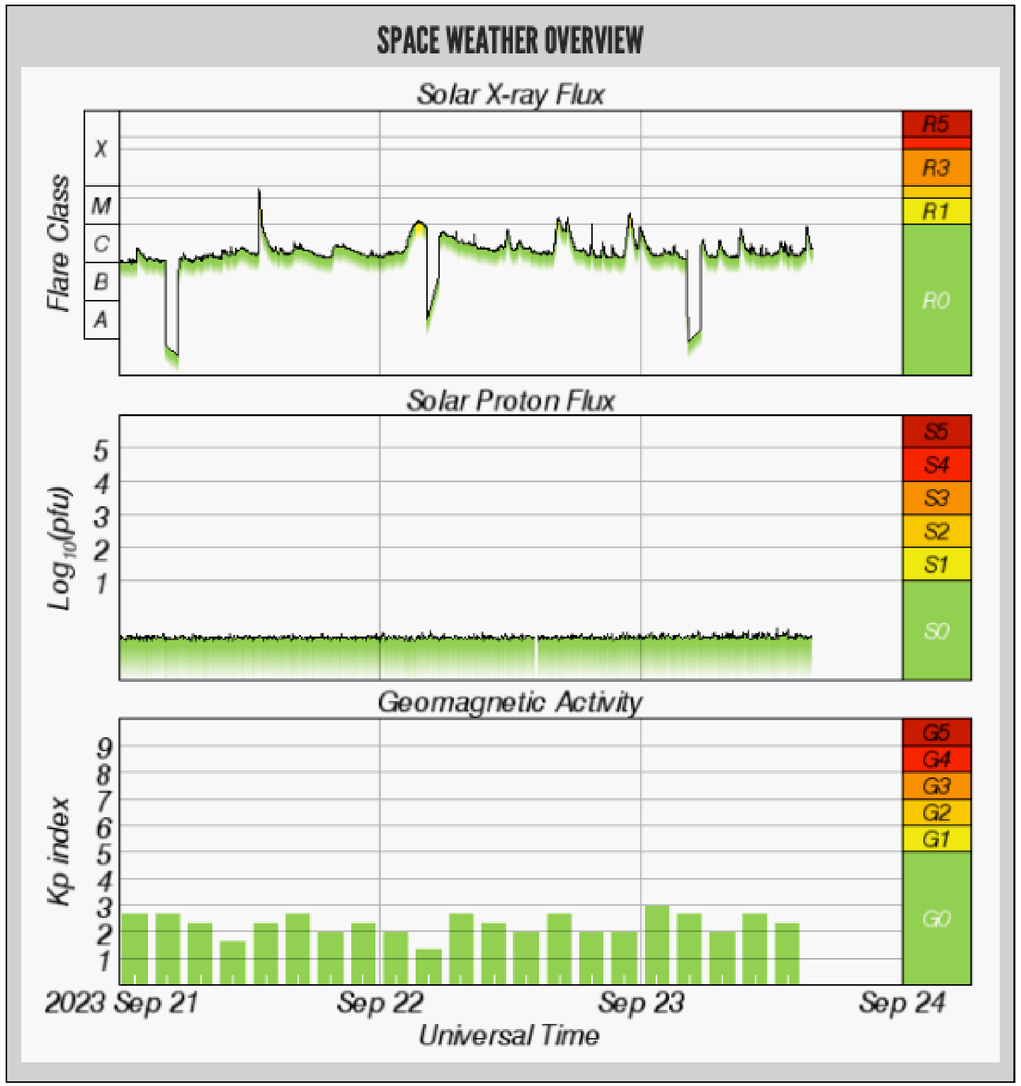
Sources

QRZ


SFI
SN
Ap Index
Kp Index
G Index
MUF
22 Sep 2023 1329 GMT
SFI 168 SN 184
A 10 K 2/ Plntry
304A 153.1 @ SEM
Ptn Flx NoRpt
Elc Flx NoRpt
Aurora 2/n=1.99
Aur Lat 66.5°
Bz -2.5 SW 378.6
VHF Conditions
Item Status
Aurora Band Closed
6m EsEU Band Closed
4m EsEU Band Closed
2m EsEU Band Closed
2m EsNA Band Closed
EME Deg Poor
MUF
MS
0 6 12 18 UTC
MIN MAX
Solar-Terrestrial Data
Provided by N0NBH
HF Conditions
Band Day Night
80m-40m Poor Good
30m-20m Poor Good
17m-15m Good Good
12m-10m Good Poor
Geomag Field QUIET
Sig Noise Lvl S1-S2
MUF US Boulder 27.99
Solar Flare Prb 56%
Current Solar Image

Sources

SPACE WEATHER ENTHUSIASTS DASHBOARD

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:Product: 3-Day Forecast
:Issued: 2023 Sep 22 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 3 (below NOAA
Scale levels).
The greatest expected 3 hr Kp for Sep 22-Sep 24 2023 is 5.00 (NOAA
Scale
G1).

NOAA Kp index breakdown Sep 22-Sep 24 2023

             Sep 22       Sep 23       Sep 24
00-03UT       2.00         3.67         5.00 (G1)
03-06UT       1.33         3.00         4.33
06-09UT       2.67         2.67         3.67
09-12UT       2.33         2.67         3.00
12-15UT       3.00         2.67         2.33
15-18UT       4.00         3.67         3.00
18-21UT       3.00         4.33         3.00
21-00UT       4.00         5.00 (G1)    3.33

Rationale: The geomagnetic field is expected to be at mostly unsettled
to active levels on 22 Sep due to negative polarity CH HSS onset. G1
(Minor) geomagnetic storming is likely 23-24 Sep due to first shock
and
glancing influences from the 20 Sep CME followed by the arrival of the
21 Sep CME by late on the 24th.

B. NOAA Solar Radiation Activity Observation and Forecast

Solar radiation, as observed by NOAA GOES-16 over the past 24 hours,
was
below S-scale storm level thresholds.

Solar Radiation Storm Forecast for Sep 22-Sep 24 2023
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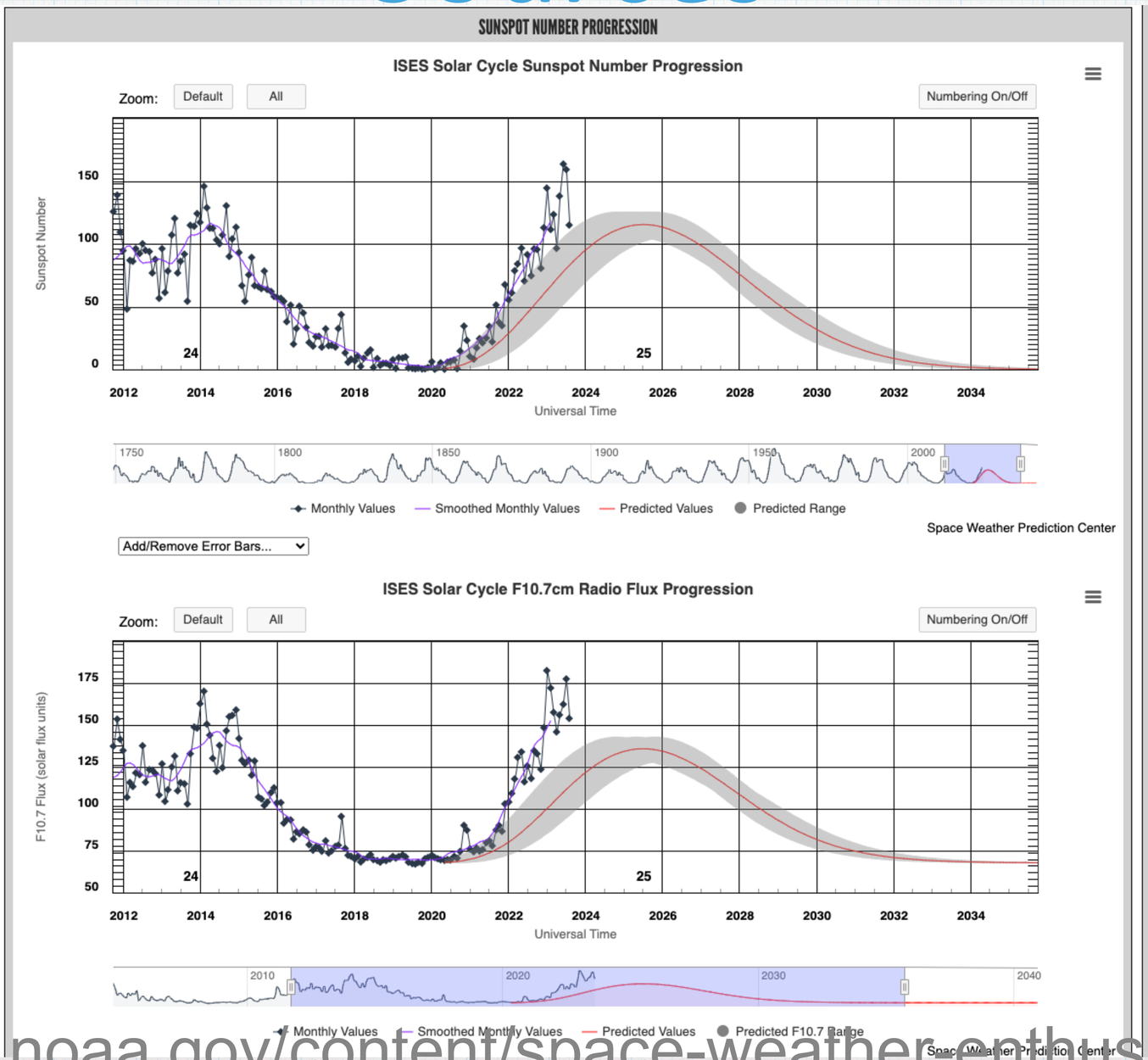
https://www.swpc.noaa.gov/content/space-weather-enthusiasts-dashboard

Sources



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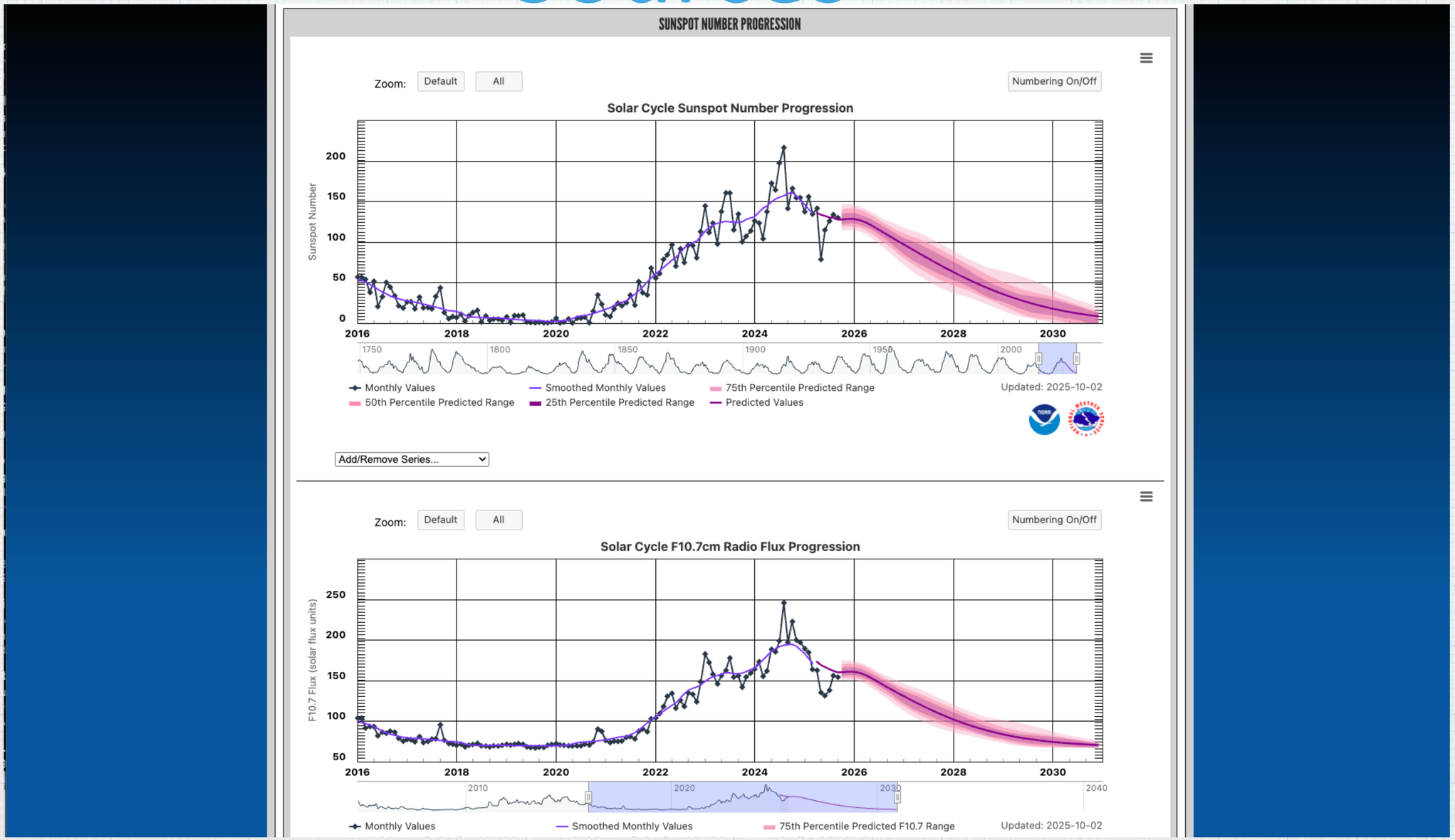

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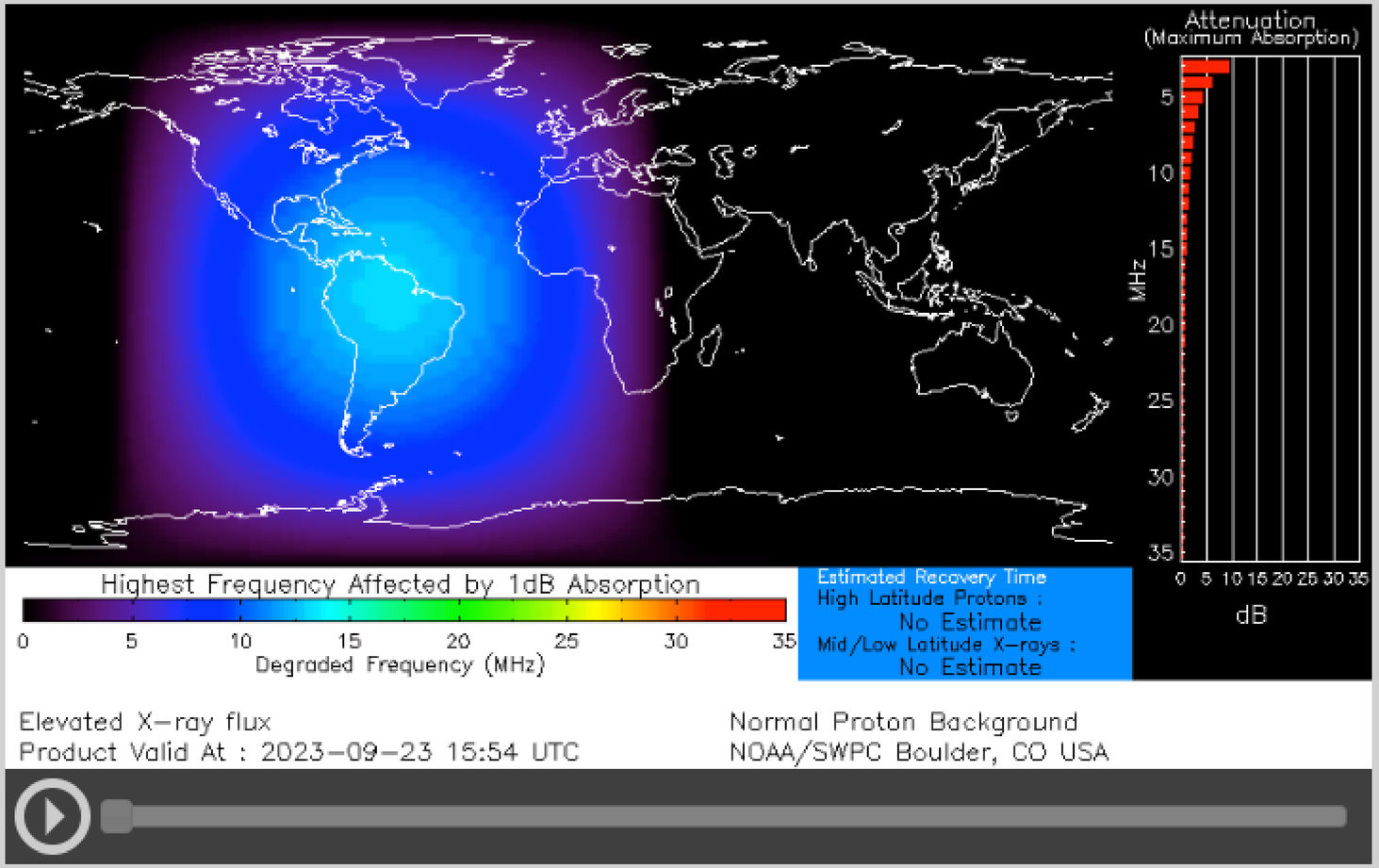
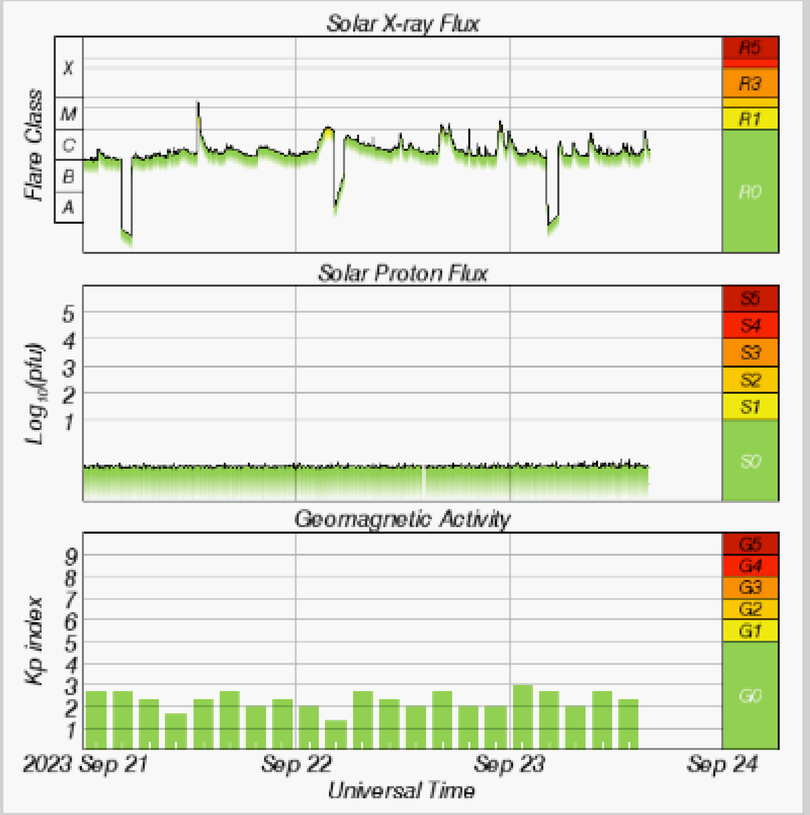
Sources

RADIO COMMUNICATIONS DASHBOARD

D REGION ABSORPTION PREDICTION



SPACE WEATHER OVERVIEW



https://www.swpc.noaa.gov/communities/radio-communications

What We've Learned

- Cycle 25 peaked about when expected, at very near the predicted maximum
- We had some crazy runs above and below average
- Periods of intense flare and CME activity markedly lowered the sunspot numbers during those periods
- The Sun's magnetic field is stabilizing, signaling the cycle has peaked

The Carrington Event

- No Solar Weather presentation would be complete without at least brief mention of the ‘Carrington Event’ of September 1859
- Solar flare followed by an immense CME
- Huge electrical disturbances observed on Earth

Questions?