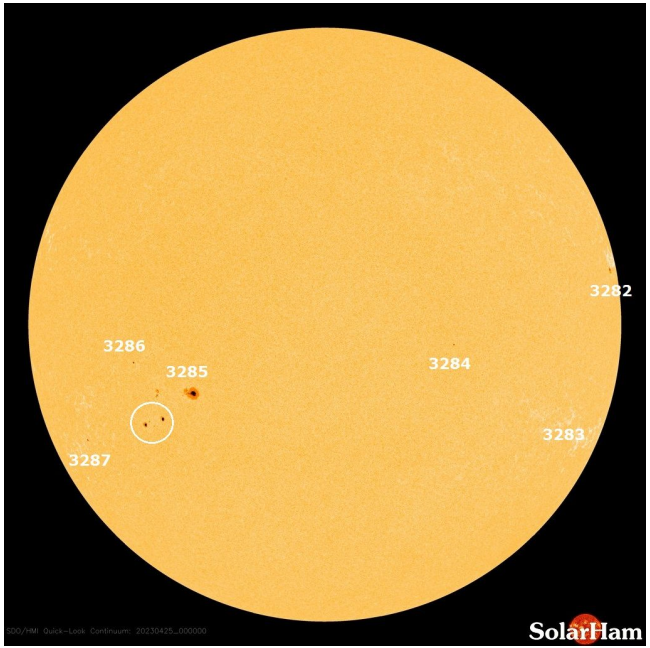
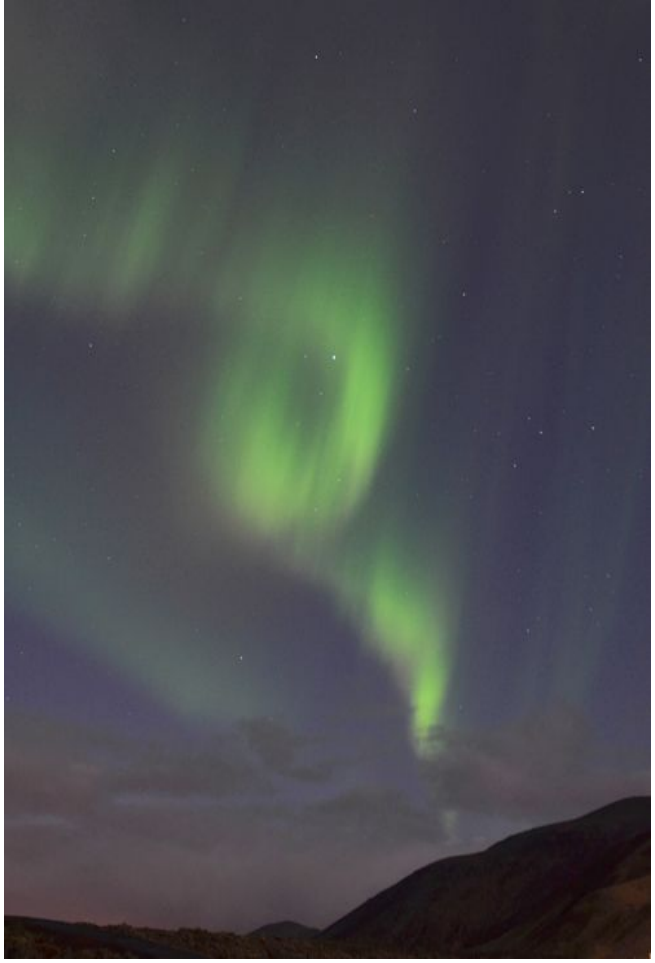
HF Propagation: What do the numbers mean?

Steve Nichols G0KYA
Chairman, Propagation Studies Committee

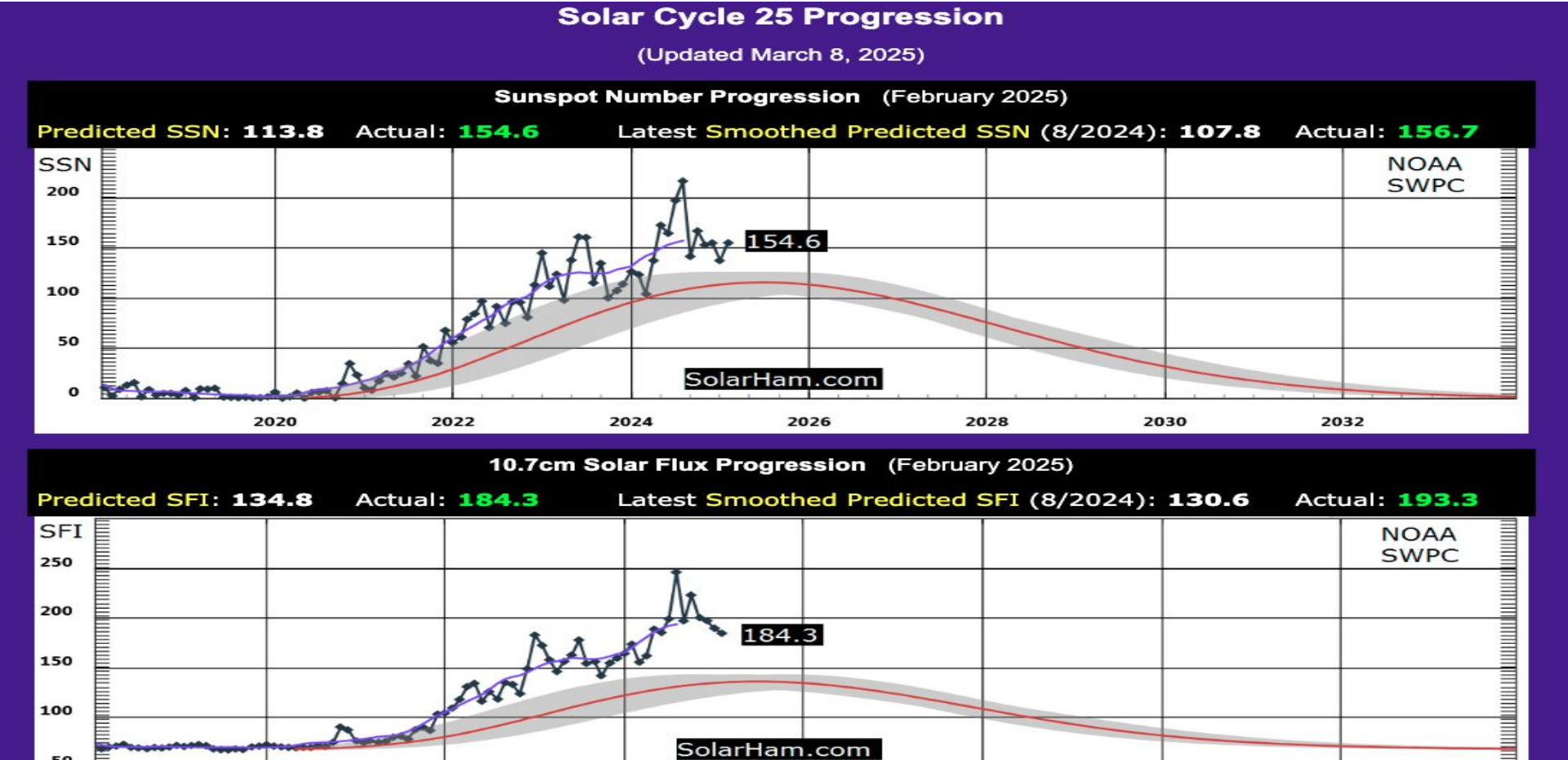


What will we look at?

- Solar Cycle 25 progression
- Solar Flux index and SSN
- K, Kp, A and Ap indices
- Solar Wind – speed and Bz direction
- Critical Frequency and MUF
- Solar Flares and others



Solar Cycle 25 - where are we?



Solar Flux Index

Last week's/month's solar flux index, K indices, events

```
#
#  Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
#  Please send comments and suggestions to SWPC.Webmaster@noaa.gov
#
#                Last 30 Days Daily Solar Data
#
#                          Sunspot       Stanford GOES15
#          Radio  SESC      Area            Solar  X-Ray  ------ Flares ------
#          Flux  Sunspot  10E-6   New      Mean  Bkgd     X-Ray       Optical
#  Date    10.7cm Number  Hemis. Regions Field  Flux    C  M  X  S  1  2  3
#-------------------------------------------------------------------------------
2023 02 20  160    135     1100      3    -999      *  14  1  0 13  1  0  0
2023 02 21  161    106      760      0    -999      *   9  2  0 17  0  0  0
2023 02 22  152    100      750      0    -999      *  10  2  0  6  0  0  0
2023 02 23  148    108      890      2    -999      *  11  2  0 13  0  0  0
2023 02 24  164    130      980      1    -999      *   6  2  0  8  1  1  0
2023 02 25  152    129      980      0    -999      *   5  2  0  0  0  0  1
2023 02 26  159    120      930      0    -999      *   6  0  0  0  0  0  0
2023 02 27  161    192     1030      1    -999      *   1  0  0  2  0  0  0
2023 02 28  161    100     1110      1    -999      *   6  1  0  4  0  0  0
2023 03 01  162    105     1110      2    -999      *  10  1  0 12  2  0  0
2023 03 02  169    103     1310      1    -999      *   7  1  0 17  1  0  0
2023 03 03  175    133     1430      3    -999      *   6  1  1 17  3  0  0
2023 03 04  182    122      620      0    -999      *  12  3  0 14  2  2  0
2023 03 05  180    137      770      1    -999      *   6  4  0 13  0  0  0
2023 03 06  188    173     1020      2    -999      *   5  3  0  4  0  1  0
2023 03 07  180    191     1220      1    -999      *   6  0  0  2  0  0  0
2023 03 08  182    146     1285      0    -999      *   6  2  0  7  1  0  0
2023 03 09  179    155      740      2    -999      *  14  0  0  8  1  0  0
2023 03 10  171    135      700      1    -999      *   5  0  0  6  2  0  0
2023 03 11  157    126      720      0    -999      *   6  0  0  4  0  0  0
2023 03 12  150    135      690      1    -999      *   2  0  0  2  0  0  0
2023 03 13  143     87      480      0    -999      *   1  0  0  2  0  0  0
2023 03 14  139     97      250      2    -999      *   5  0  0  3  0  0  0
2023 03 15  136     96      280      0    -999      *   2  0  0  0  0  0  0
2023 03 16  135     84      120      0    -999      *   2  0  0  0  0  0  0
2023 03 17  134     58      150      1    -999      *   5  1  0  7  0  0  0
2023 03 18  140     35      320      1    -999      *   2  0  0  2  1  0  0
2023 03 19  143     73      510      3    -999      *   9  0  0  6  0  0  0
2023 03 20  156     75      550      0    -999      *   3  1  0  1  1  0  0
2023 03 21  152     70      640      1    -999      *   5  0  0  0  0  0  0
```

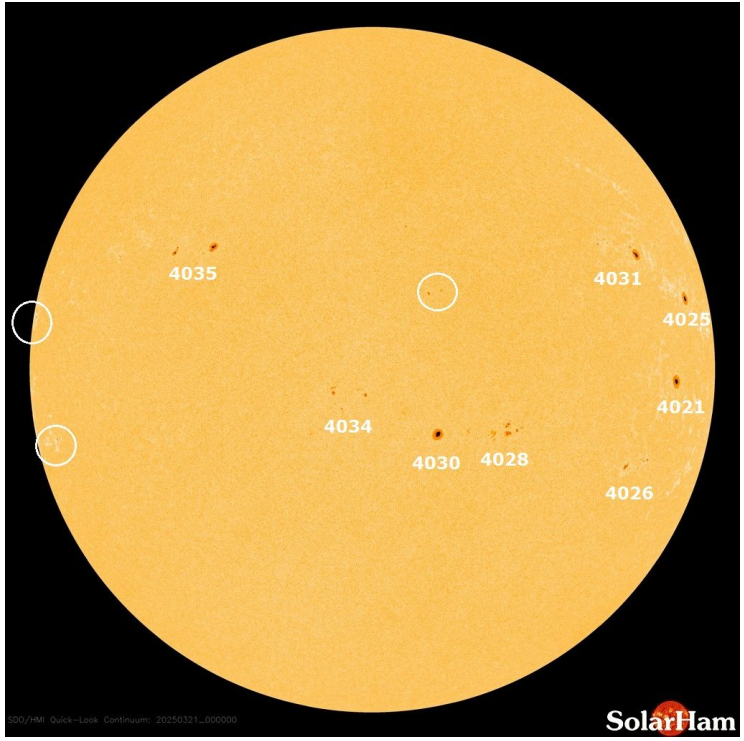
From:

ftp://ftp.swpc.noaa.gov/pub/indices/DSD.txt

ftp://ftp.swpc.noaa.gov/pub/indices/DGD.txt

Solar Flux Index

March 21, 2025: SFI 170 Sunspot number 139



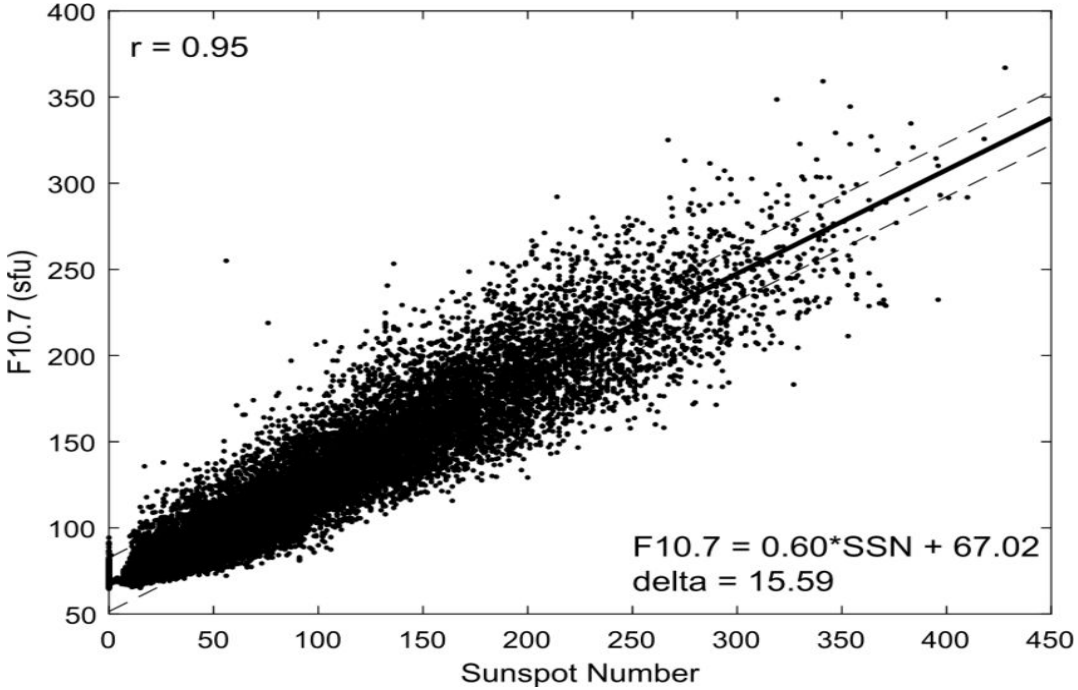
Solar Flux Index

- The solar flux index is the strength of the radio signals off the Sun at a wavelength of 10.7cm (2800 MHz).
- Never lower than about 65. Can go as high as 300.
- For 10 metres to open up to F2-layer propagation really need >100.
- High values generally indicate there is sufficient ionisation to support long-distance communication at higher-than-normal frequencies.

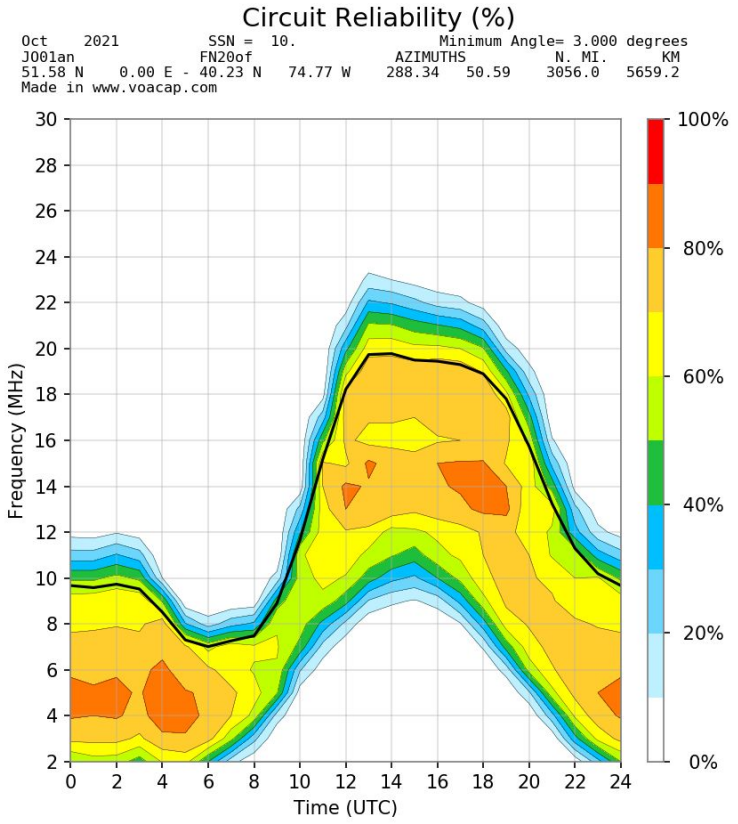
Sunspot Number

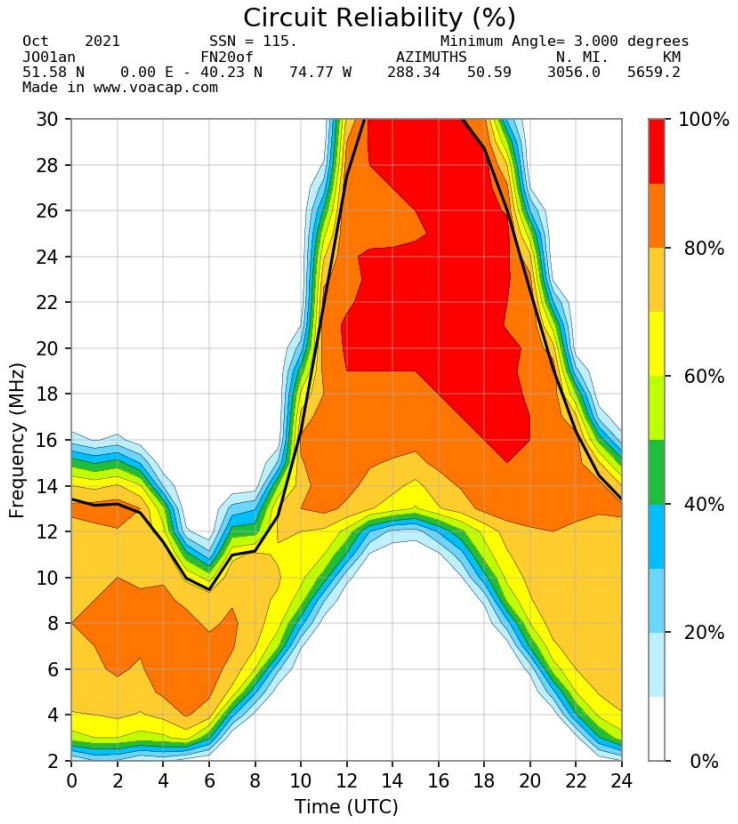
- An alternative way of looking at solar activity
- Score 10pts for each sunspot group and one for each sunspot
- So one sunspot in one group is: 10+1 = 11
- And three sunspots that are well separated is: 10+10+10+1+1+1 = 33
- So lowest value is zero and highest can be as high as 286 (Solar Cycle 19 – 1954-1964)

Sunspot Number v Solar Flux Index



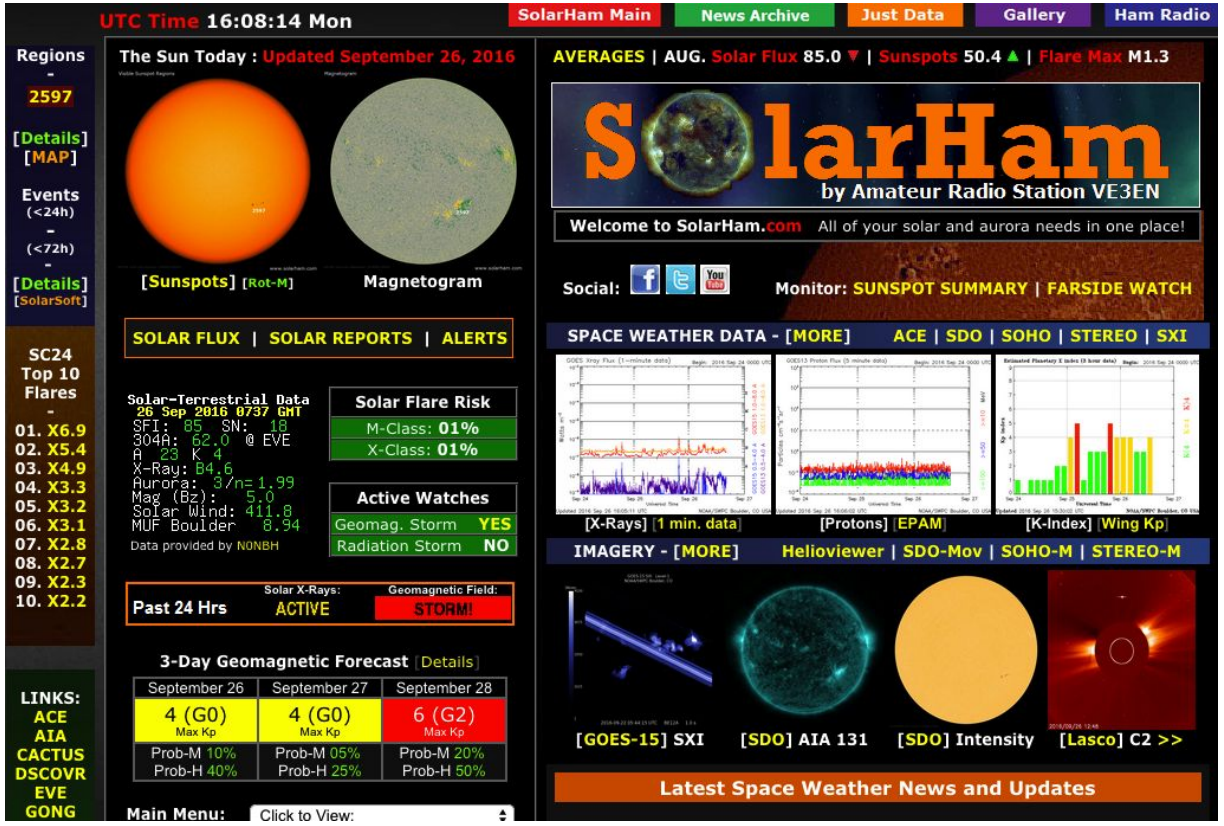
So an SSN of 139 is roughly equal to an SFI of 150.





- MUF between G and New York in October for SSNs of 10 and 115.

State of the Sun – solarham.net

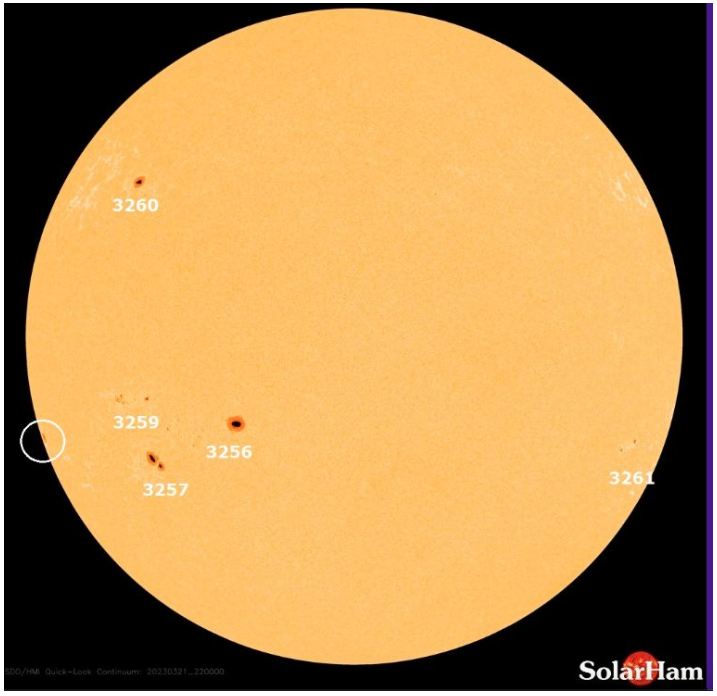


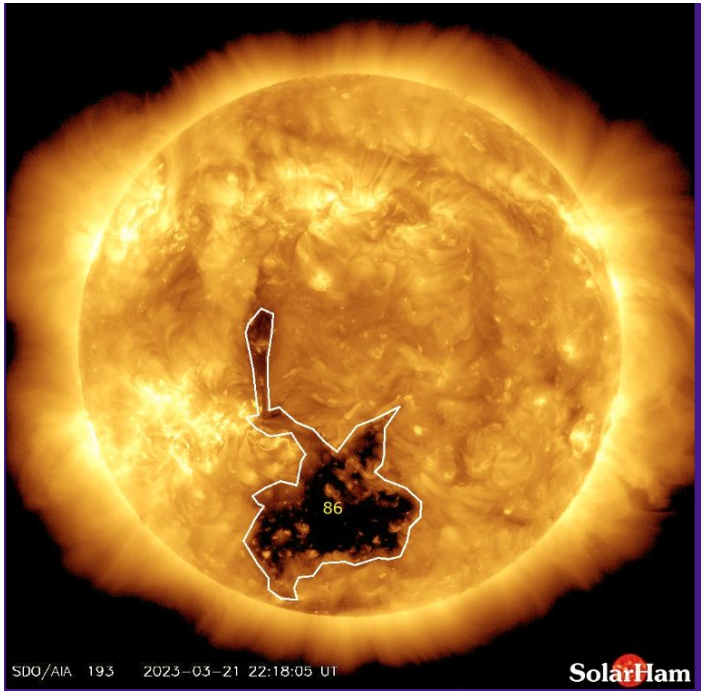
Geomagnetic Disturbances

- The Sun is constantly losing matter (plasma) out into space. This is called the solar wind.
- At times, the wind can be more ferocious with increased density and speed.
- This can be caused by coronal holes and coronal mass ejections.
- The solar wind also has a “frozen-in” magnetic field and if that field (Bz) is pointing “South” it more easily couples with the Earth.
- When this happen the plasma flows to Earth, disrupting the ionosphere and distorting the Earth’s magnetic field. Can also trigger aurora.

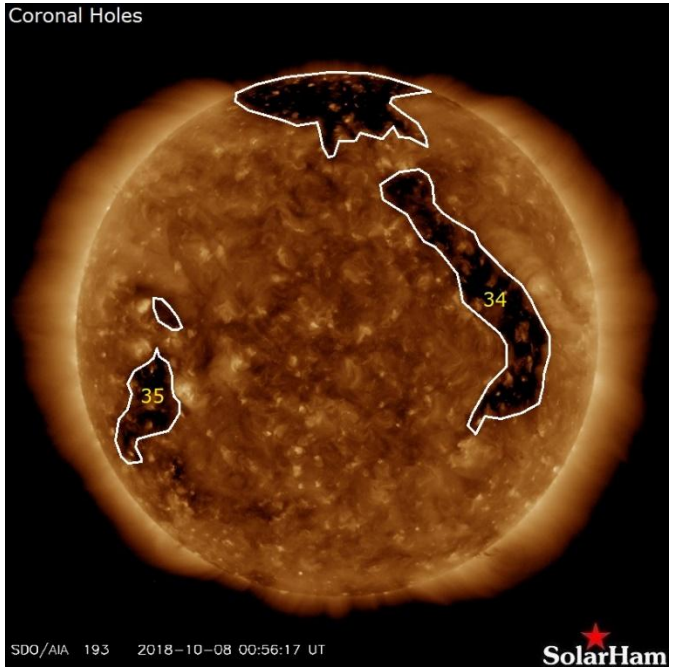
Coronal Holes

State of the Sun – in both visible and extreme ultraviolet using SDO

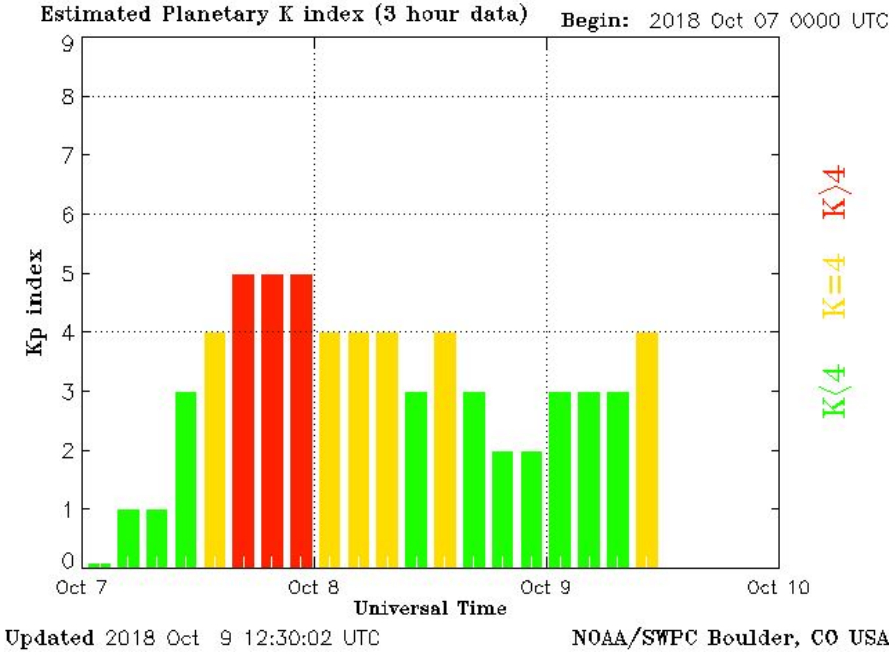




Coronal Holes



Direction of rotation



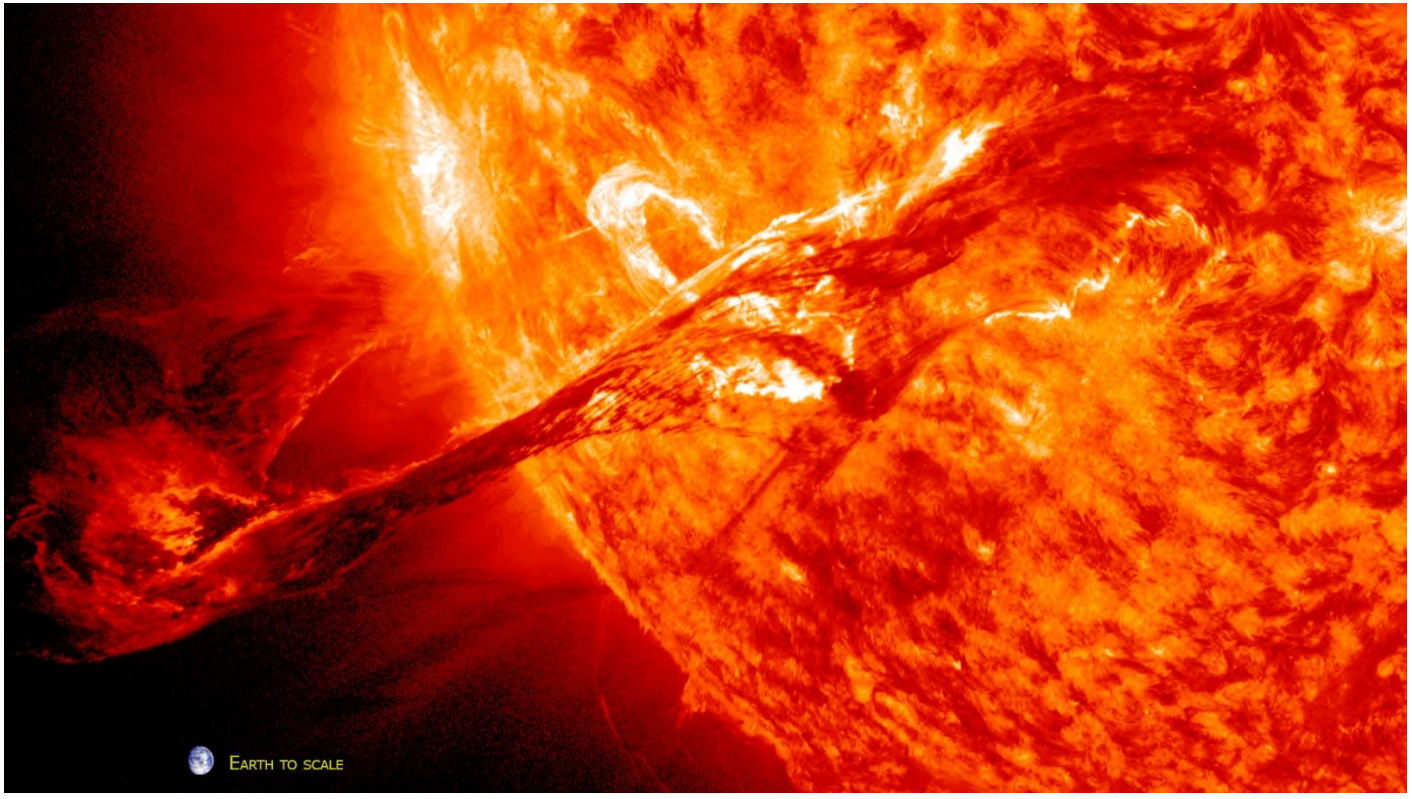
Coronal Holes

How long does it take the solar wind / a CME to hit Earth?

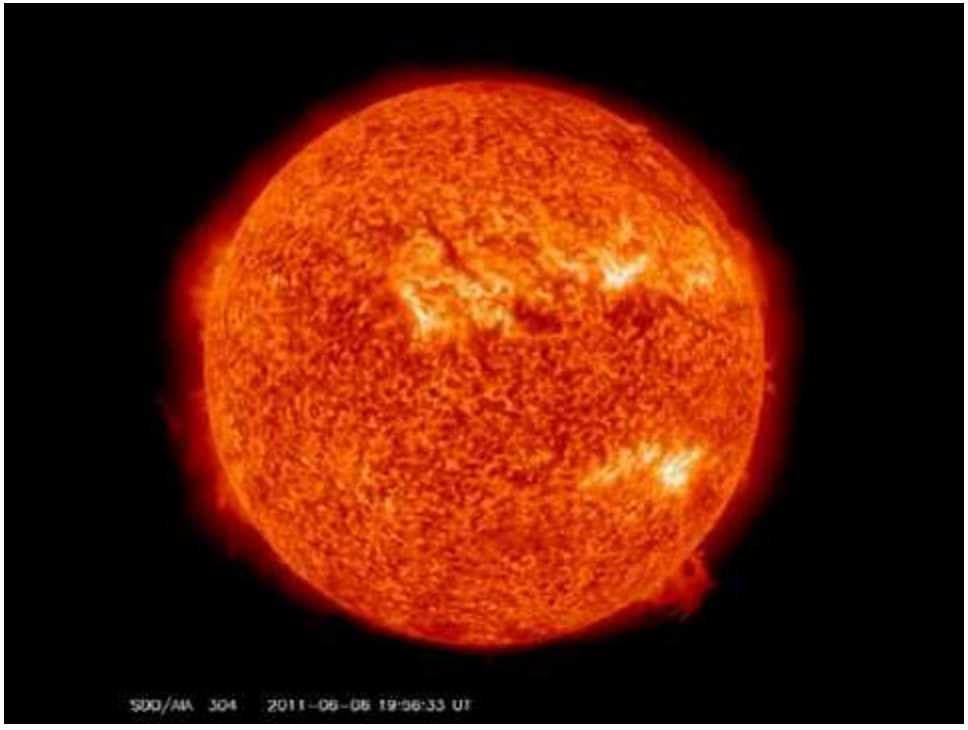
- Distance Earth from Sun: 149.6 million km
- Speed of CME / solar wind: 400 – 800km/s
- Therefore average time to hit Earth: 187,000 – 374,000 seconds

= 2.1 days to 4.3 days

Solar Flares and CMEs

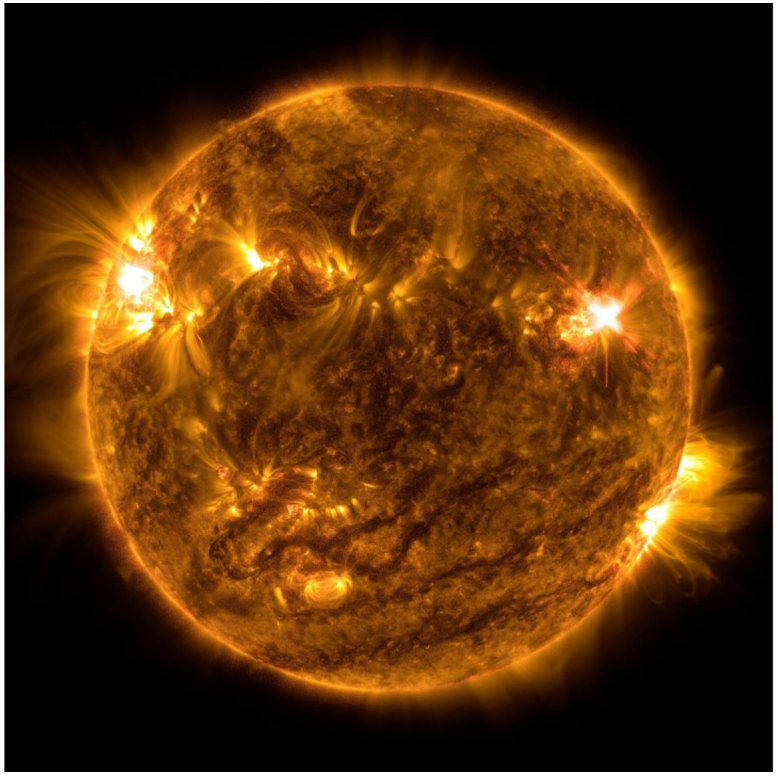


Solar Flares and CMEs



Solar Flares and CMEs

- The main component is a massive surge of X-rays/Extreme UV
- The energy released can exceed 10^{20} Joules of energy, while a major event can emit up to 10^{25} Joules
- For comparison, the atom bomb dropped on Hiroshima released 6.3 x 10^{13} J
- World's biggest hydrogen bomb (Tsar Bomba), could release 2.0 x 10^{17} joules



Solar Flares and CMEs

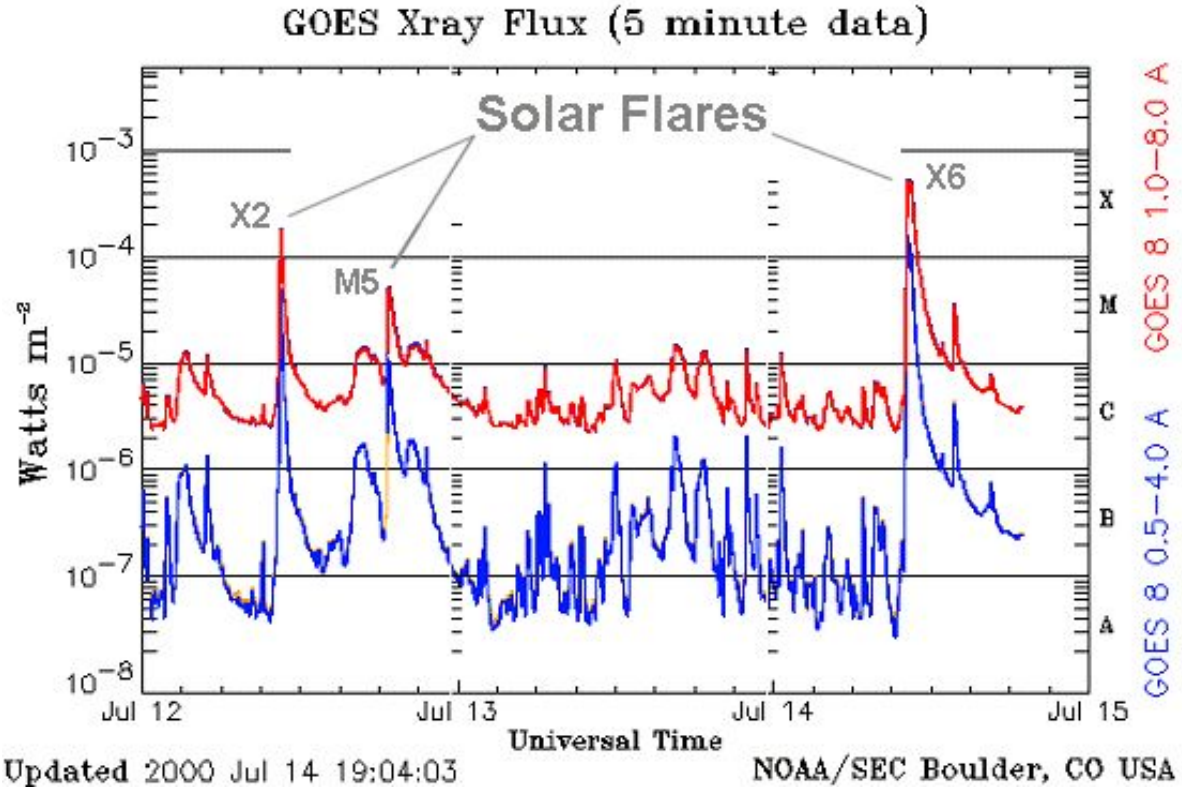
Event	Arrival Time on Earth after Solar Flare	Typical Duration Time	Types of Radiation Released	Effects
Sudden Ionosphereic Disturbances (SIDS)	8.3 minutes	10-60 minutes	Ultraviolet and X-Ray Photons	Increase in D-layer absorption in all daytime regions.
Polar Cap Absorption (PCA)	15 minutes to several hours	1 to 2 days (sometimes several years)	High Energy Protons and Alpha Particles	Increase in D-layer absorption especially in polar regions.
Ionospheric Storms	20-40 hours	2-5 days	Low Energy Protons and Electrons	Increase in D-layer absorption, and depression of F2 MUF, auroras, and sporadic E events.

Solar Flares and CMEs

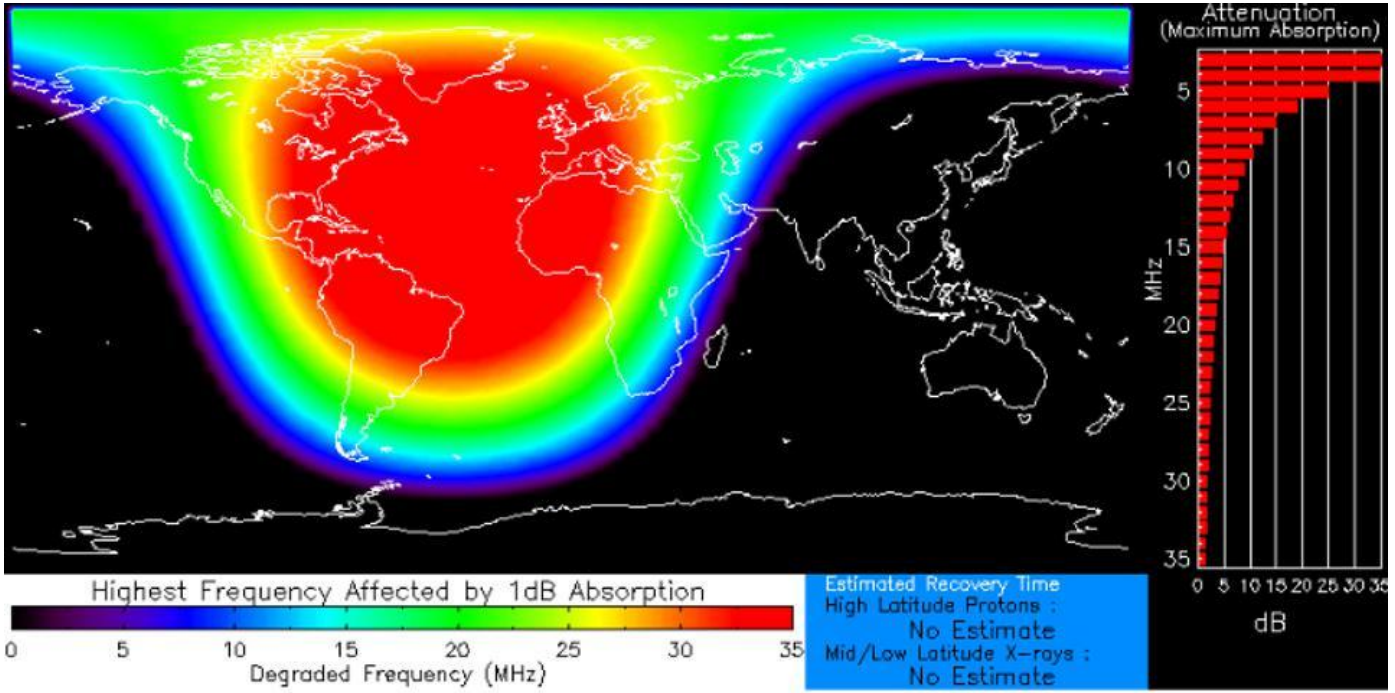
Level	Radio blackouts		Proton storms		Geomagnetic storms	
	Scale	X-ray	Scale	Pfu*	Scale	Kp
Extreme	R5	X20	S5	100000	G5	9
Severe	R4	X10	S4	10000	G4	8
Strong	R3	X1	S3	1000	G3	7
Moderate	R2	M5	S2	100	G2	6
Minor	R1	M1	S1	10	G1	5

Pfu: Particle flux unit: number of particles with an energy ≥ 10 MeV*

Solar Flares and CMEs



Solar Flares

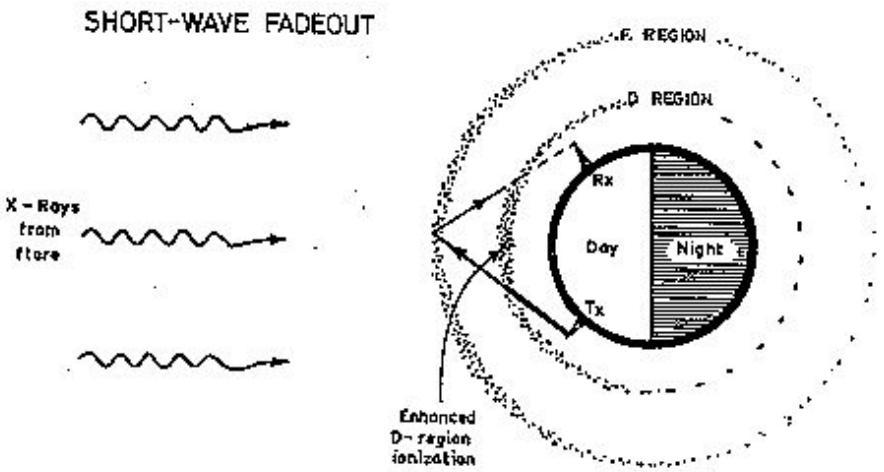


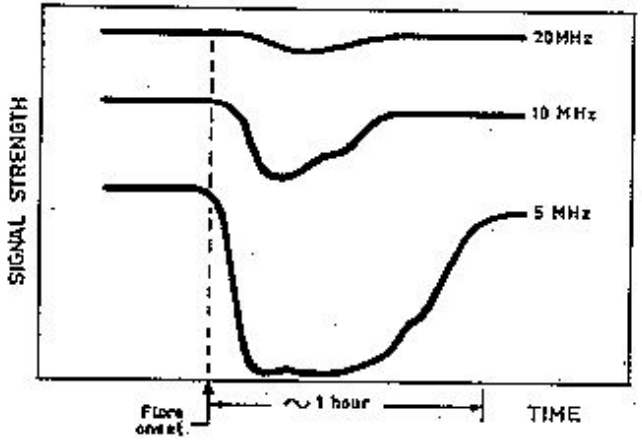
Strong X-ray flux
Product Valid At : 2021-07-03 14:31 UTC

Normal Proton Background
NOAA/SWPC Boulder, CO USA

Solar Flares

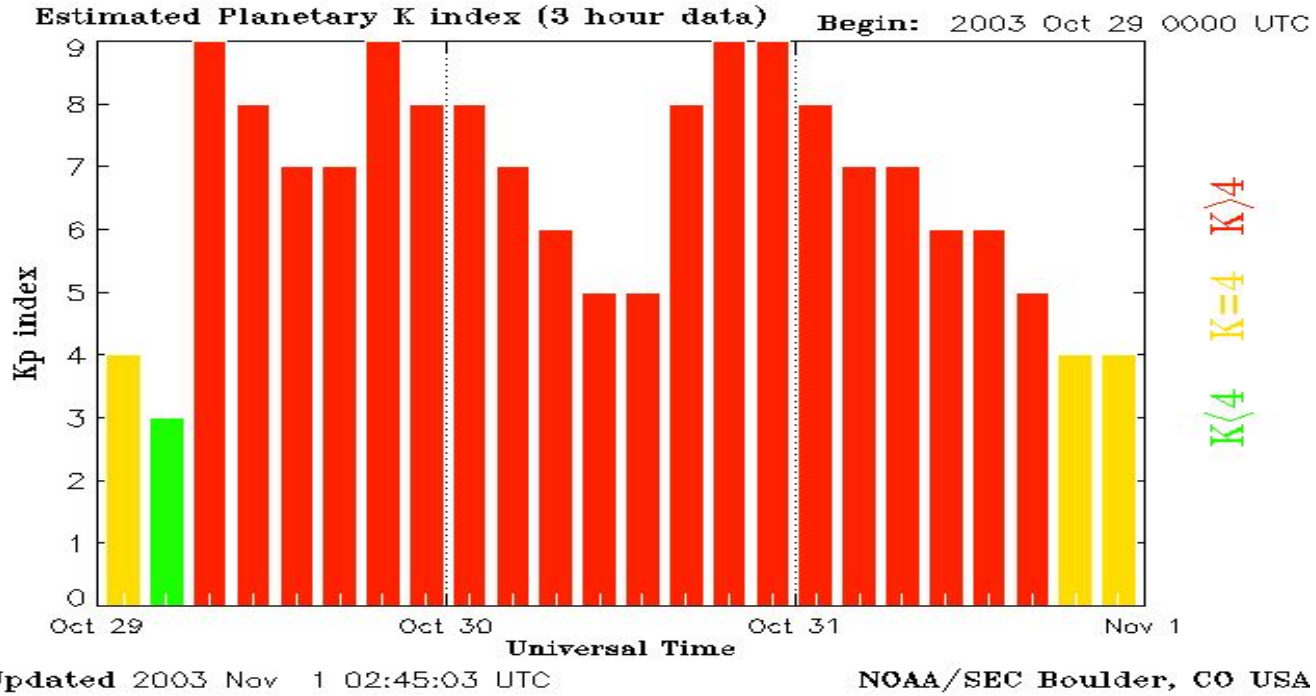
1. Flares ONLY affect the daylight side of the Earth
2. If visible on the Sun's surface, a flare's X-rays WILL impact the Earth
3. Whereas a CME tends to only affect us if fired directly at Earth. That is, a CME off the edge of the Sun may not.
4. Lower bands are most affected
5. 28MHz may be unaffected at all, depending on the flare's severity





K indices

The current unsettled geomagnetic conditions are typical of this point in the solar cycle. This is October 29 2003.




G4TUK, Norfolk, 11pm on 10-05-2024

K indices

Updated every three hours. Kp (planetary) is an average from around the world

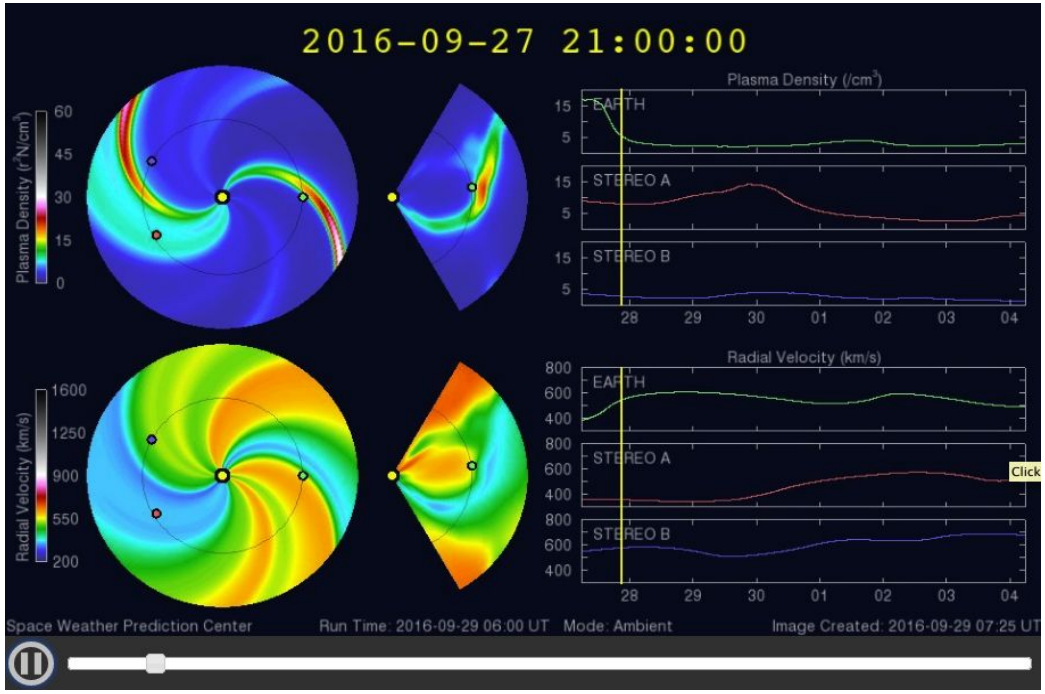
A indices

Updated every 24 hours. Ap (planetary) is an average from around the world

Geomagnetic Disturbances

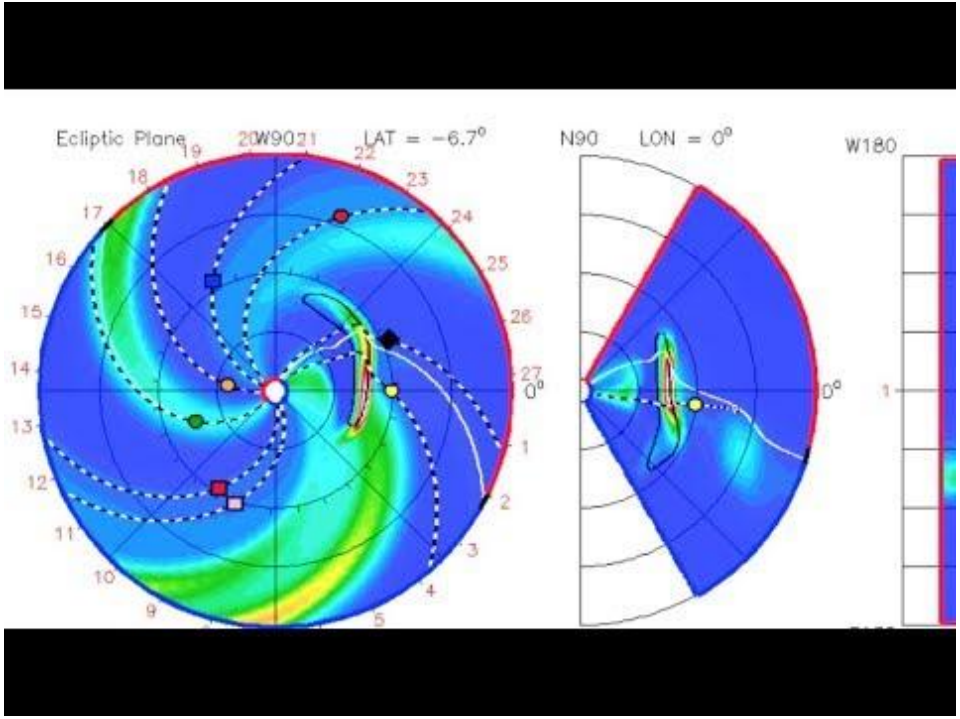
- Generally, a high Kp index means a lowering of the MUF and bad conditions.
- However, just as the Kp index is rising you can get a pre-auroral enhancement with an increased MUF.
- These are very hard to predict.
- The solar wind speed can vary dramatically, but is typically in the range 400-600 Km/second.
- See Solarham.com for more details.

CME Predictions



Coronal mass ejection (CME) prediction – www.solarham.com

CME Predictions



Coronal mass ejection (CME) prediction – www.solarham.com

A and K indices

Next week's solar flux index, A/K indices, events – both NOAA and USAF

27-DAY OUTLOOK OF 10.7 CM RADIO FLUX AND GEOMAGNETIC INDICES

```
:Product: 27-day Space Weather Outlook Table 27DO.txt
:Issued: 2016 Sep 26 0104 UTC
# Prepared by the US Dept. of Commerce, NOAA, Space Weather Prediction Center
# Product description and SWPC contact on the Web
# http://www.swpc.noaa.gov/wwire.html
#
#      27-day Space Weather Outlook Table
#                Issued 2016-09-26
#
#   UTC       Radio Flux    Planetary   Largest
#  Date         10.7 cm      A Index    Kp Index
2016 Sep 26       85           18          5
2016 Sep 27       85           12          4
2016 Sep 28       85           35          6
2016 Sep 29       85           35          6
2016 Sep 30       80           35          6
2016 Oct 01       80           25          5
2016 Oct 02       80           20          5
2016 Oct 03       80           16          4
2016 Oct 04       80           10          3
2016 Oct 05       85            8          3
2016 Oct 06       85            5          2
```

* K/A index prediction may also inform us about VHF aurora

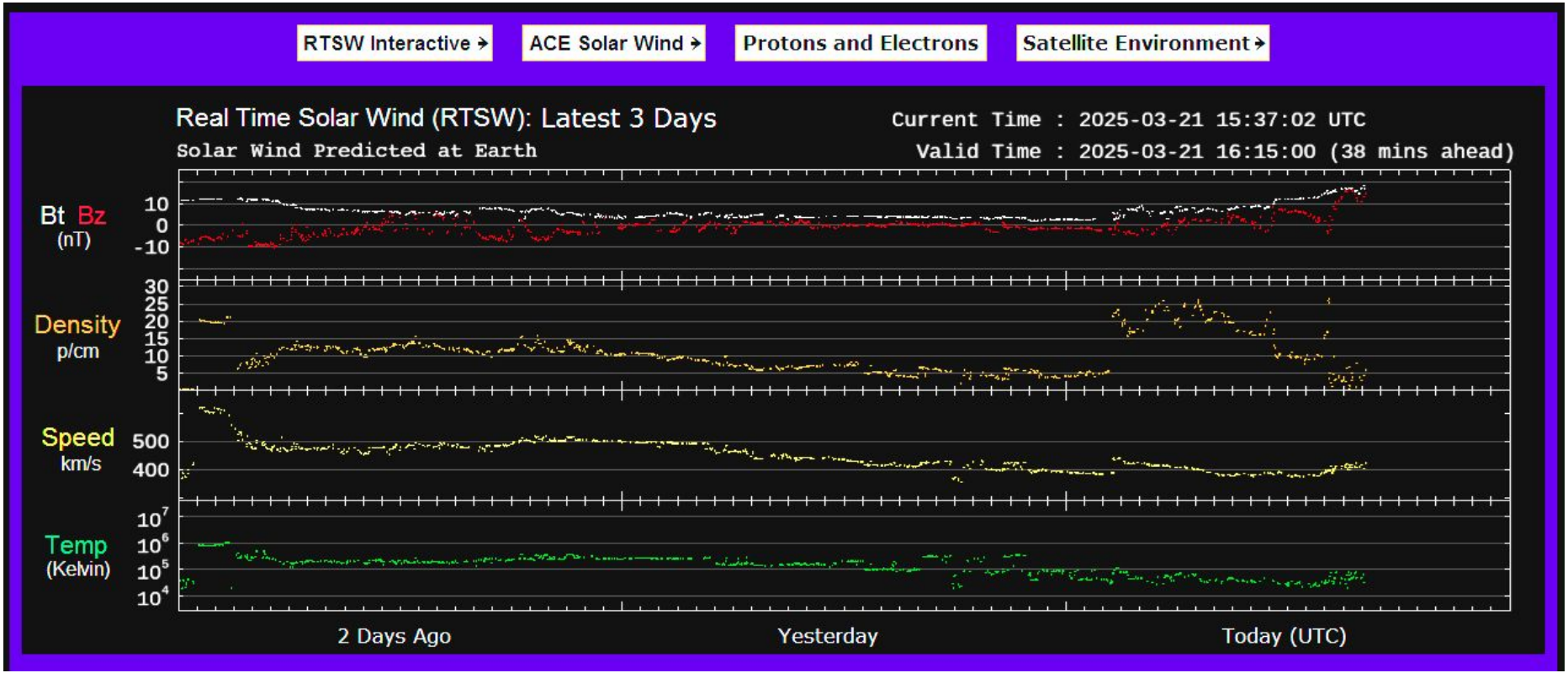
USAF 45-DAY AP AND F10.7CM FLUX FORECAST

```
:Issued: 2016 Sep 25 2101 UTC
# Prepared by the U.S. Air Force.
# Retransmitted by the Dept. of Commerce, NOAA, Space Weather Prediction Center
# Please send comments and suggestions to SWPC.Webmaster@noaa.gov
#
#
#          45-Day AP and F10.7cm Flux Forecast
#-------------------------------------------------------------
45-DAY AP FORECAST
26Sep16 018 27Sep16 012 28Sep16 035 29Sep16 035 30Sep16 035
01Oct16 025 02Oct16 020 03Oct16 015 04Oct16 015 05Oct16 015
06Oct16 005 07Oct16 005 08Oct16 005 09Oct16 005 10Oct16 005
11Oct16 005 12Oct16 005 13Oct16 005 14Oct16 005 15Oct16 005
16Oct16 018 17Oct16 020 18Oct16 012 19Oct16 008 20Oct16 005
21Oct16 005 22Oct16 005 23Oct16 015 24Oct16 010 25Oct16 035
26Oct16 035 27Oct16 035 28Oct16 030 29Oct16 015 30Oct16 015
31Oct16 015 01Nov16 015 02Nov16 005 03Nov16 005 04Nov16 005
05Nov16 005 06Nov16 005 07Nov16 005 08Nov16 005 09Nov16 005
45-DAY F10.7 CM FLUX FORECAST
26Sep16 085 27Sep16 085 28Sep16 085 29Sep16 085 30Sep16 080
01Oct16 080 02Oct16 080 03Oct16 080 04Oct16 090 05Oct16 090
06Oct16 090 07Oct16 085 08Oct16 085 09Oct16 085 10Oct16 085
11Oct16 085 12Oct16 085 13Oct16 085 14Oct16 080 15Oct16 080
16Oct16 085 17Oct16 085 18Oct16 085 19Oct16 085 20Oct16 085
```

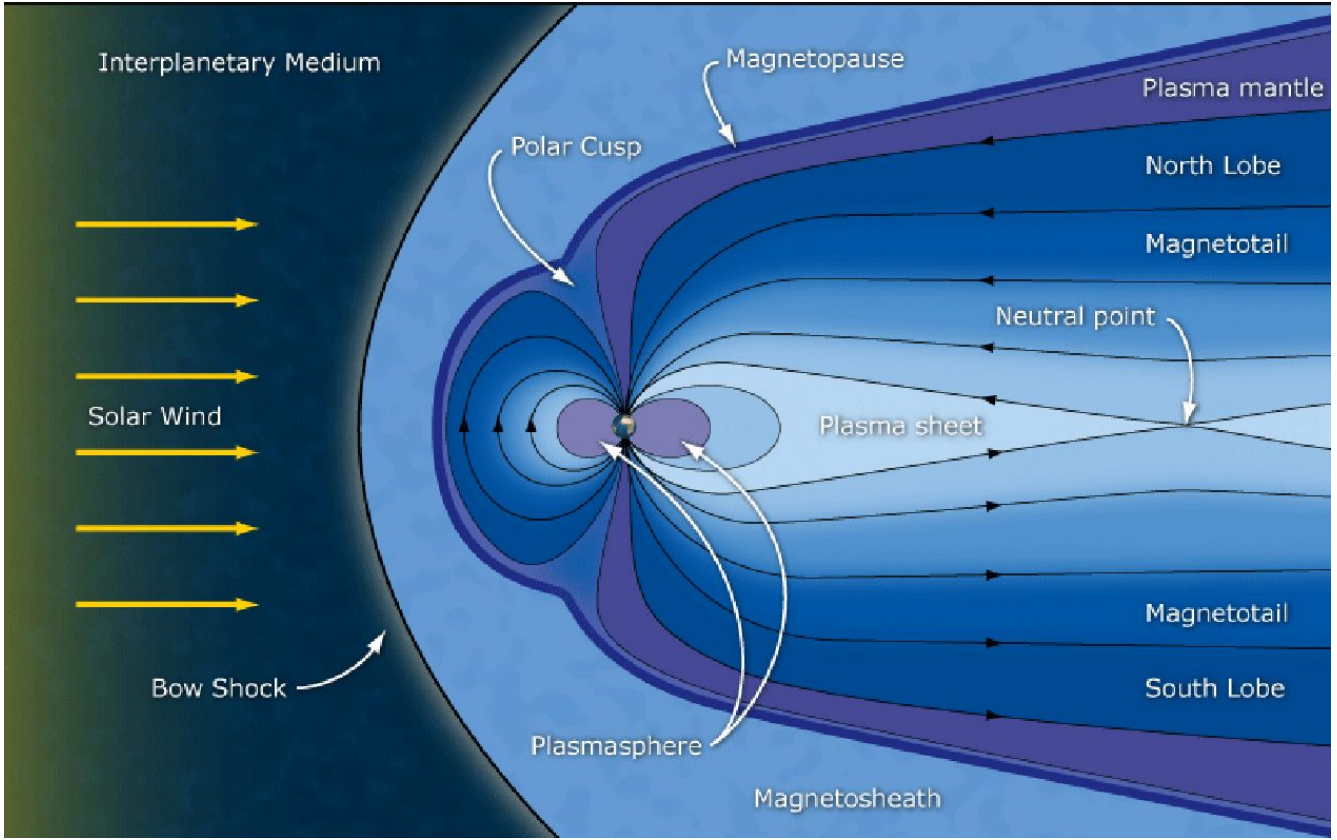
From:

http://www.swpc.noaa.gov/products/27-day-outlook-107-cm-radio-flux-and-geomagnetic-indices
http://www.swpc.noaa.gov/products/usaf-45-day-ap-and-f107cm-flux-forecast

Solar Wind


RTSW Interactive
ACE Solar Wind
Protons and Electrons
Satellite Environment
Real Time Solar Wind (RTSW): Latest 3 Days
Current Time : 2025-03-21 15:37:02 UTC
Solar Wind Predicted at Earth
Valid Time : 2025-03-21 16:15:00 (38 mins ahead)
Bt Bz
(nT)
10
0
-10
Density
p/cm
30
25
20
15
10
5
Speed
km/s
500
400
Temp
(Kelvin)
10^7
10^6
10^5
10^4
2 Days Ago
Yesterday
Today (UTC)

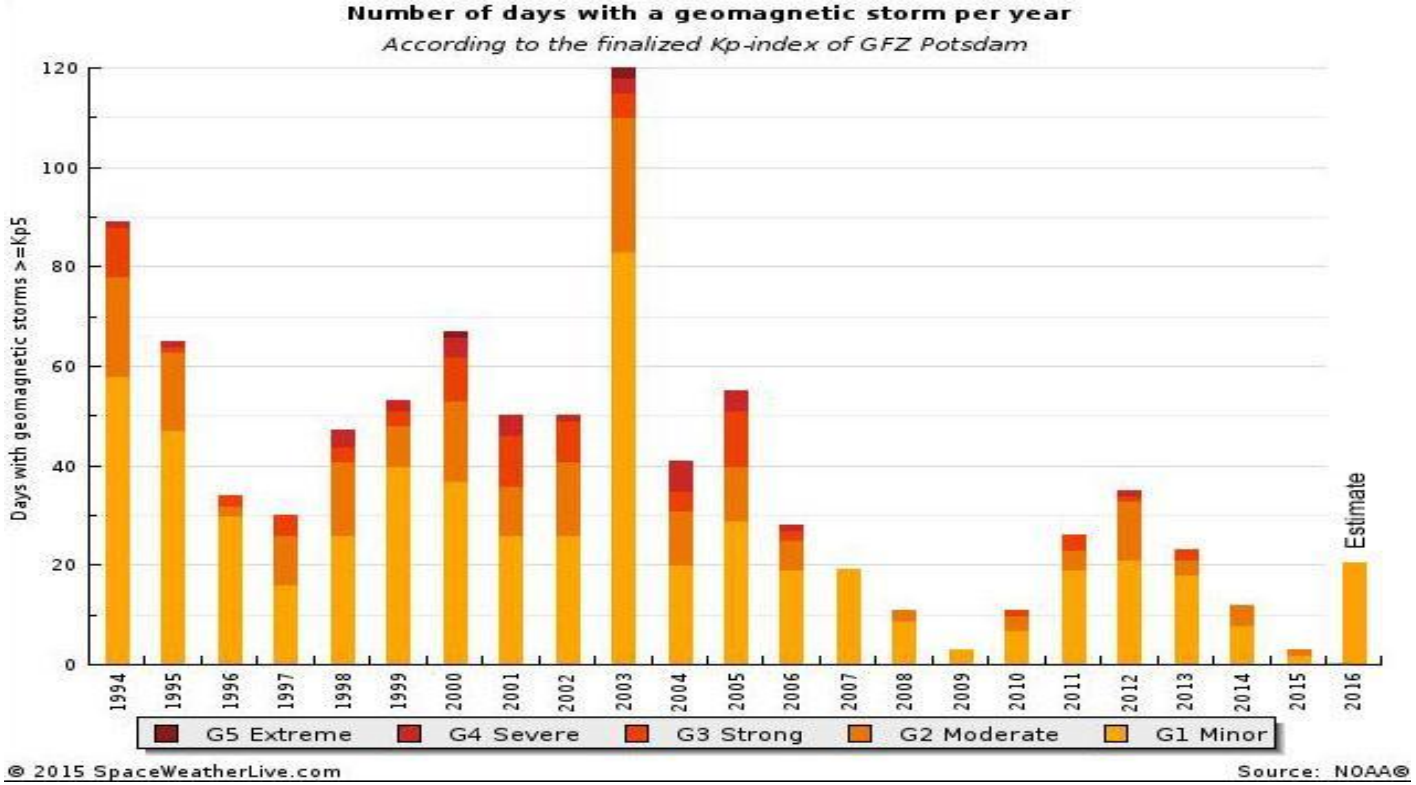
What is the IMF or Bz?



What is the IMF or Bz?

- The Sun's magnetic field isn't confined to the immediate vicinity of our star. The solar wind carries it throughout the solar system.
- Earth's magnetic field (pointing North) and the IMF come into contact at the magnetopause.
- If the IMF points south -- a condition scientists call "southward B_z" -- then the IMF can partially cancel Earth's magnetic field at the point of contact.
- A south-pointing or negative B_z opens a door through which energy from the solar wind can reach Earth's atmosphere.
- A southward B_z often heralds widespread auroras

Geomagnetic Storms

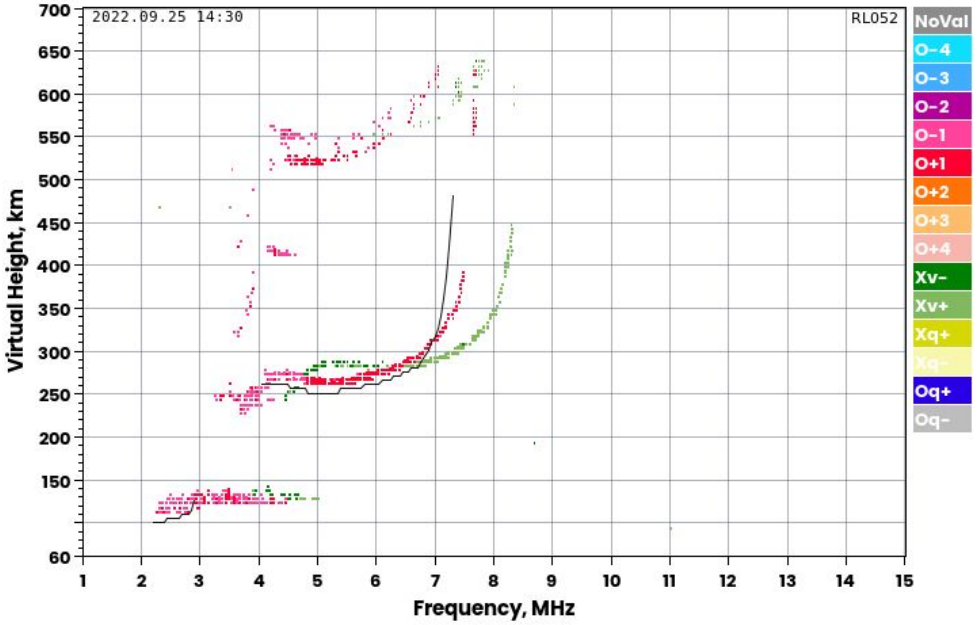


Critical frequency and MUF

Station YYYY DAY DDD HHMMSS P1 FFS S AXN PPS IGA PS
Chilton 2022 Sep25 268 143000 MMM 000 1 015 200 00+ 12

foF2	7.300
foF1	N/A
foF1p	3.77
foE	2.91
foEp	2.65
fxI	8.00
foEs	4.00
fmin	2.20
MUF(D)	25.42
M(D)	3.48
D	3000.0
h`F	251.0
h`F2	N/A
h`E	100.0
h`Es	115.0
hmF2	232.6
hmF1	N/A
hmE	98.5
yF2	71.4
yF1	N/A
yE	8.3
B0	75.1
B1	2.18
C-level	21

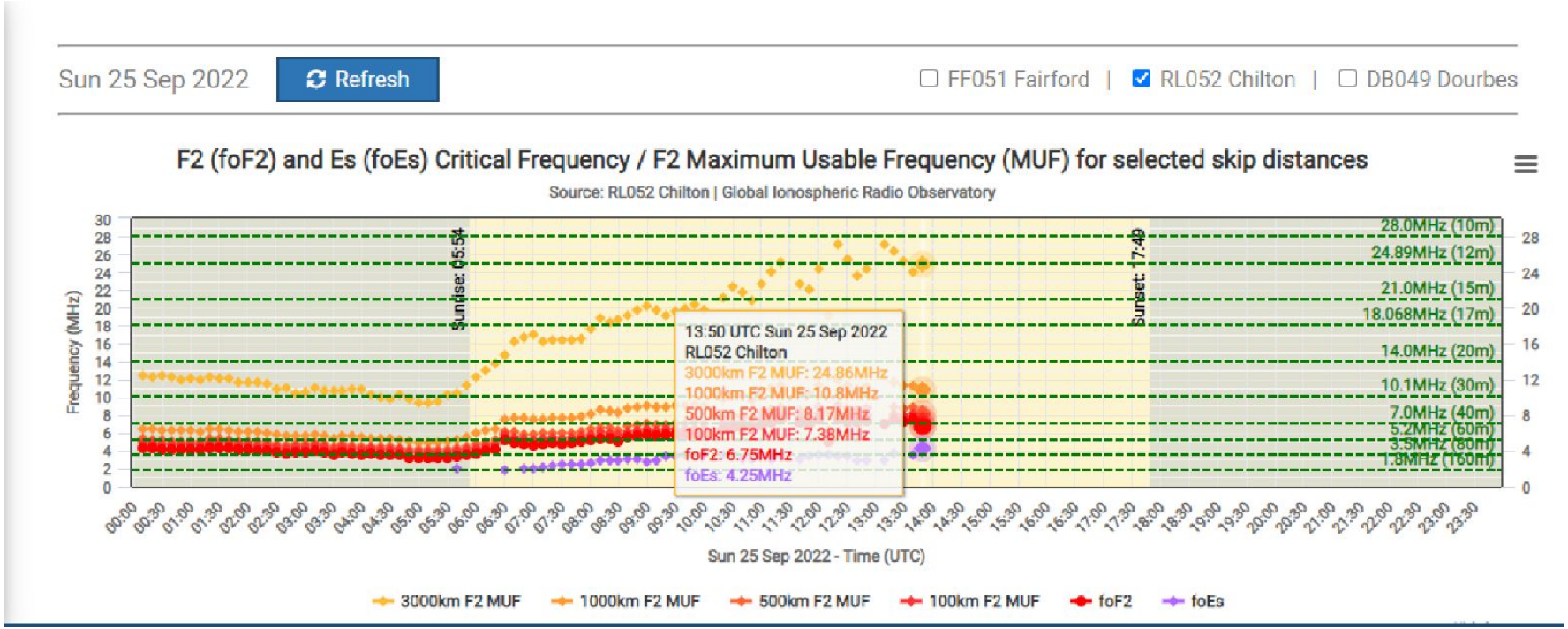
Auto:
Artist4
199905



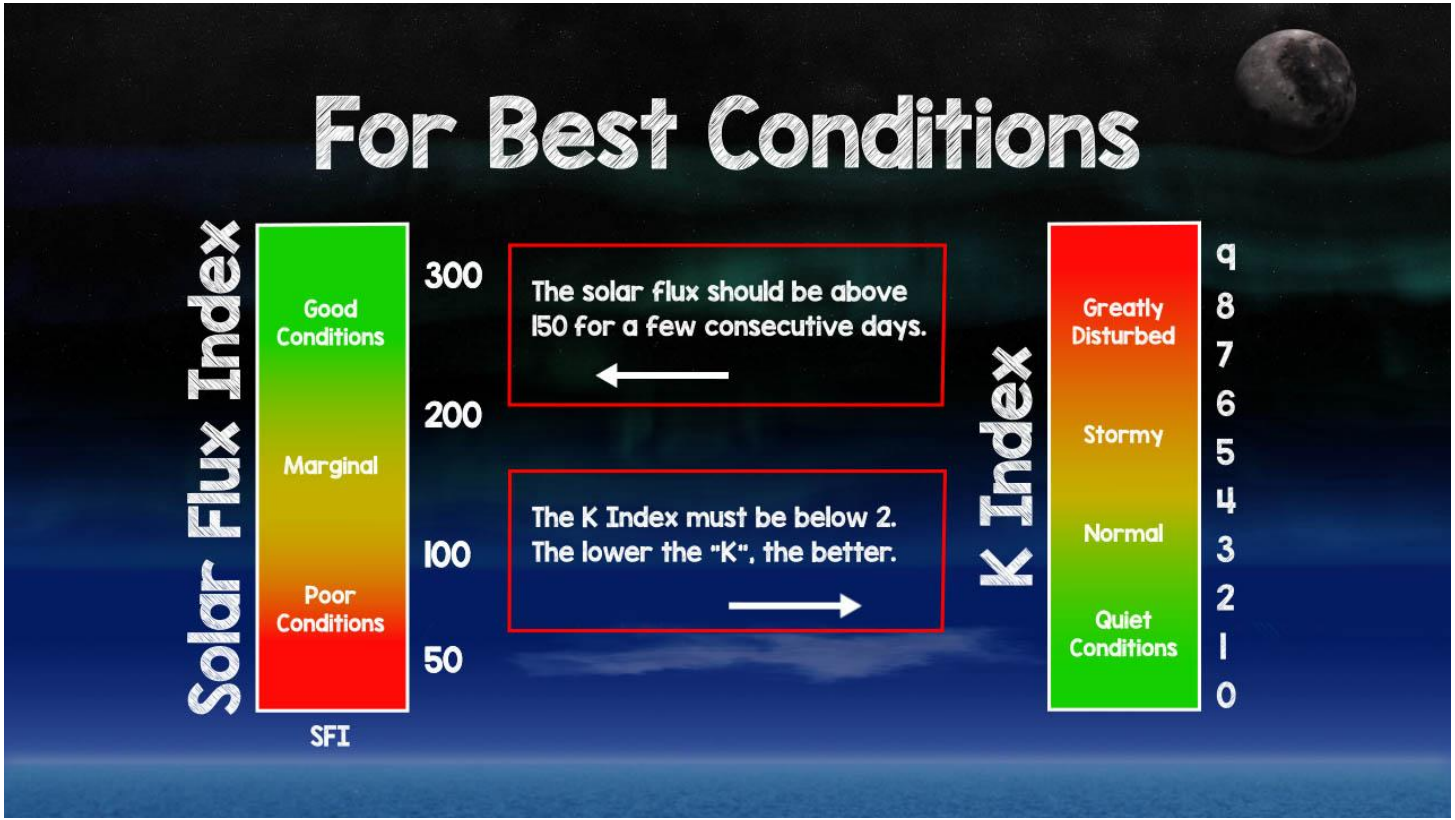
D 100 200 400 600 800 1000 1500 3000 [km]
MUF 7.9 8.0 8.4 9.1 10.0 11.4 15.3 25.4 [MHz]
RL052 2022268143000.MMM / 281fx129h 0 kHz 5.0 km / DPS-1 RL052 52 / 51.5 N 359.4 E

Ion2Png 1.5.0

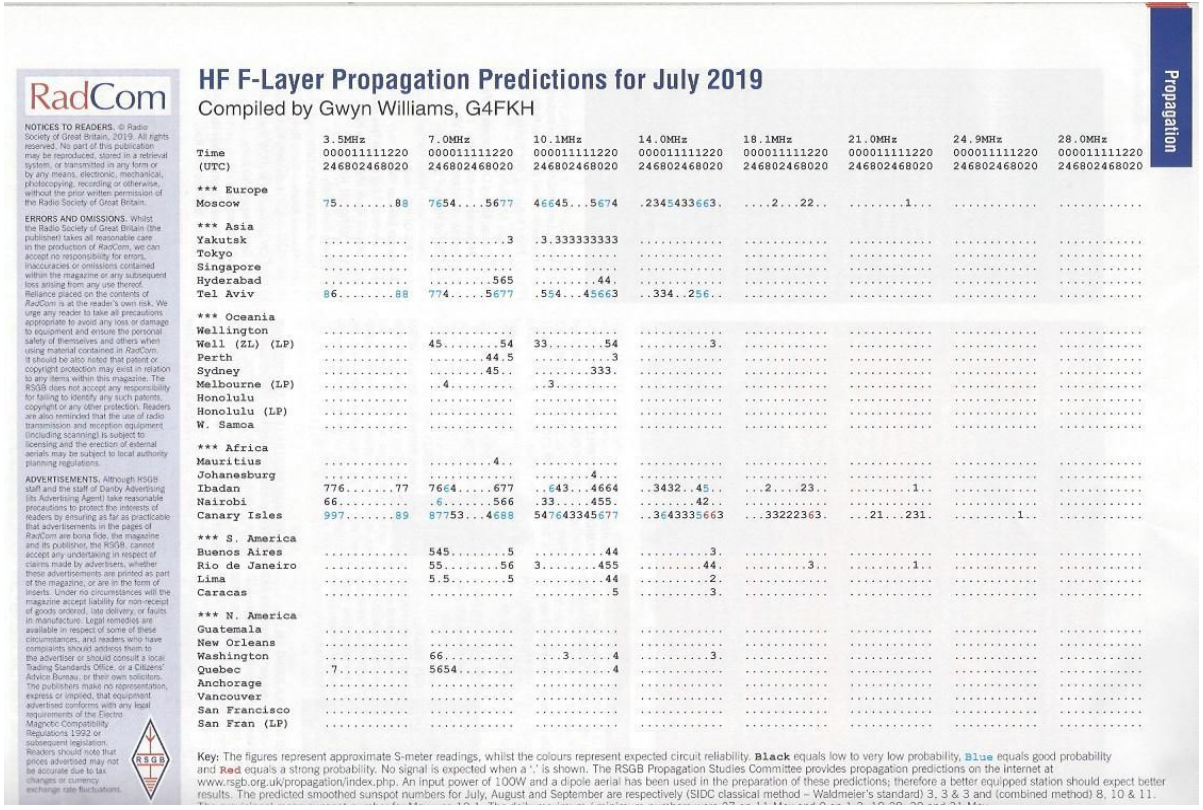
Critical frequency and MUF



Putting it all together – from VK3FS



Monthly RadCom charts



RadCom

Propagation

HF F-Layer Propagation Predictions for July 2019

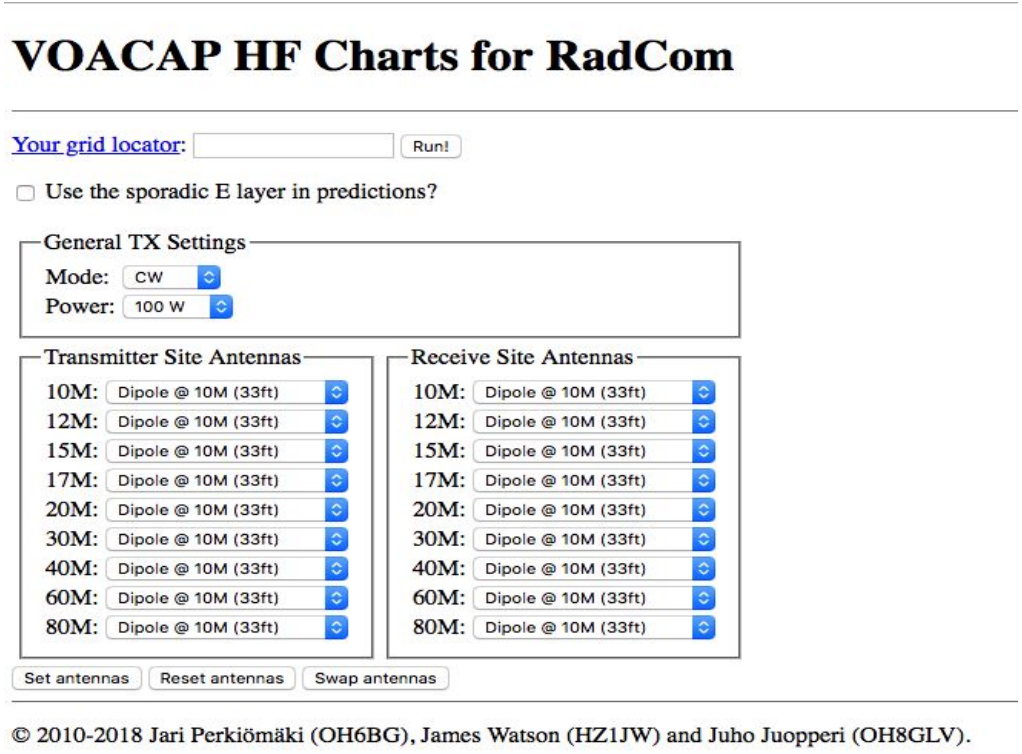
Compiled by Gwyn Williams, G4FKH

	3.5MHz	7.0MHz	10.1MHz	14.0MHz	18.1MHz	21.0MHz	24.9MHz	28.0MHz
Time	000011111220	000011111220	000011111220	000011111220	000011111220	000011111220	000011111220	000011111220
(UTC)	246802468020	246802468020	246802468020	246802468020	246802468020	246802468020	246802468020	246802468020
*** Europe								
Moscow	75.....88	7654....5677	46645...5674	.2345433663.	....2...22..	.....1...	.....	.....
*** Asia								
Yakutsk	.....	3	.3.333333333	.....	.....	.....	.....	.....
Tokyo	.....	.....	.....	.....	.....	.....	.....	.....
Singapore	.....	.....	.....	.....	.....	.....	.....	.....
Hyderabad	.....	565	.....44.	.....	.....	.....	.....	.....
Tel Aviv	86.....88	774.....5677	.554...45663	..334..256..	.....	.....	.....	.....
*** Oceania								
Wellington	.....	.....	.....	.....	.....	.....	.....	.....
Well (ZL) (LP)	.....	45.....54	33.....54	.....3.	.....	.....	.....	.....
Perth	.....	.....44.5	3	.....	.....	.....	.....	.....
Sydney	.....	.....45..	.....333.	.....	.....	.....	.....	.....
Melbourne (LP)	.....	..4.....	..3.....	.....	.....	.....	.....	.....
Honolulu	.....	.....	.....	.....	.....	.....	.....	.....
Honolulu (LP)	.....	.....	.....	.....	.....	.....	.....	.....
W. Samoa	.....	.....	.....	.....	.....	.....	.....	.....
*** Africa								
Mauritius	.....	.....4..	.....	.....	.....	.....	.....	.....
Johanesburg	.....	.....	.....4...	.....	.....	.....	.....	.....
Ibadan	776.....77	7664.....677	..643...4664	..3432..45..	...2....23..	.....1..	.....	.....
Nairobi	66.....	.6.....566	.33.....455.	.....42..	.....	.....	.....	.....
Canary Isles	997.....89	87753...4688	54764334567 7	..364333566 3	...33222363.	...21...231.	.....1..	.....
*** S. America								
Buenos Aires	.....	545.....5	44	.....3.	.....	.....	.....	.....
Rio de Janeiro	.....	55.....56	3.....455	.....44.	.....3..	.....1..	.....	.....
Lima	.....	5.5.....5	44	.....2.	.....	.....	.....	.....
Caracas	.....	.....	5	.....3.	.....	.....	.....	.....
*** N. America								
Guatemala	.....	.....	.....	.....	.....	.....	.....	.....
New Orleans	.....	.....	.....	.....	.....	.....	.....	.....
Washington	.....	66.....	....3.....4	.....3.	.....	.....	.....	.....
Quebec	.7.....	5654.....	4	.....	.....	.....	.....	.....
Anchorage	.....	.....	.....	.....	.....	.....	.....	.....
Vancouver	.....	.....	.....	.....	.....	.....	.....	.....
San Francisco	.....	.....	.....	.....	.....	.....	.....	.....
San Fran (LP)	.....	.....	.....	.....	.....	.....	.....	.....

Key: The figures represent approximate S-meter readings, whilst the colours represent expected circuit reliability. **Black** equals low to very low probability, **Blue** equals good probability and **Red** equals a strong probability. No signal is expected when a '.' is shown. The RSGB Propagation Studies Committee provides propagation predictions on the internet at www.rsgb.org.uk/propagation/index.php. An input power of 100W and a dipole aerial has been used in the preparation of these predictions; therefore a better equipped station should expect better results. The predicted smoothed sunspot numbers for July, August and September are respectively (SIDC classical method – Waldmeier's standard) 3, 3 & 3 and (combined method) 8, 10 & 11.

How have we augmented RadCom predictions?

Now available at voacap.com/radcom:



VOACAP HF Charts for RadCom

Your grid locator: Run!

Use the sporadic E layer in predictions?

General TX Settings

Mode: CW

Power: 100 W

	Transmitter Site Antennas	Receive Site Antennas
10M:	Dipole @ 10M (33ft)	Dipole @ 10M (33ft)
12M:	Dipole @ 10M (33ft)	Dipole @ 10M (33ft)
15M:	Dipole @ 10M (33ft)	Dipole @ 10M (33ft)
17M:	Dipole @ 10M (33ft)	Dipole @ 10M (33ft)
20M:	Dipole @ 10M (33ft)	Dipole @ 10M (33ft)
30M:	Dipole @ 10M (33ft)	Dipole @ 10M (33ft)
40M:	Dipole @ 10M (33ft)	Dipole @ 10M (33ft)
60M:	Dipole @ 10M (33ft)	Dipole @ 10M (33ft)
80M:	Dipole @ 10M (33ft)	Dipole @ 10M (33ft)

Set antennas | Reset antennas | Swap antennas

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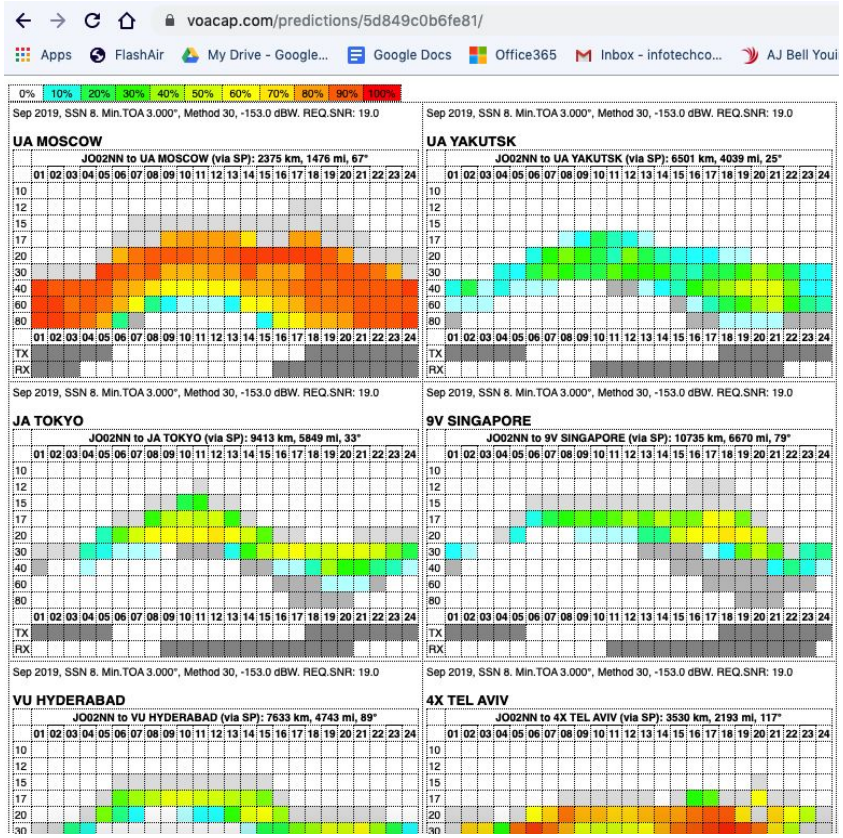
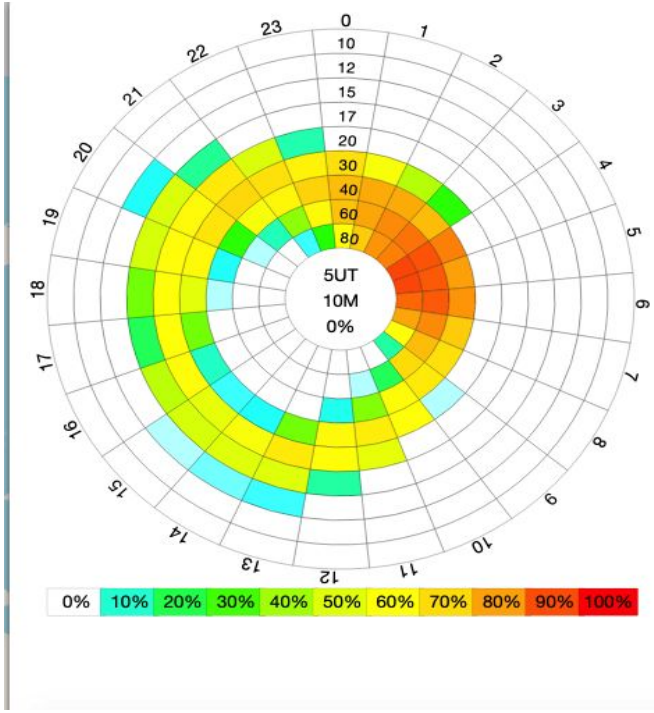
VOACAP RadCom tool



Looks at 28 locations around the world (four of them SP and LP).

Generates hour-by-hour reliability predictions for each band.

VOACAP.com


0
1
2
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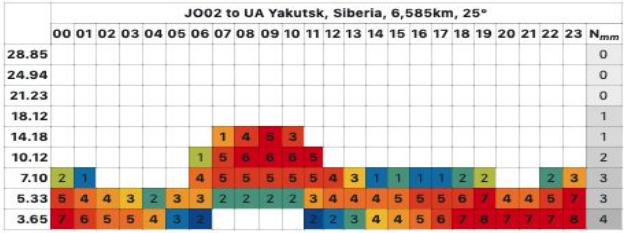
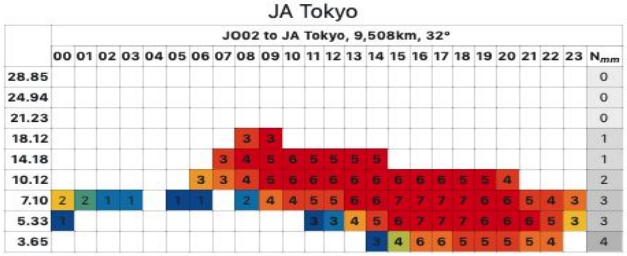
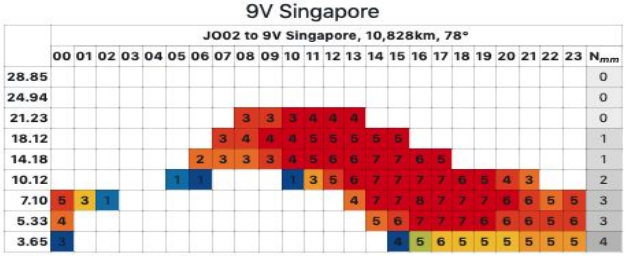
21
22
23
10
12
15
17
20
30
40
60
80
5UT
10M
0%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%


+
−
SP
NoEs
14:10

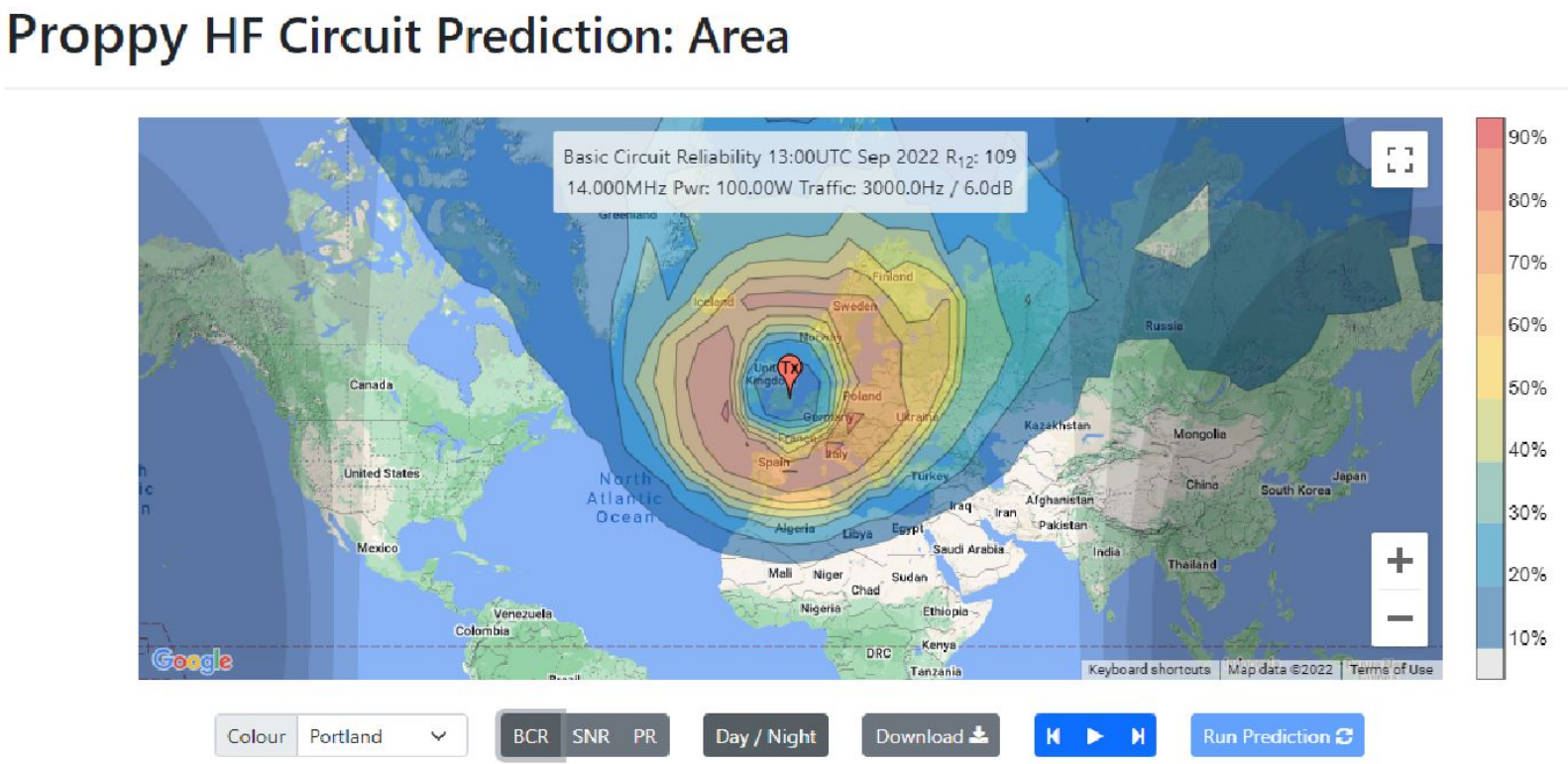
Proppy RadCom tool - https://soundbytes.asia/proppy/radcom





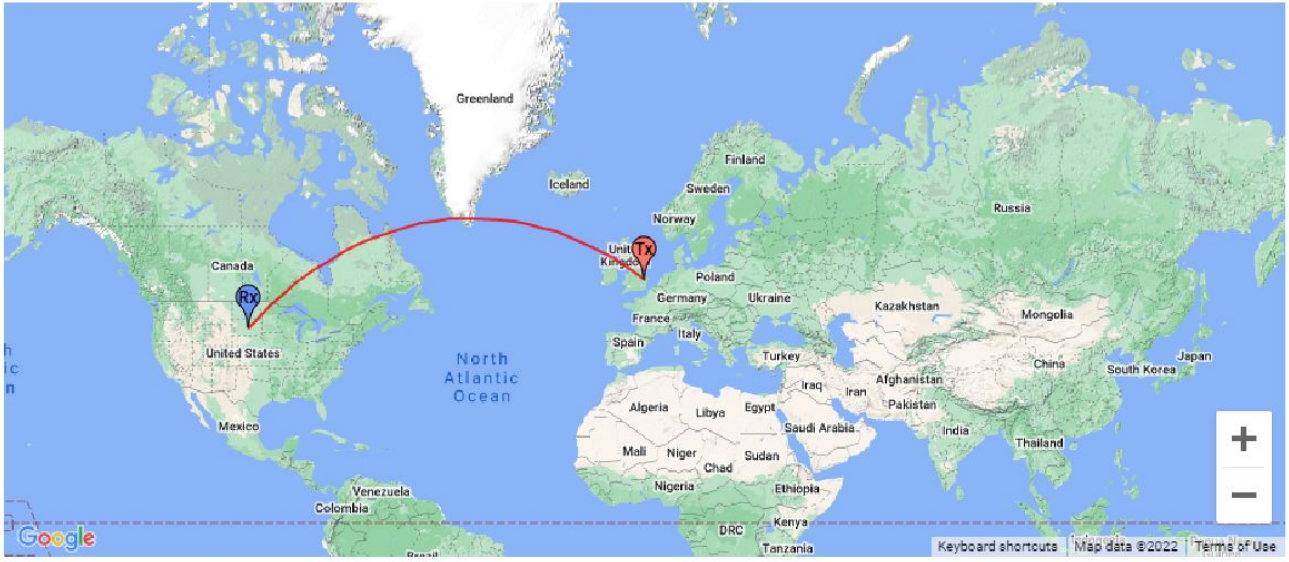


Proppy - soundbytes.asia/proppy/area



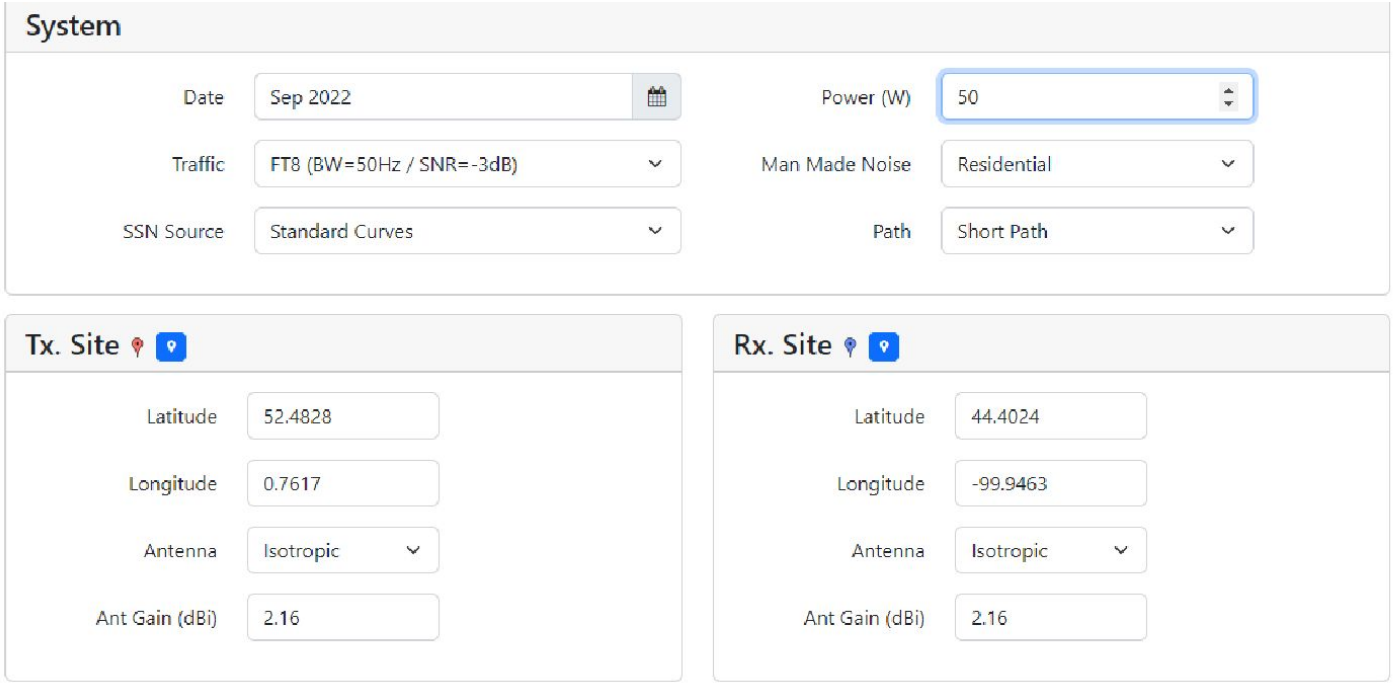
Proppy - soundbytes.asia/proppy/p2p

Proppy HF Circuit Prediction: Point-to-Point

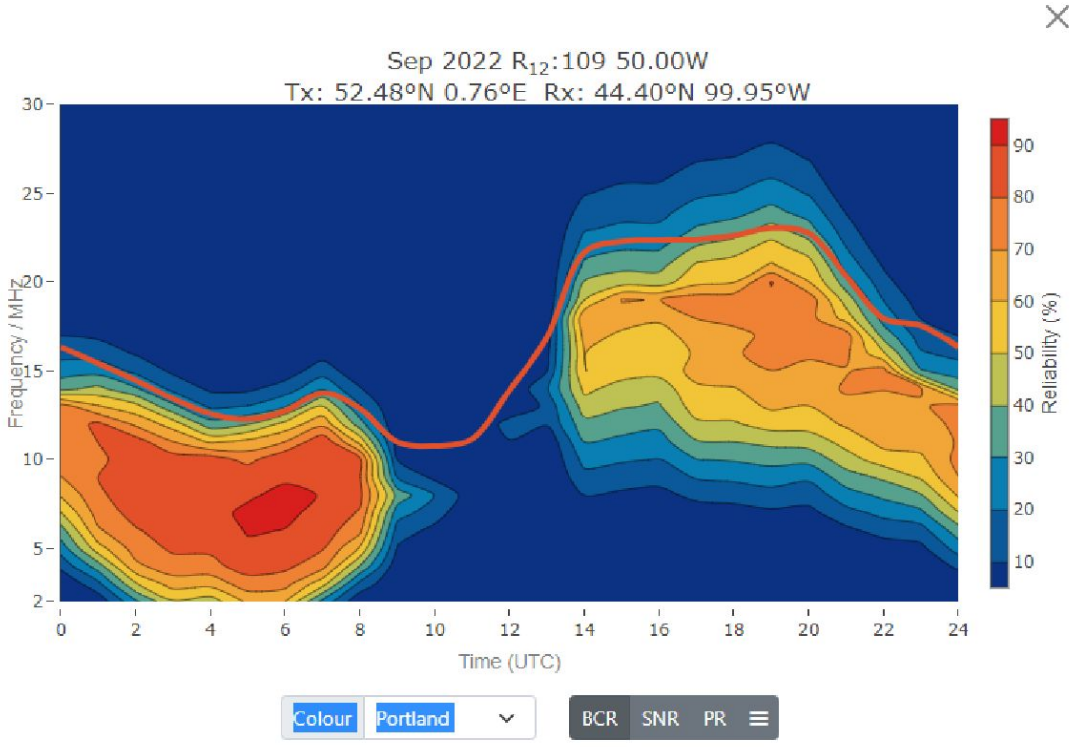


Run Prediction

Proppy - soundbytes.asia/proppy/p2p



Proppy - soundbytes.asia/proppy/p2p



Any questions + club YouTube presentations

- Understanding HF Propagation
- Understanding VHF Propagation

Steve Nichols G0KYA
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Presentation at: g0kya.blogspot.co.uk