Long Distance HF Propagation During the Slow Decline of Solar Cycle 25

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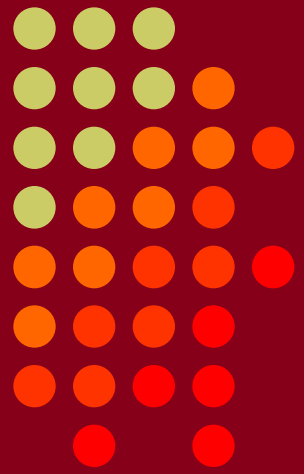

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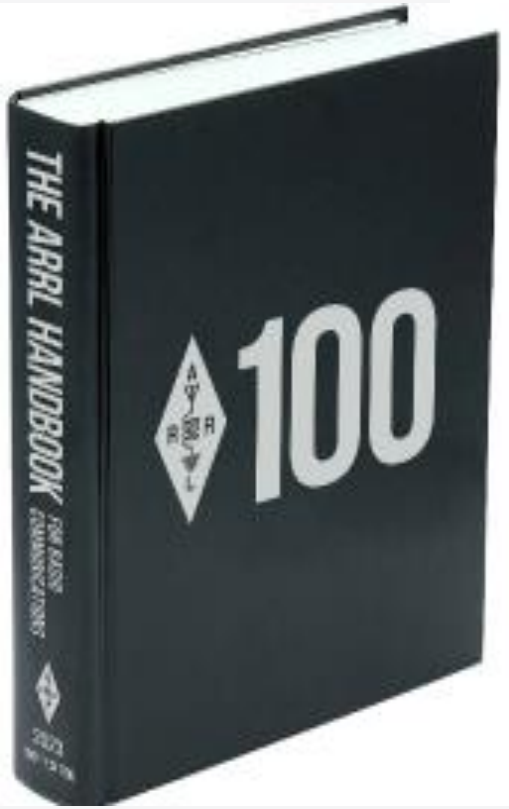
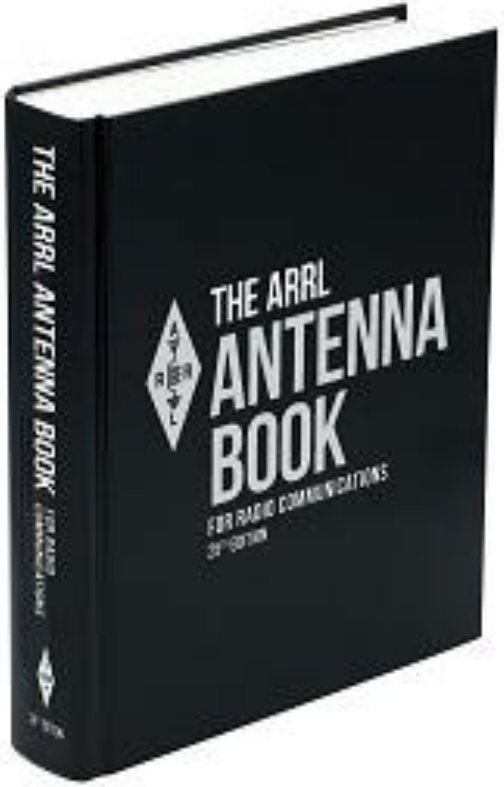
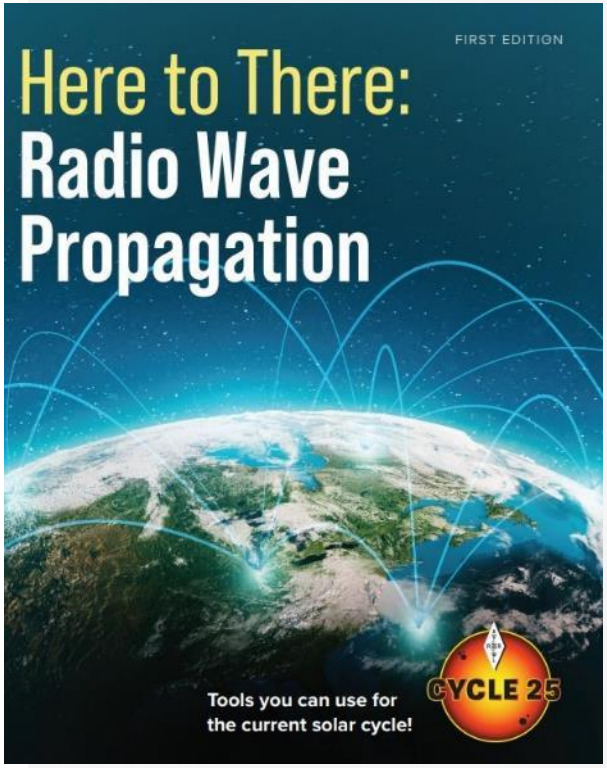
The Three Most Valuable Investments to Greatly Improve Your Detailed Knowledge of Antennas and Propagation







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All HF Propagation Originates on the Sun

Solar Cycle: rising, maximum, declining, minimum

Solar Magnetic Field: source of sunspots & IMF

IMF: The solar magnetic field extended into space

IMF orientation: affects geomagnetic storm intensity

Corona: Superheated magnetized plasma

Active Regions: sunspots, solar flares and CMEs

Sunspots: concentrated closed magnetic fields

CMEs: cause nearly all strong geomagnetic storms

Coronal Holes: source of the high speed solar wind

High Speed Solar Wind: minor geomagnetic storms

Solar Flares: cause daytime HF propagation dropouts

Key Features of the Sun-Earth System

every HF operator should understand these basic concepts

Sunspots and Active Regions Intense closed magnetic fields emerge from the corona to form sunspots and their surrounding active regions. Ionizing extreme ultraviolet radiation and disturbances from solar flares, hard x-rays, energetic protons and CMEs originate in active regions

Solar Cycles usually 11 years, as short as 9 years, as long as 14 years. Some cycles have a long lasting and more energetic solar maximum. Some cycles have a long lasting and less energetic solar minimum.

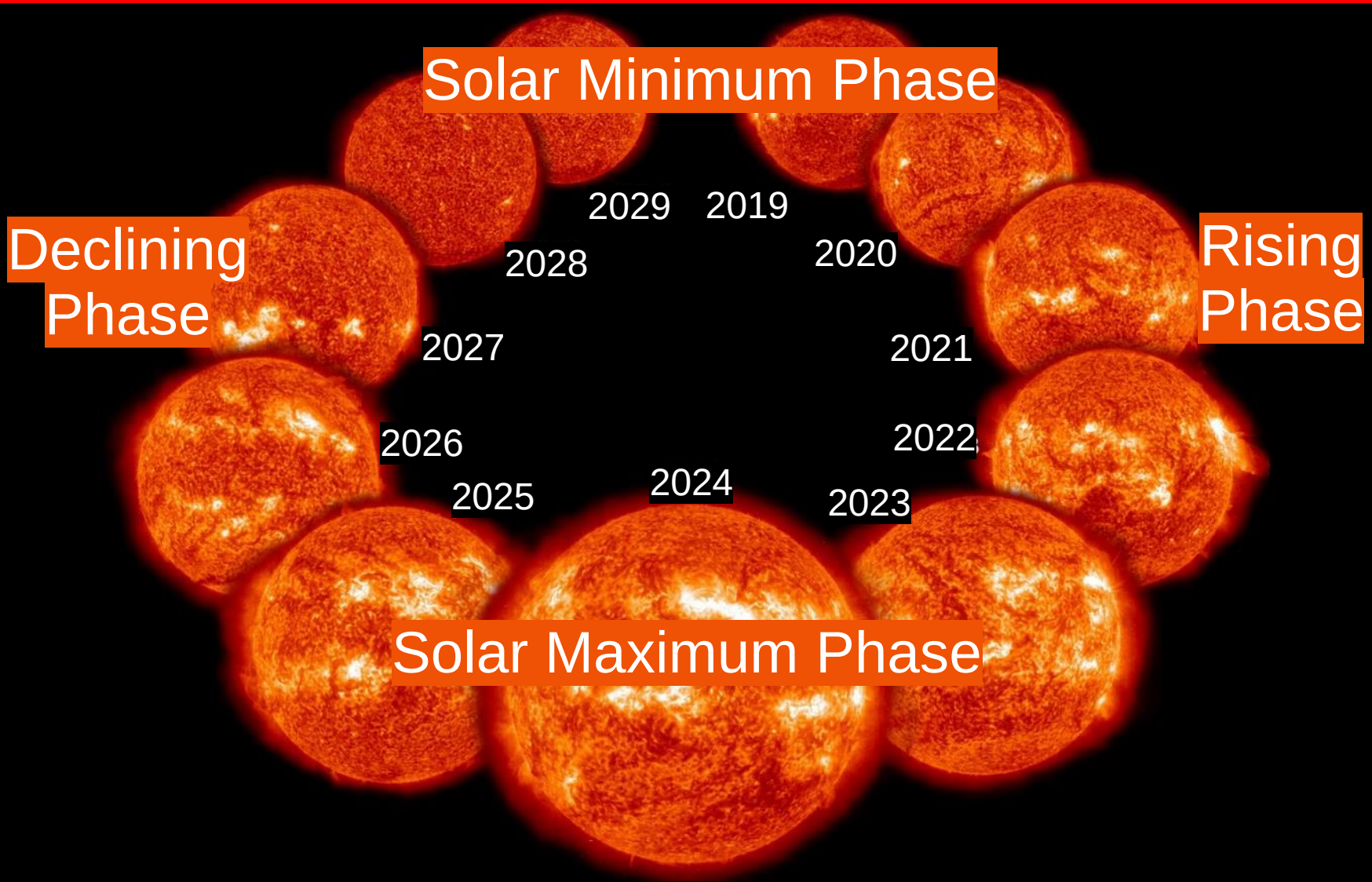
Ionizing Radiation Ten times more ionizing extreme ultraviolet radiation during solar maximum improves HF propagation especially during fall, winter and spring. Highly energetic x-rays from solar flares can suddenly black out daytime HF propagation for up to two hours with no warning

Geomagnetic Disturbances HF propagation is often degraded by the enhanced hypersonic flow of magnetized plasma in the fast solar wind

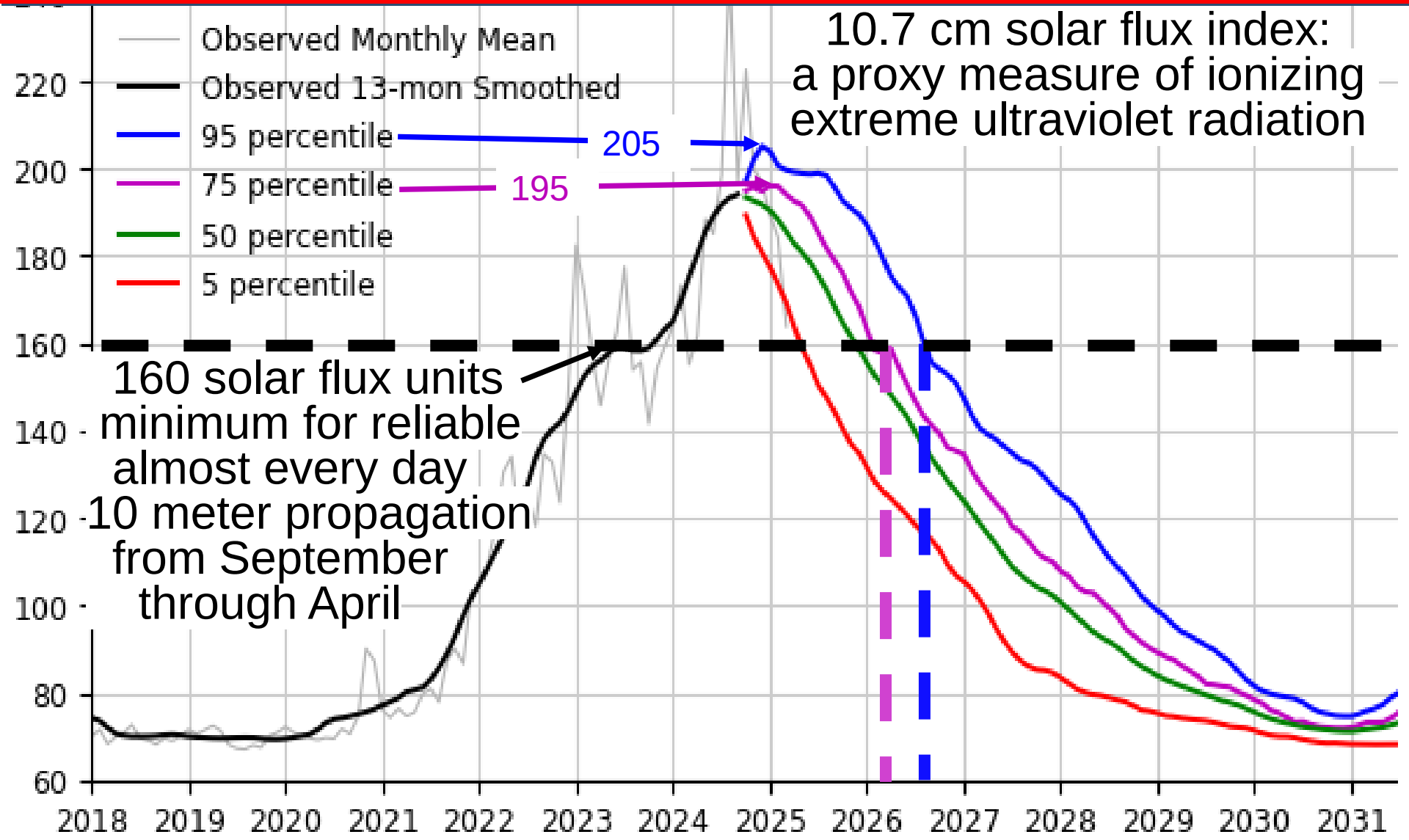
27 Day Solar Rotation 27 day repetitive enhancement and disturbance

Seasonal Variability Earth's 23.5º tilted axis increases ionizing EUV radiation intensity at mid and high latitudes during summer and decreases it during winter. Earth's tilted axis also reduces the intensity and frequency of disturbed HF propagation during summer and winter

Enhanced Ionizing Extreme Ultraviolet Radiation Continues to Greatly Improve 40 to 10 Meter Propagation Through 2026

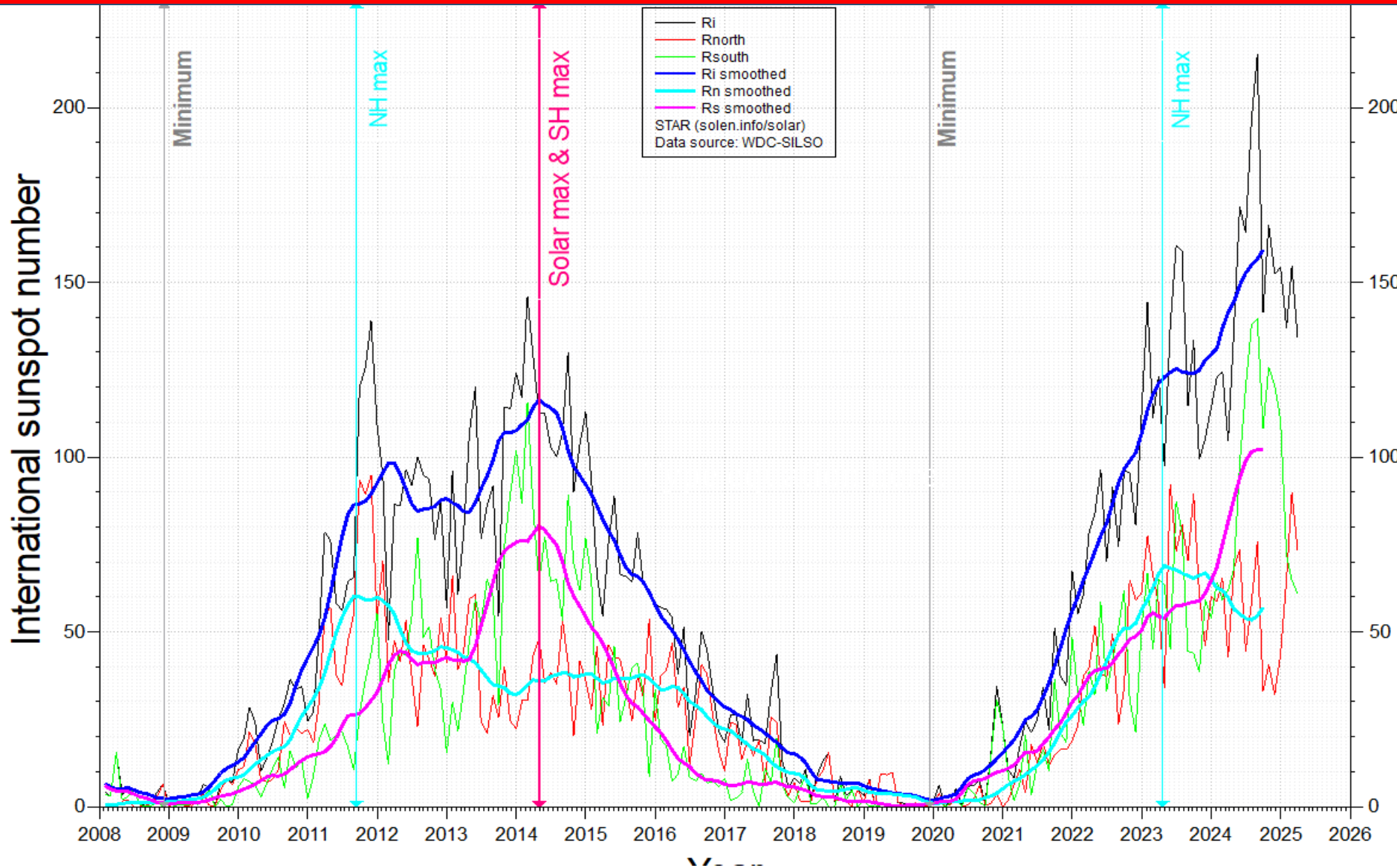


Solar Cycle 25 Solar Flux Index Forecast
NASA Marshall Space Flight Center - April 2025



www.nasa.gov/msfcsolar

Solar Cycle 25 Progress vs Solar Cycle 24



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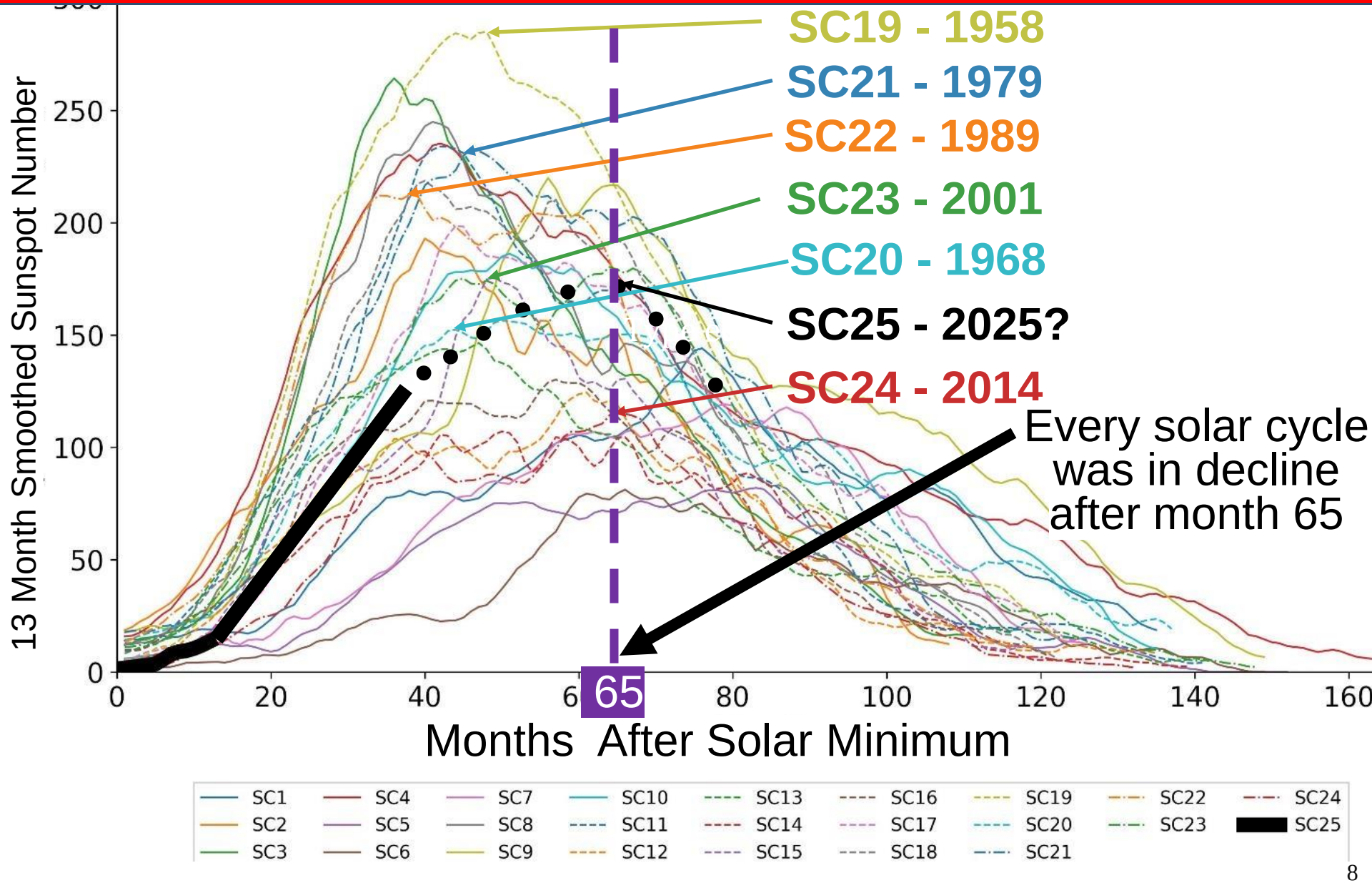
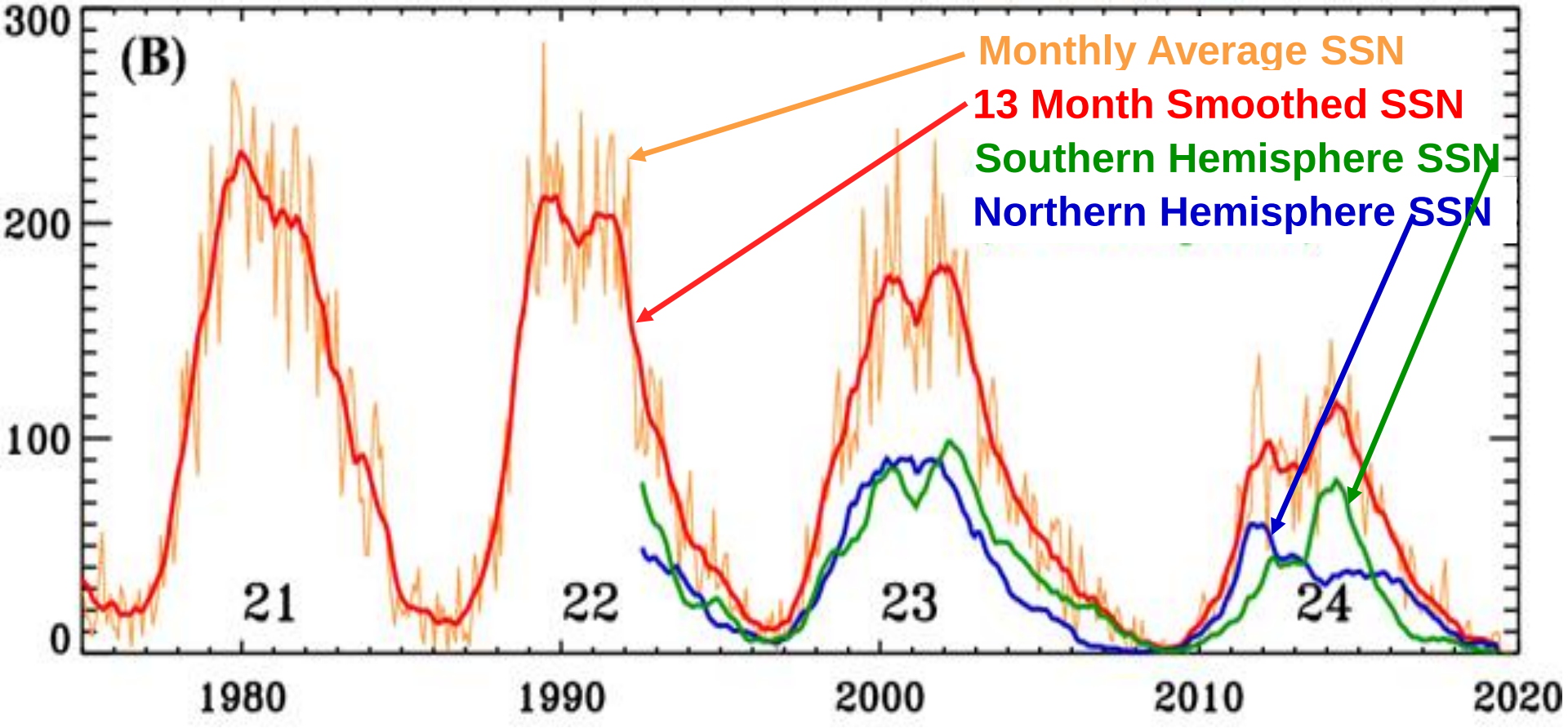
Solar Cycle 25 Sunspot Activity Increased More Slowly Than All Recent Solar Cycles Except SC24



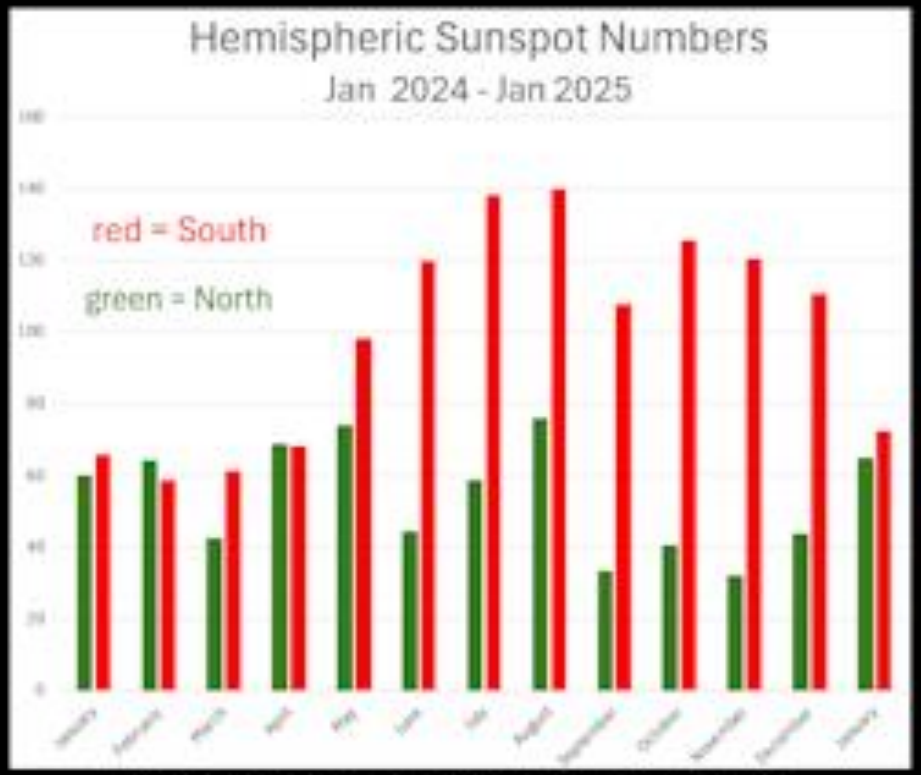
The Sun's Northern and Southern Hemisphere Solar Cycles are Almost Always Offset, Sometimes by up to Two Years

Solar cycle duration varies from 8 to more than 14 years

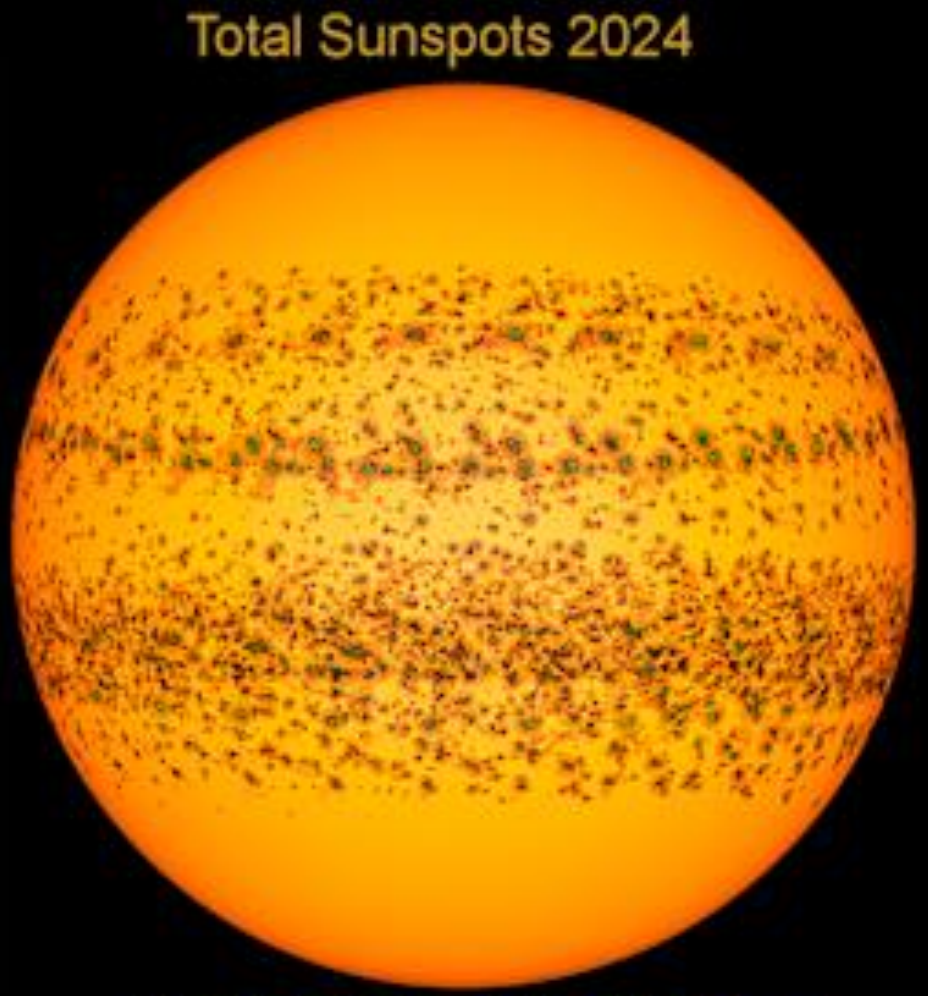
Propagation models use the 13 month smoothed SSN



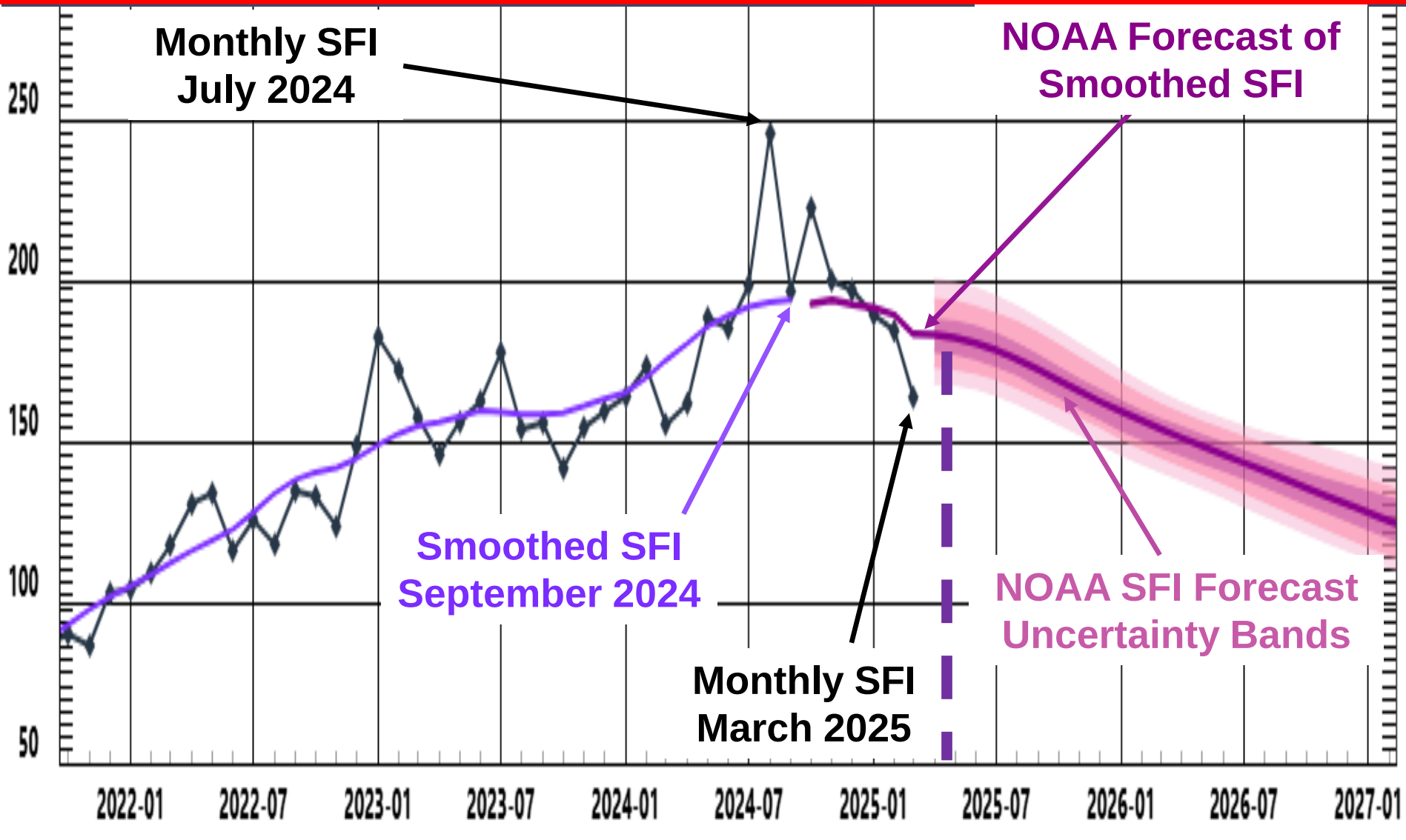
Solar Cycle 25 is Very Unlikely to Have a Second Sunspot Peak in 2025/2026



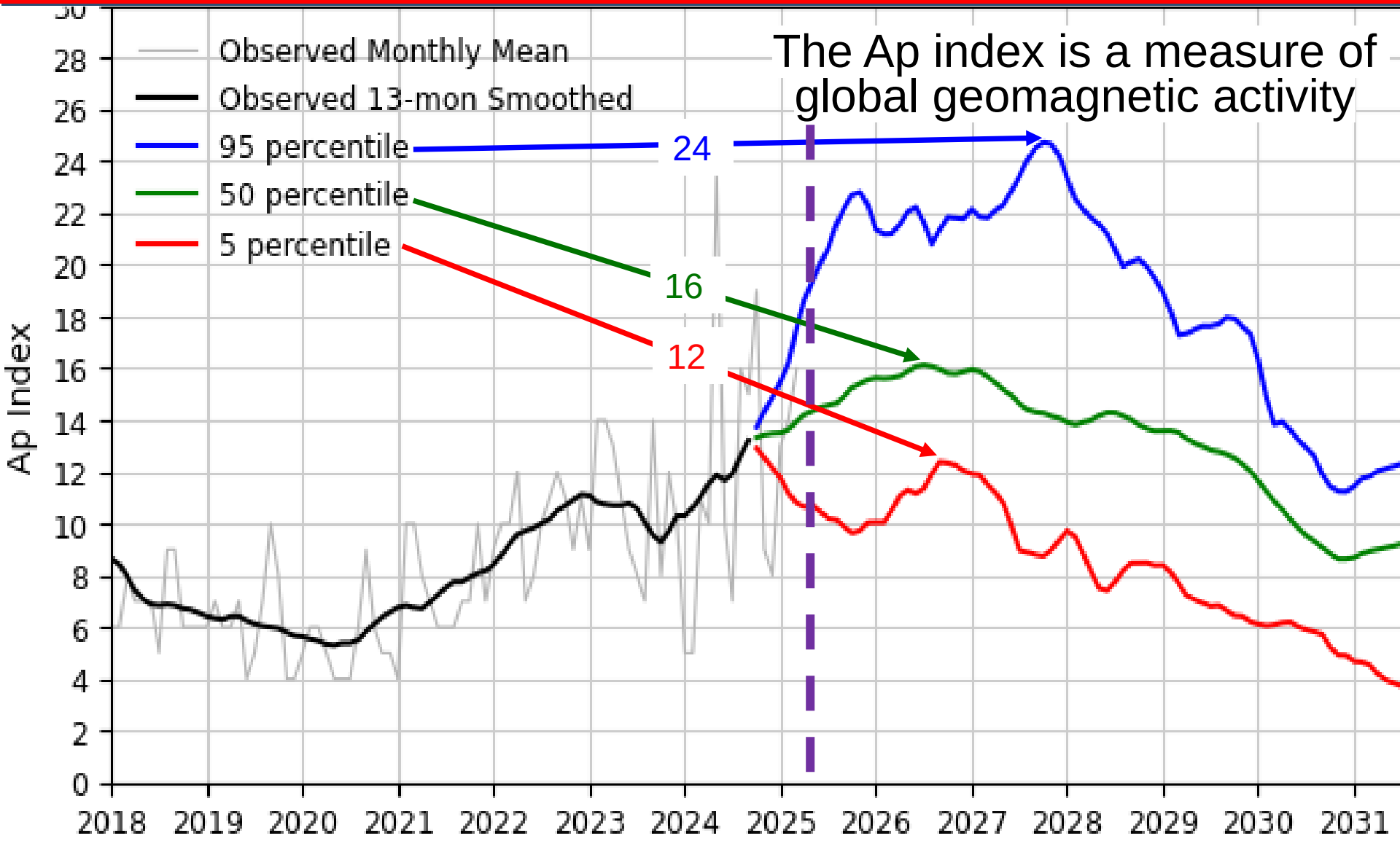
Data from the Solar Influences Data Analysis Center
Royal Observatory of Belgium



April 2025 SWPC Solar Cycle 25 10.7 cm Solar Flux Index Forecast



Solar Cycle 25 Geomagnetic Ap Index Forecast
NASA Marshall Space Flight Center – April 2025



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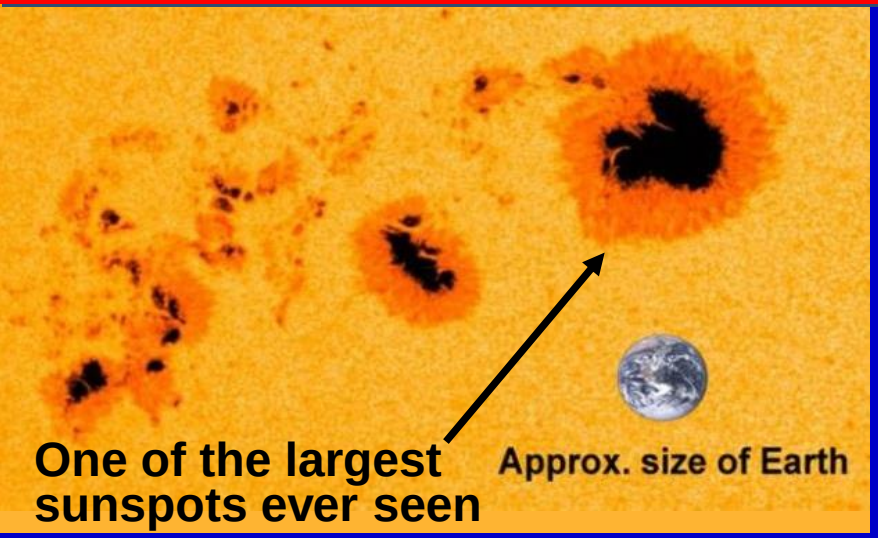
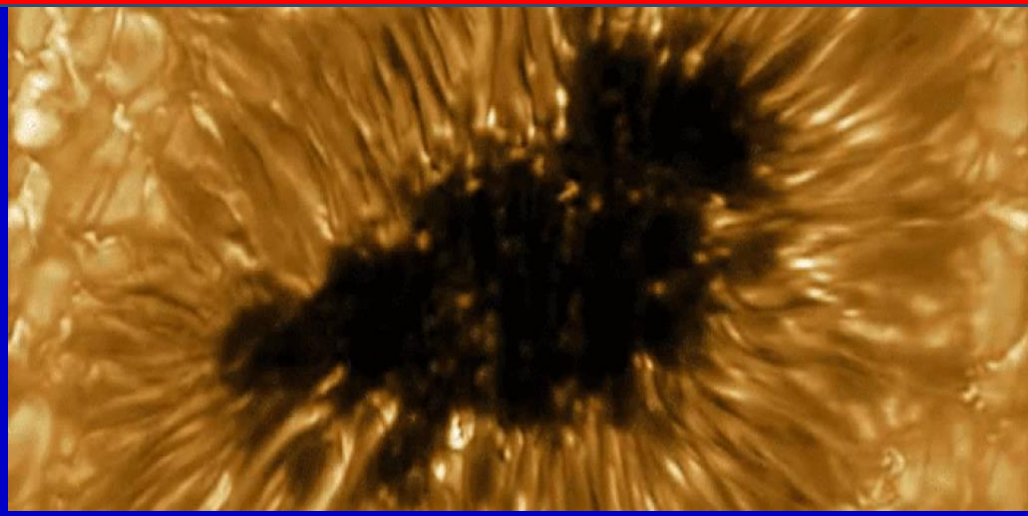
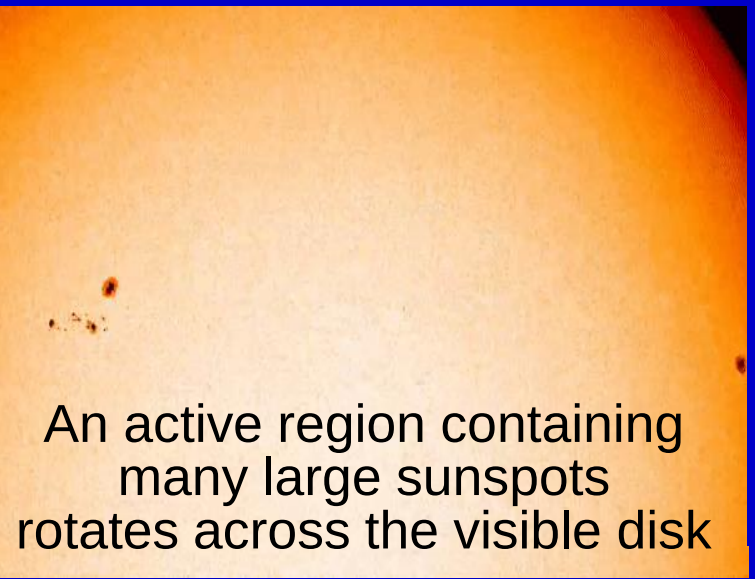
More Frequent, More Energetic Active Regions Produce Many More Sunspots, Solar Flares and Coronal Mass Ejections







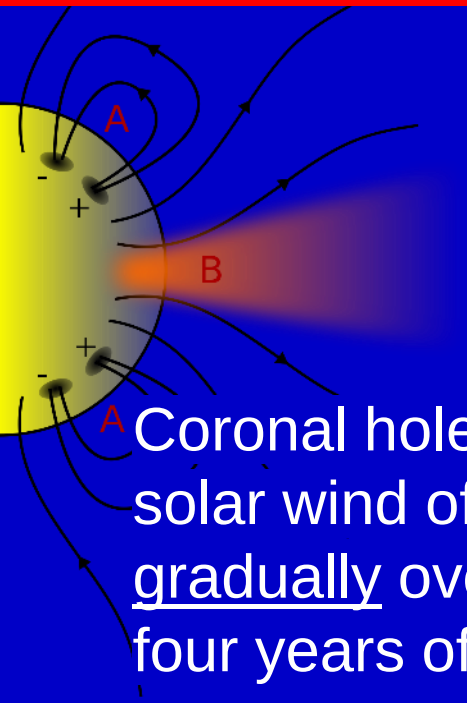
An active region containing many large sunspots rotates across the visible disk

During solar maximum active regions radiate:

- Stronger ionizing extreme ultraviolet radiation enhancing HF propagation on upper HF bands
- Highly energetic magnetized plasma from fast interplanetary CMEs causing more frequent strong geomagnetic storms
- Highly energetic hard x-rays from solar flares cause more frequent daytime radio blackouts

Coronal Hole High Speed Streams

The open magnetic fields of coronal holes
allow the corona's magnetized plasma to escape
forming the high speed solar wind



Coronal hole high speed streams are the most frequent source of minor geomagnetic storms throughout the solar cycle but most frequently during the declining four years of each solar cycle

Coronal hole high speed streams interact with the slow ambient solar wind often causing minor geomagnetic storms that develop gradually over several hours most frequently during the declining four years of each solar cycle

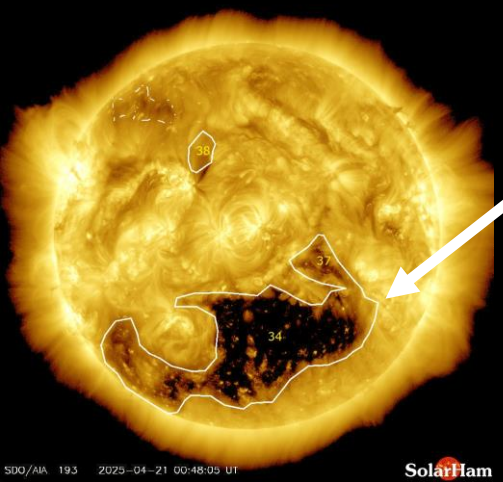
Conversely, fast interplanetary CMEs originating in active regions sometimes cause strong and rare extreme geomagnetic storms that develop suddenly mostly during the four years near solar maximum

Short Duration Minor Geomagnetic Storms
Caused by Coronal Hole High Speed Stream Effects

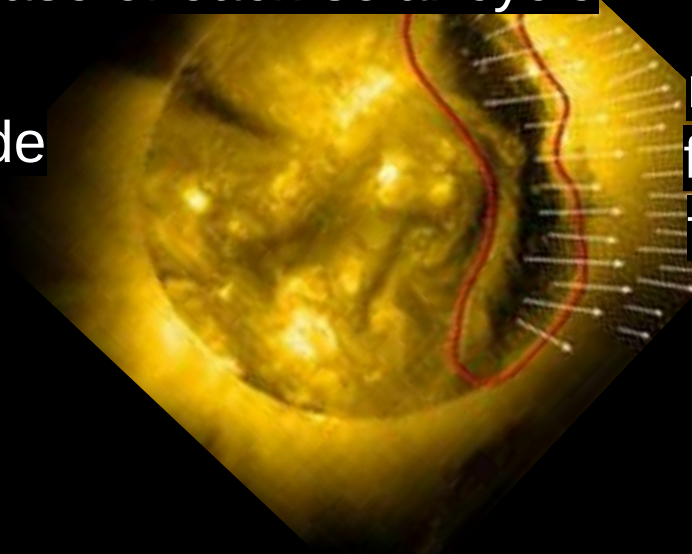
Open magnetic fields flowing from small coronal holes at low solar latitudes allow magnetized plasma to escape the Sun's gravity forming the ambient solar wind and the interplanetary magnetic field

Coronal hole high speed streams originating from large Earth facing low latitude coronal holes cause frequent unsettled to active geomagnetic disturbances and occasional minor geomagnetic storms

Disturbed geomagnetic activity and minor geomagnetic storms caused by coronal hole high speed stream effects occur most frequently during the declining phase of each solar cycle

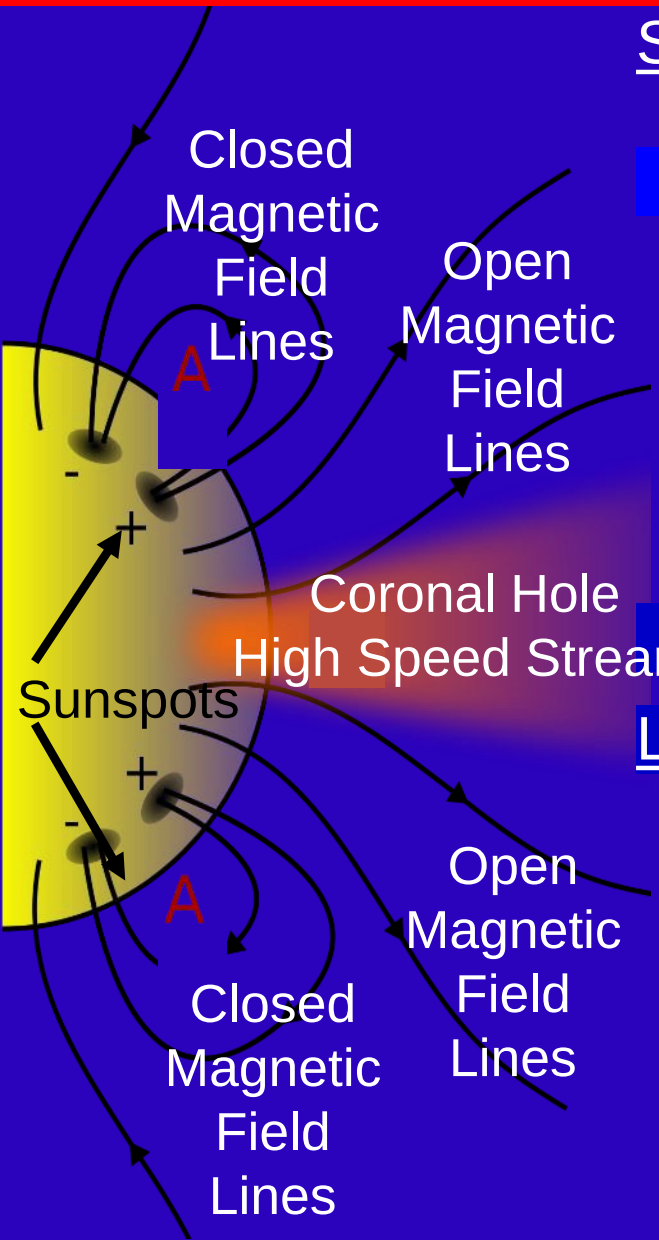


450,000 mile wide Earth facing coronal hole April 21 2025



Open magnetic field lines flow from coronal holes

Short and Long Duration Minor Geomagnetic Storms



Short duration minor geomagnetic storms

- caused by coronal hole high speed stream interactions with the ambient slow solar wind
- minor geomagnetic storms do not significantly degrade HF propagation during the four years near solar maximum
- the most frequent cause of degraded HF propagation during the four years near solar minimum

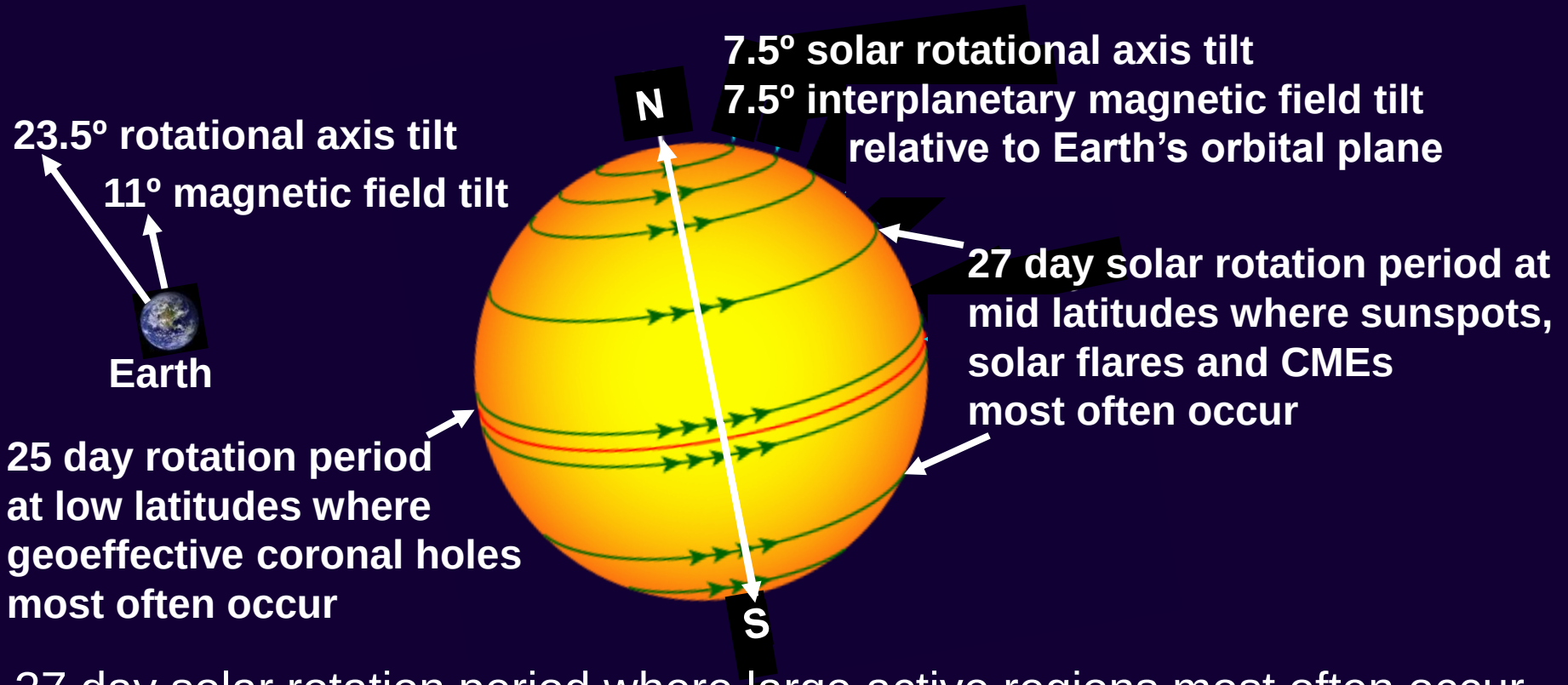
Long duration minor geomagnetic storms

- caused by weak interplanetary fast coronal mass ejections and near misses by CMEs
- do not significantly degrade HF propagation during the four years near solar maximum
- occur about twice as frequently during the declining years of each solar cycle

27 Day Recurrent Large Active Regions and 25 Day Recurrent Large Coronal Holes

Enhanced HF propagation can repeat about every 27 days as large sunspots rise on the east solar limb and set on the west limb

Geomagnetic disturbances can repeat about every 27 days when large active regions are +/- 30º latitude from the central meridian



27 day solar rotation period where large active regions most often occur

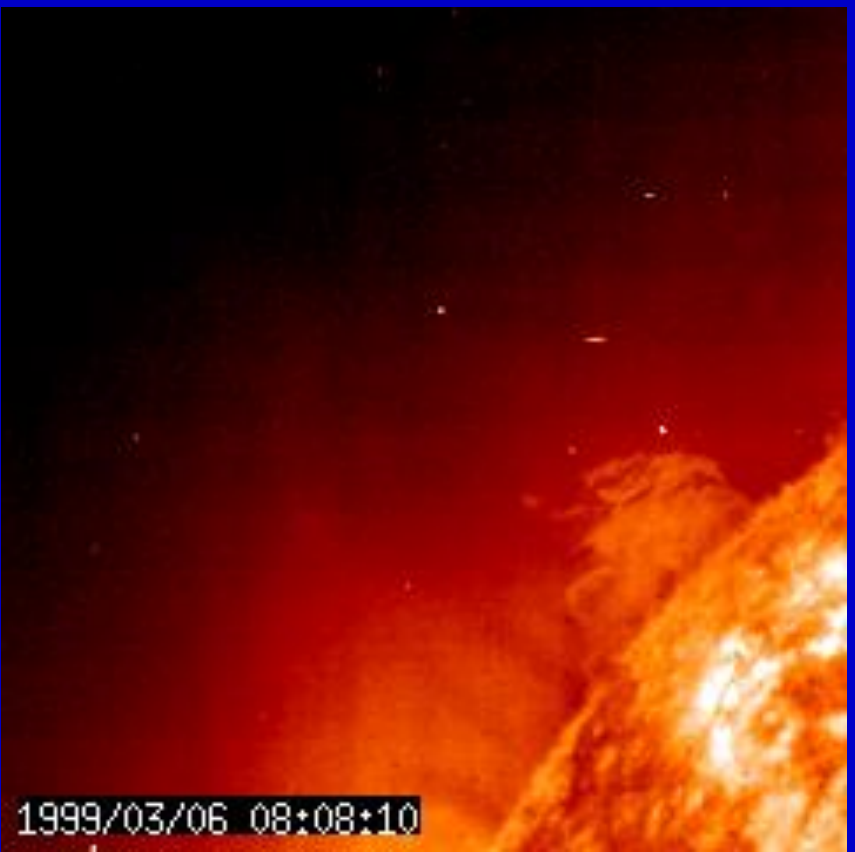
25 day solar rotation period where geoeffective coronal holes often occur

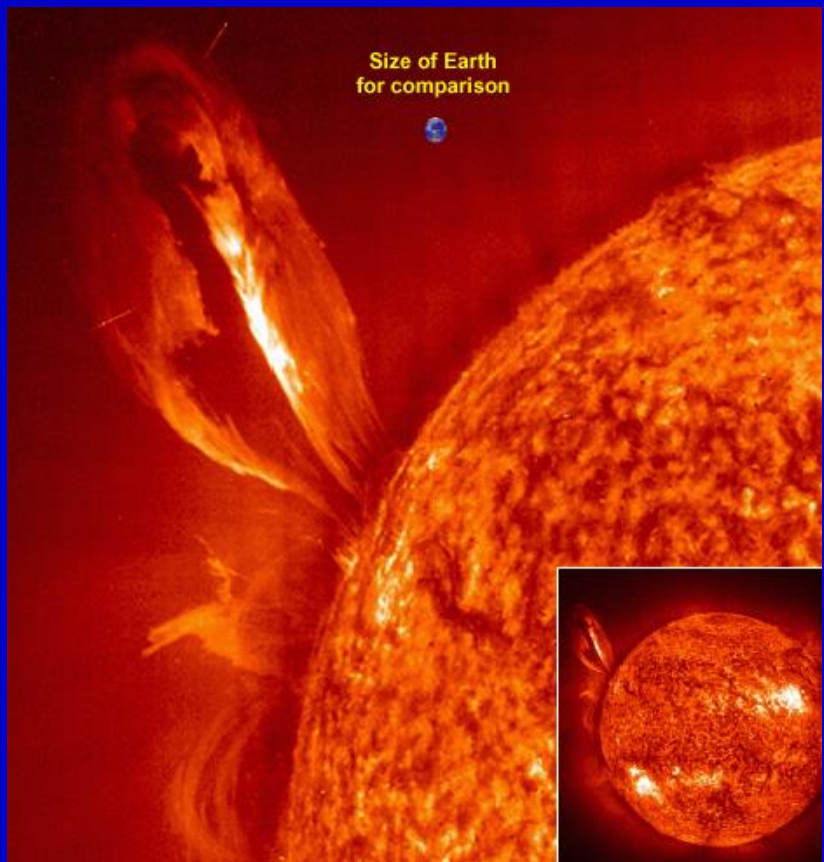
Frequent Solar Flares and Associated CMEs

Massive explosions of X-rays and plasma from active regions

95% of solar flares occur when the solar flux index is 90 or greater during the four years of greatest solar activity near solar maximum

In just a few minutes coronal mass ejections often associated with solar flares can release as much as ten billion tons of magnetized plasma travelling to the planets from 700 to more than 1000 km/second



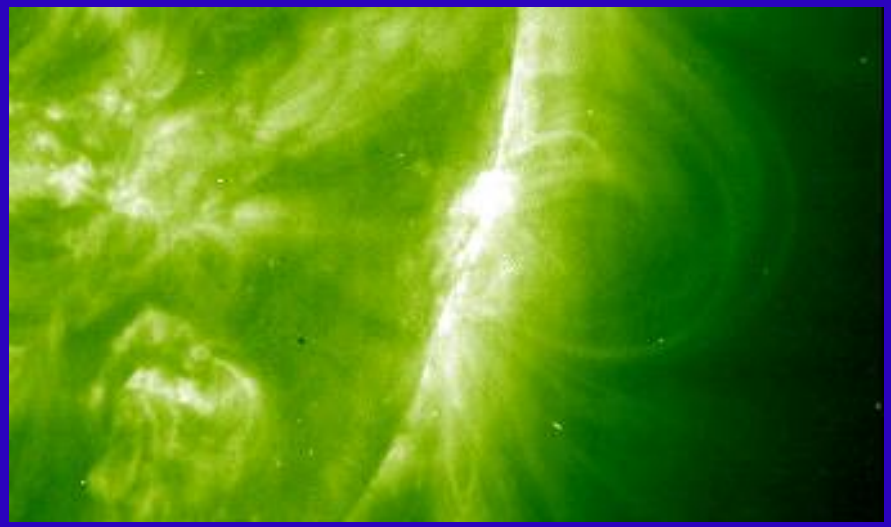


X-Class Major and Extreme Solar Flares Severely Impact HF Ionospheric Propagation

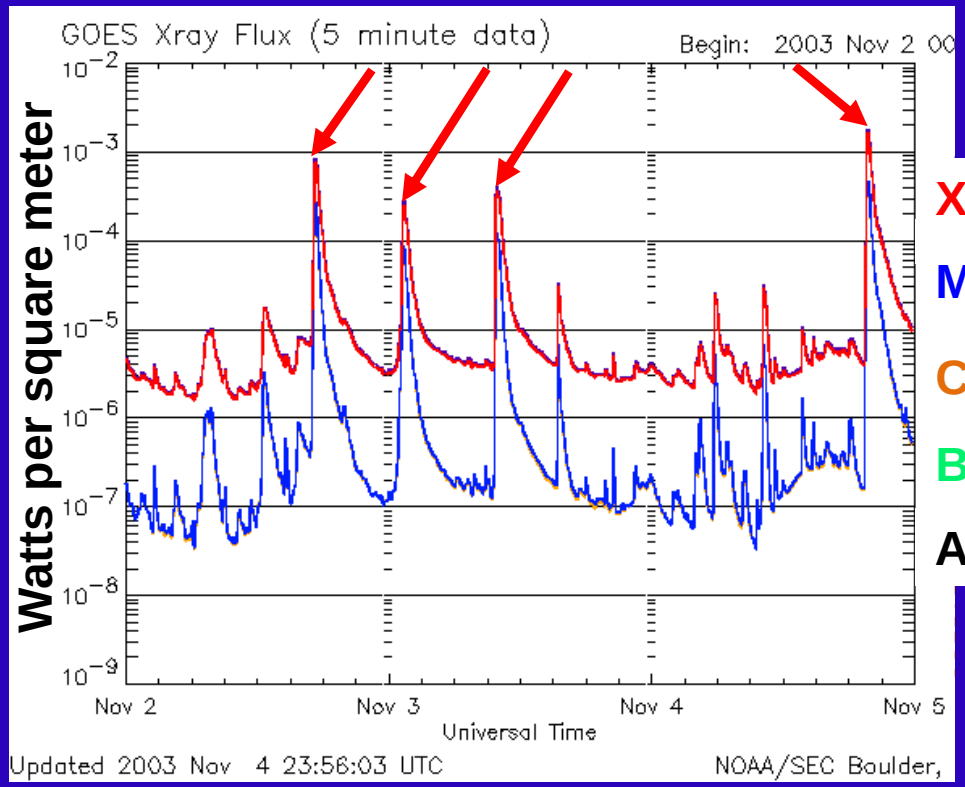
Extreme X10-Class produce long duration hemisphere-wide radio blackouts

Major X-Class produce hemisphere-wide radio blackouts and severe geomagnetic storms especially during the four years near solar maximum

Strong M-Class – medium flares produce less severely degrade HF ionospheric propagation mostly at high latitudes during the seven years near solar maximum



X28 solar flare the largest ever recorded November 4, 2003



Four Major X-Class flares
2 to 4 November 2003

Flares are classified on a logarithmic scale according to their X-ray strength

Moderate to Severe Daytime HF Radio Blackouts Caused by X-ray Radiation from X-Class Major Solar Flares During the Four Years Near Solar Maximum

X-rays propagating at the speed of light arrive on Earth in 8 minutes
- causing radio blackouts due to extreme D region absorption
- radio blackouts begin suddenly and with no warning

Radio blackouts affect *only* propagation crossing daylight regions

Disrupts HF propagation at lower frequencies for a longer duration and with significantly more D region absorption than higher frequencies

HF ionospheric propagation gradually returns to near pre-blackout conditions about an hour or two after the onset of radio blackouts

Propagation on the higher frequency HF bands returns to near pre-blackout conditions more quickly than the lower frequencies

Fast Coronal Mass Ejections (CMEs) The Dominant Cause of Strong to Severe Geomagnetic Storms

Fast CMEs from solar active regions
the dominant cause of moderate
to severe HF propagation disturbances
caused by geomagnetic storms

Fast CME impacts are greatly magnified when the interplanetary magnetic field (IMF) persists in a southward orientation -- opposite to Earth's magnetic field -- for more than a few hours

Strong to Severe Geomagnetic Storms

Always Caused by Persistent Southward IMF Orientation

Persistent Southward Oriented Interplanetary Magnetic Field (IMF)

causes strong to severe geomagnetic storms when the IMF persists in a southward orientation for at least several hours when enhanced by a fast (>500 km/sec) CME

Fast CMEs occur most frequently during the seven most active years of the solar cycle

The most severe geomagnetic storms occur most often:

- when they occur within a few weeks of the equinoxes on Earth, and
- when directed toward the Earth from 30º solar latitude or lower, and
- when directed from +/- 30º longitude from the Sun's central meridian

High Level Overview of HF Propagation as Solar Cycle 25 Slowly Declines

- Solar maximum propagation conditions began in Dec 2022 and is likely to continue for about four years, into early 2026
- Almost daily 10 meter DX propagation continues into early 2026
- 10 and especially 15 meter worldwide propagation will frequently persist well into the night through 2025
- 20 and 40 meter DX propagation will frequently persist throughout the entire night through 2026
- Geomagnetic disturbances will gradually become more frequent as low latitude geoeffective large coronal holes occur frequently through 2027
- Sunspot activity will steadily decline until solar minimum propagation conditions begin to dominate by about 2029

What HF Bands Should I Use for DX Contesting Through 2026?

- Each band has unique advantages and disadvantages
- 15 and 10 meters provides daytime worldwide propagation almost every day from September through May
  - but less reliably during summer months
- 20 meters provides reliable daytime and nighttime worldwide propagation throughout the year
  - but not during midday hours during summer months
- 40 meters provides reliable nighttime worldwide propagation throughout the year
- 80 meters often provides good nighttime worldwide propagation from October through April especially during the hours near midnight

How Slowly Declining Solar Cycle 25 Sunspot Activity Affects 10 Meter Worldwide Propagation Through 2026

- Worldwide propagation improved dramatically since late 2022
  - almost every day from September through May
  - excellent propagation to Europe from sunrise through early afternoon
  - excellent propagation to Japan and Asia after 2130Z sometimes continuing for as long as three or four hours
  - is likely to continue through early 2026
- Worldwide sporadic-E propagation between northern hemisphere locations will occur during many days from May through early August
  - Sporadic-E is the often dominant 10 meter propagation from May to early August

How Slowly Declining Solar Cycle 25 Sunspot Activity Affects 15 Meter Worldwide Propagation Through 2026

- Worldwide propagation improved dramatically since 2022
  - almost every day from September through May
  - Excellent propagation to Europe from before sunrise to mid-afternoon
  - excellent propagation to Japan and Asia after 2130Z sometimes for four hours or more
- Worldwide propagation between northern hemisphere locations begins later and is shorter in duration from June to August
  - Sporadic-E is sometimes the dominant propagation mode from May through early August

How Slowly Declining Solar Cycle 25 Sunspot Activity Affects 20 Meter Worldwide Propagation Through 2026

- Nighttime worldwide propagation improved dramatically since 2022
  - almost 24 hours per day worldwide propagation
    - but not during summer mid-day hours
  - excellent nighttime propagation to Europe from 0700-0900Z
  - excellent propagation to Europe resumes before our sunrise
  - DX activity switches to 15 and 10 meters shortly after our sunrise
- Propagation to Japan and east Asia is strongest for three or four hours after 2130Z, somewhat weaker throughout the night then improves for several hours after local sunrise in the USA
- 20 meter DX propagation within a few hours of local noon is always very poor from June through August

How Slowly Declining Solar Cycle 25 Sunspot Activity Affects 40 Meter Worldwide Propagation Through 2026

- Worldwide propagation throughout the night became much more reliable and more long lasting since 2022
  - propagation to Europe starts about an hour before sunset
  - continues throughout the night until a few hours after European sunrise when European activity shifts to higher frequency bands
  - the best European propagation and activity is often around European sunrise (0600-0800Z)
- Mid-afternoon propagation to Europe is weaker since 2022
  - most DX activity remains on the higher bands
- Propagation from the east coast to Japan and east Asia is more reliable since 2022 starting at sunset in Japan (0830Z) until about 30 minutes after local sunrise in the USA

How Slowly Declining Solar Cycle 25 Sunspot Activity Affects 80 Meter Worldwide Propagation Through 2026

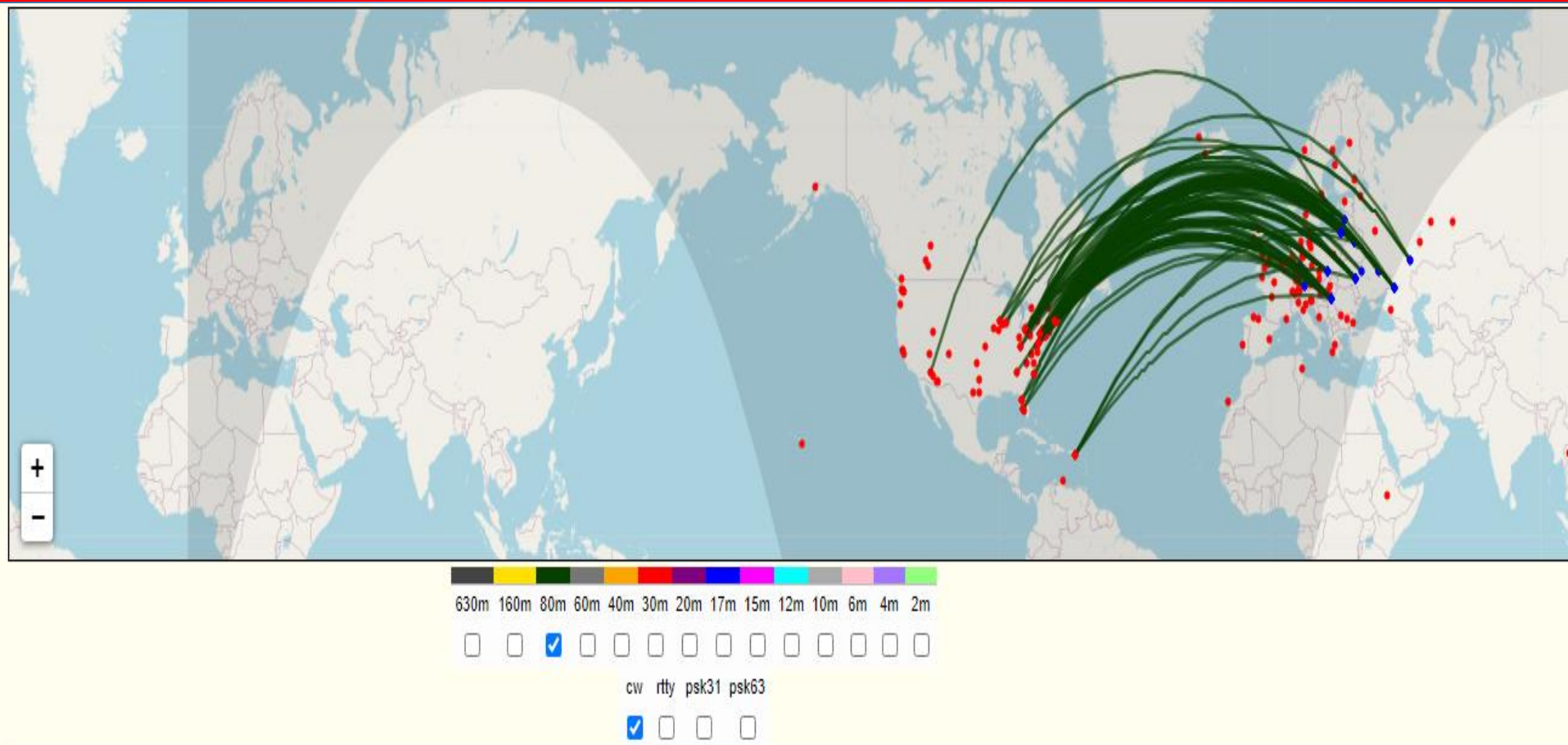
- 80 meter DX propagation is often shorter in duration since 2022
  - weak and less reliable DX propagation begins at USA sunset
  - stronger European propagation usually starts a few hours after local USA sunset
  - the best European activity is often during the hours before their sunrise
    - continuing until just after European sunrise (0600-0800Z) when most Europeans shift their operating to the higher frequency bands
- 80 meter worldwide propagation will steadily improve after 2026

How Slowly Declining Solar Cycle 25 Sunspot Activity Affects 160 Meter Worldwide Propagation Through 2026

- 160 meter DX propagation is very unreliable since 2022
  - weak unreliable DX propagation begins after sunset
  - propagation to Europe sometimes improves around midnight for just a few hours and sometimes much less
- 160 meter DX propagation will begin to slowly improve after 2026

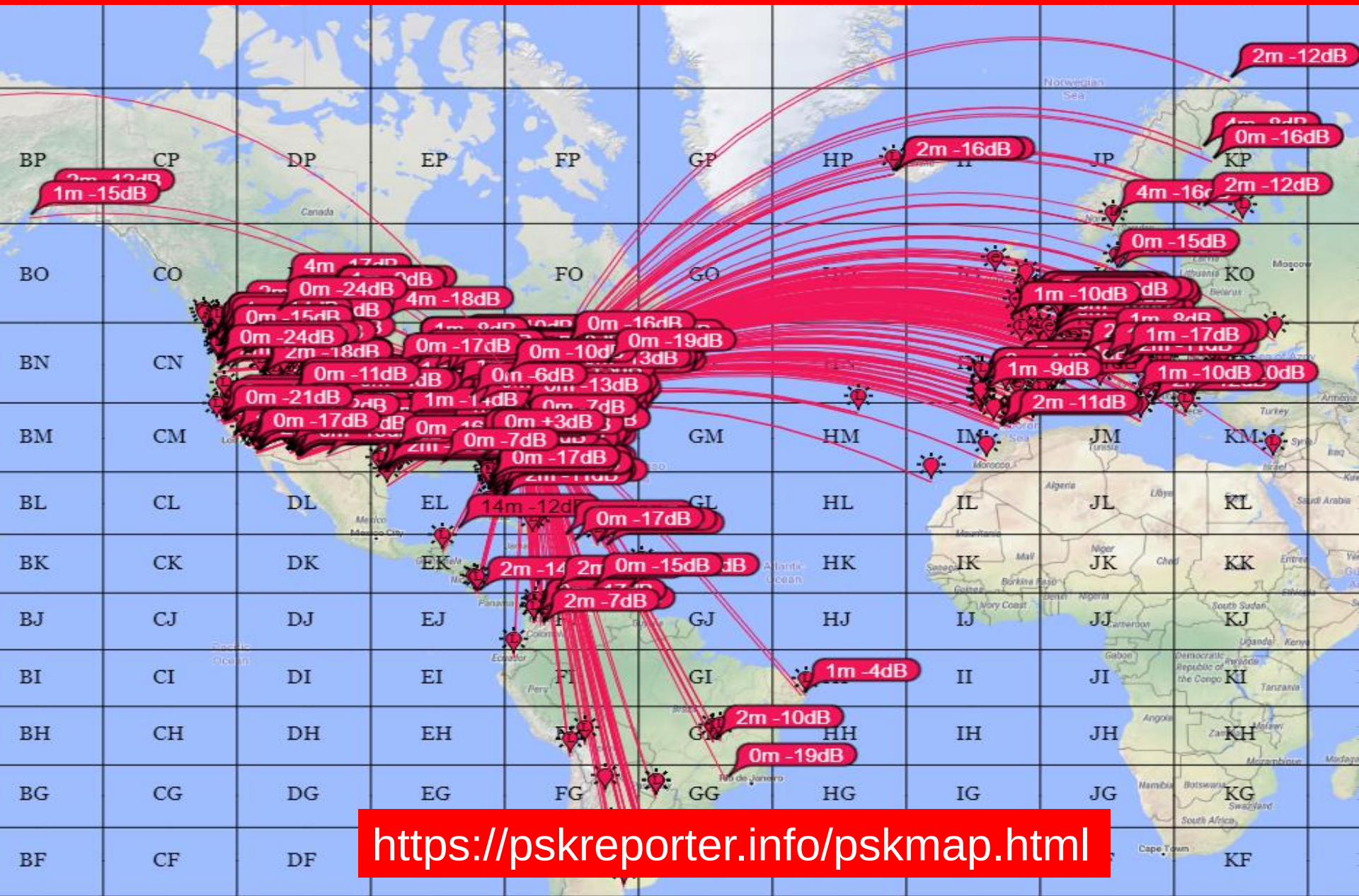
Nowcasting using the Reverse Beacon Network

80 Meters European CW CQs heard in North America 0500Z



Nowcasting using PSK Reporter

20 Meters Worldwide FT8 heard in North America 2200Z



https://pskreporter.info/pskmap.html