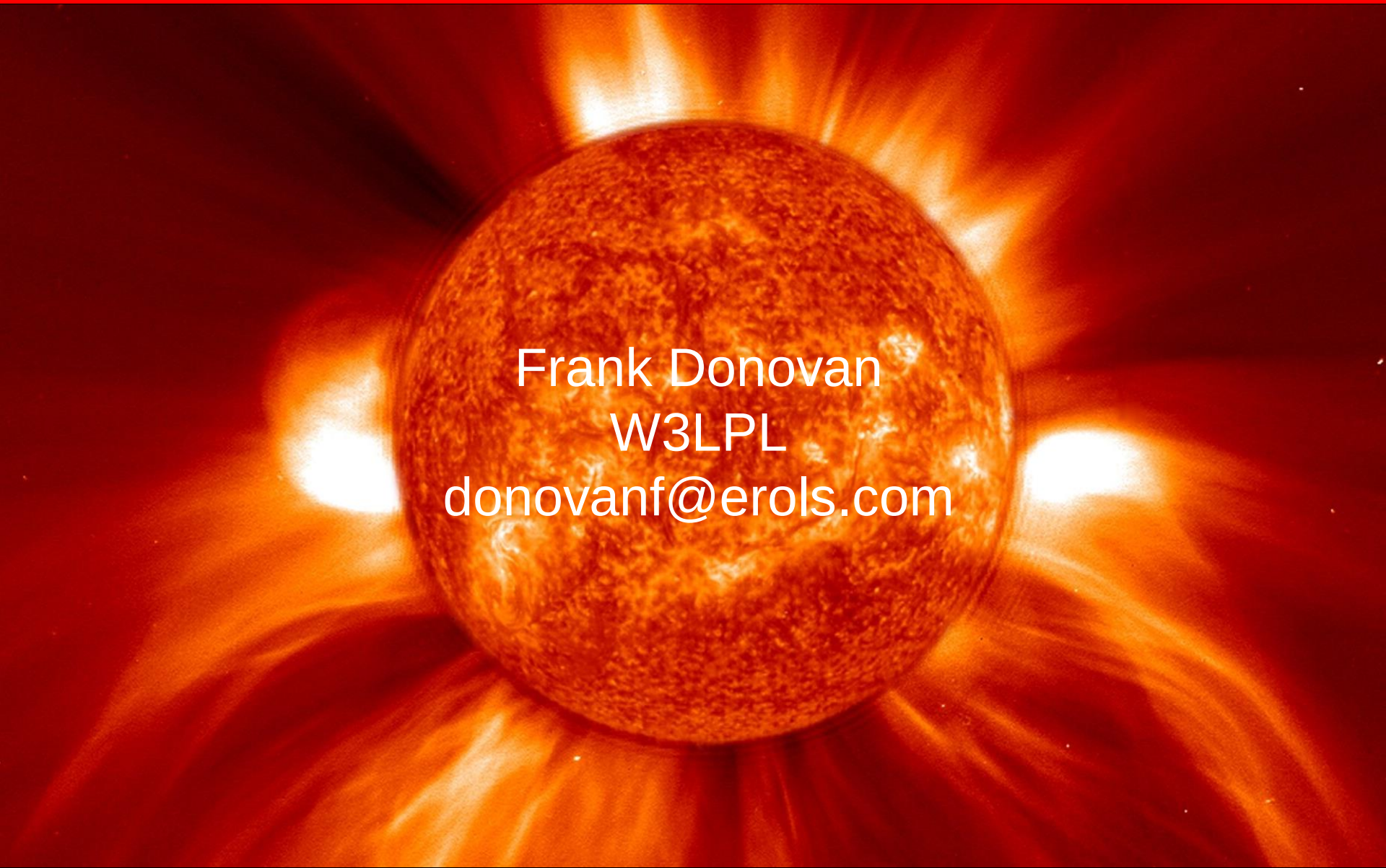
HF Worldwide Propagation
During the Next Three Years of Solar Maximum



Frank Donovan
W3LPL
donovanf@erols.com


Sunspots
Sunspot Number
Solar Cycles
Solar Maximum
Coronal Hole High Speed Streams
Solar Flares
Coronal Mass Ejections

Experience the Wonders of Solar Cycle 25's Solar Maximum

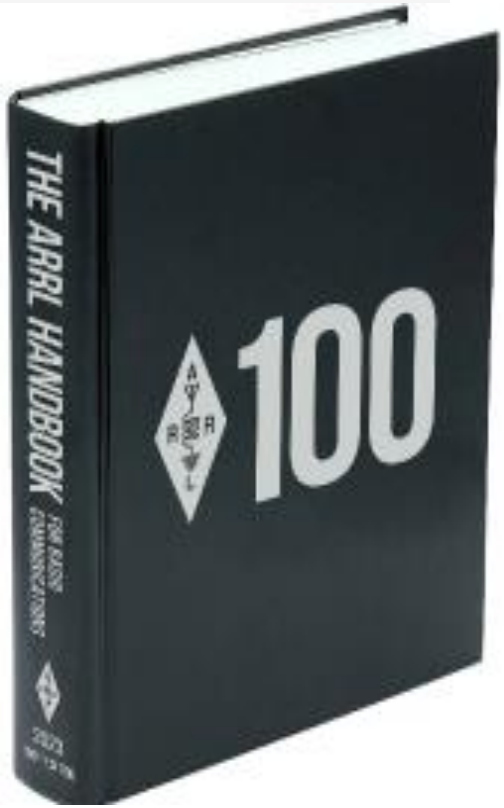
The next three years of this solar cycle will continue to produce the best HF and 6-meter DX propagation in 20 years

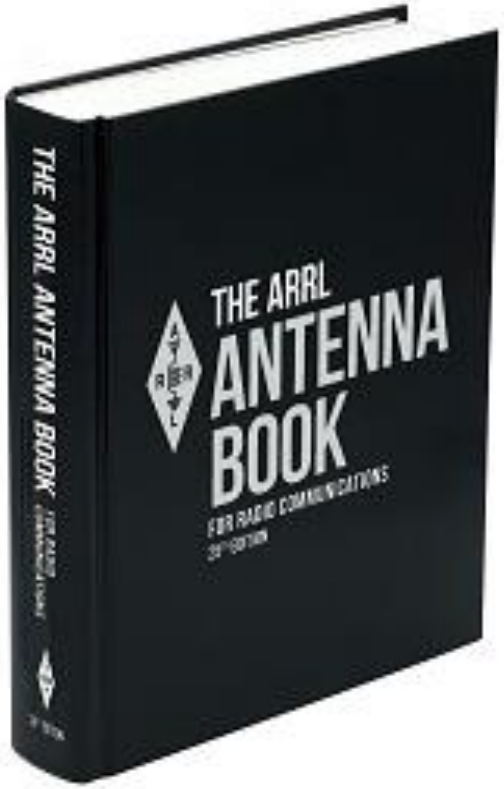
Frank Donovan W3LPL

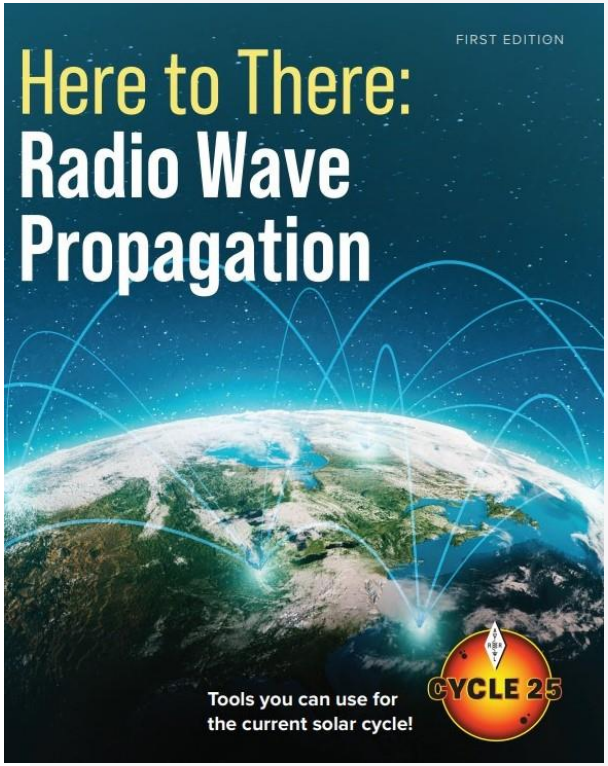
May 2023 QST

arrl.org/qst

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





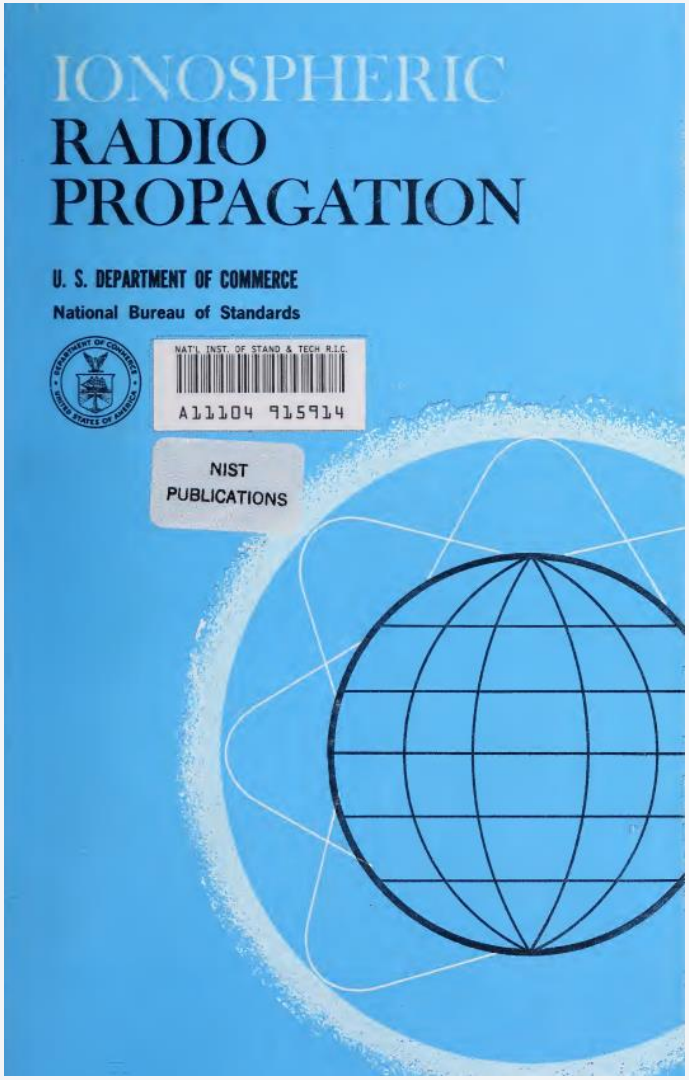


home.arrl.org/action/Store/Product-Details/productId/2003373106

www.rsgbshop.org/acatalog/ARRL-Antenna-Book---25th-Edition-Paperback-2275.html#SID=37

www.rsgbshop.org/acatalog/ARRL-Here-to-There-2219.html

An Excellent Free Technical Reference for Scientifically Inclined Amateurs



nvlpubs.nist.gov/nistpubs/Legacy/MONO/nbsmonograph80.pdf

Key Features of the Sun-Earth System
every HF operator should understand these terms

Sunspots and Active Regions Intense magnetic fields emerging from the Sun's corona form sunspots and their surrounding active regions. Ionizing extreme ultraviolet radiation, hard x-rays, solar flares and fast coronal mass ejections emerge from active regions

Solar Cycles Duration varies from 9 to 14+ years
Some cycles have a long lasting, more energetic solar maximum
Some cycles have a long lasting, deeper solar minimum

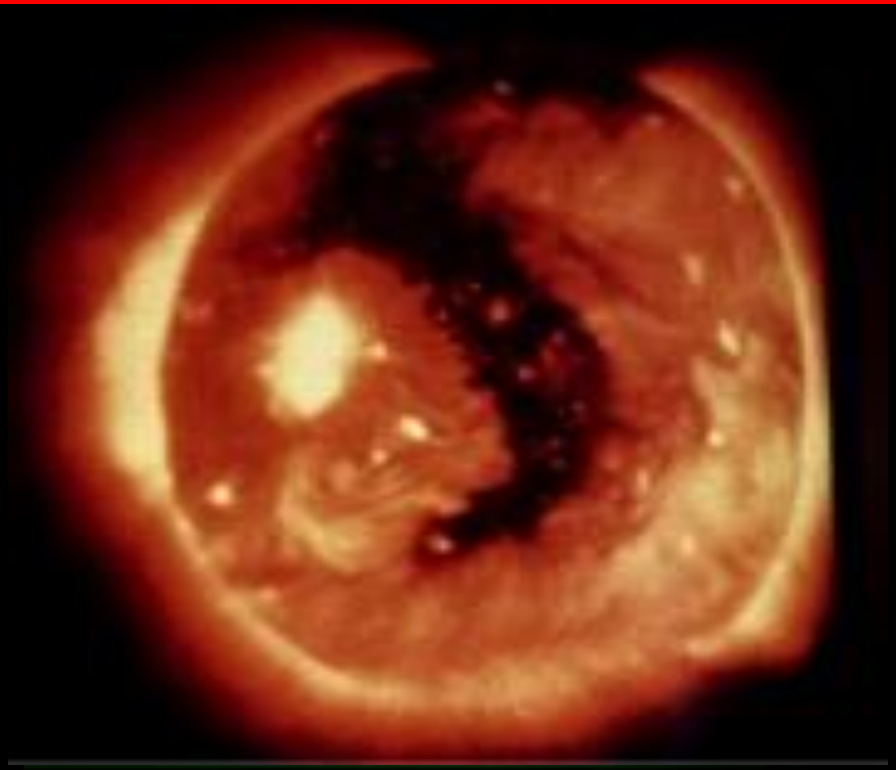
Ionizing Radiation Ten times more ionizing extreme ultraviolet radiation during solar maximum improves HF skywave propagation especially from October through May. Highly energetic hard x-rays from solar flares can degrade HF propagation with no warning

Geomagnetic Disturbances Earth's ionosphere is disturbed by the solar wind's hypersonic flow of high energy magnetized plasma

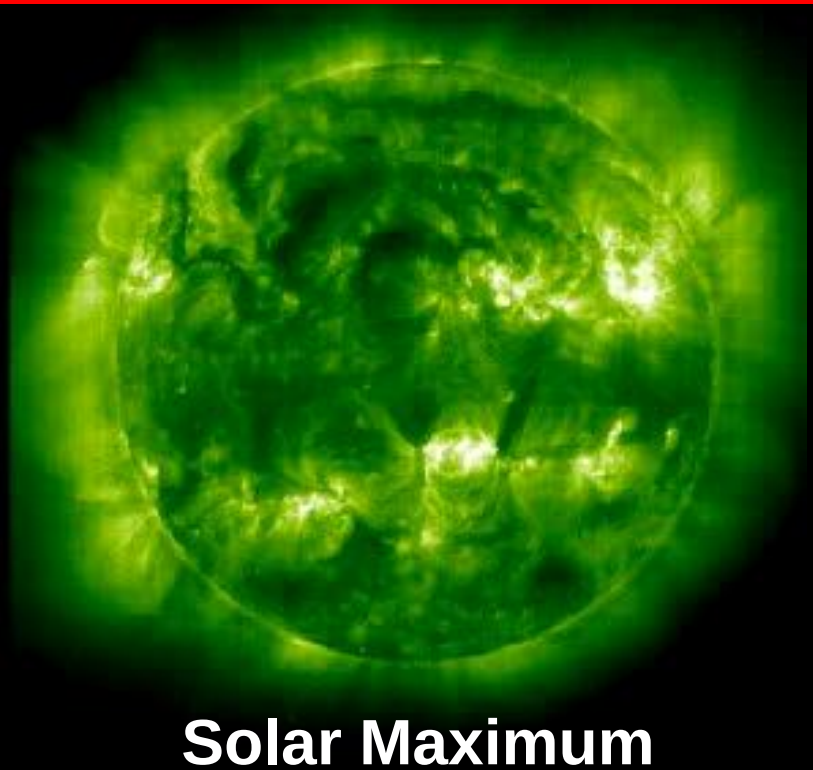
27 Day Solar Rotation Causes repetitive, predictable solar events

Seasonal Variability Earth's 23.5º tilt reduces the amount of magnetized plasma disturbing the ionosphere in summer and winter and the intensity of ionizing radiation received at mid-latitude and polar regions during summer and winter

Increasing Ionizing Extreme Ultraviolet Radiation Through 2026 Greatly Improves 40 to 10 Meter Propagation



Solar Minimum
December 2019



Solar Maximum
estimated
during 2024

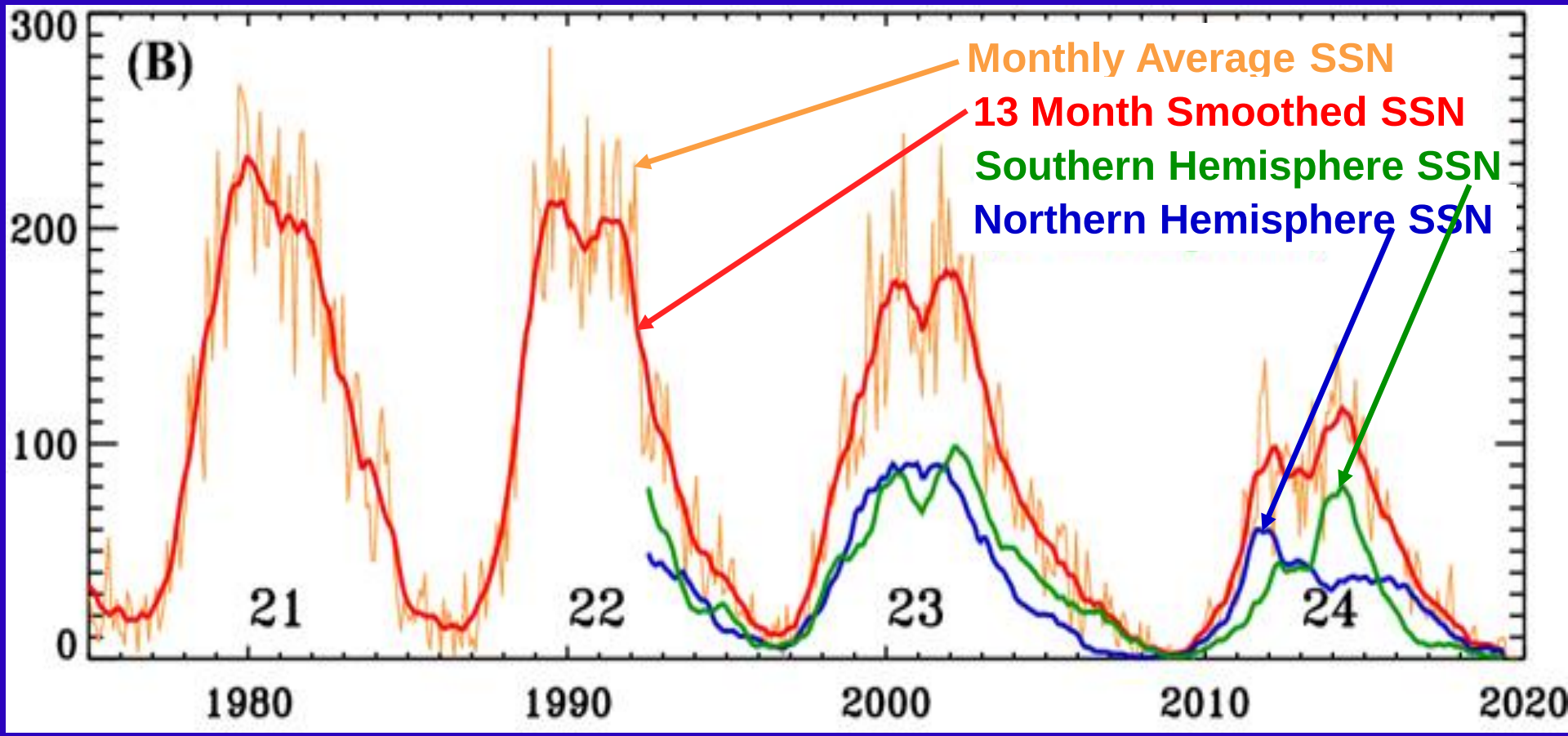
Solar maximum often brings geomagnetic disturbances especially during the two weeks before and after the equinoxes

Nominal 11 Year Duration of the Solar Cycle

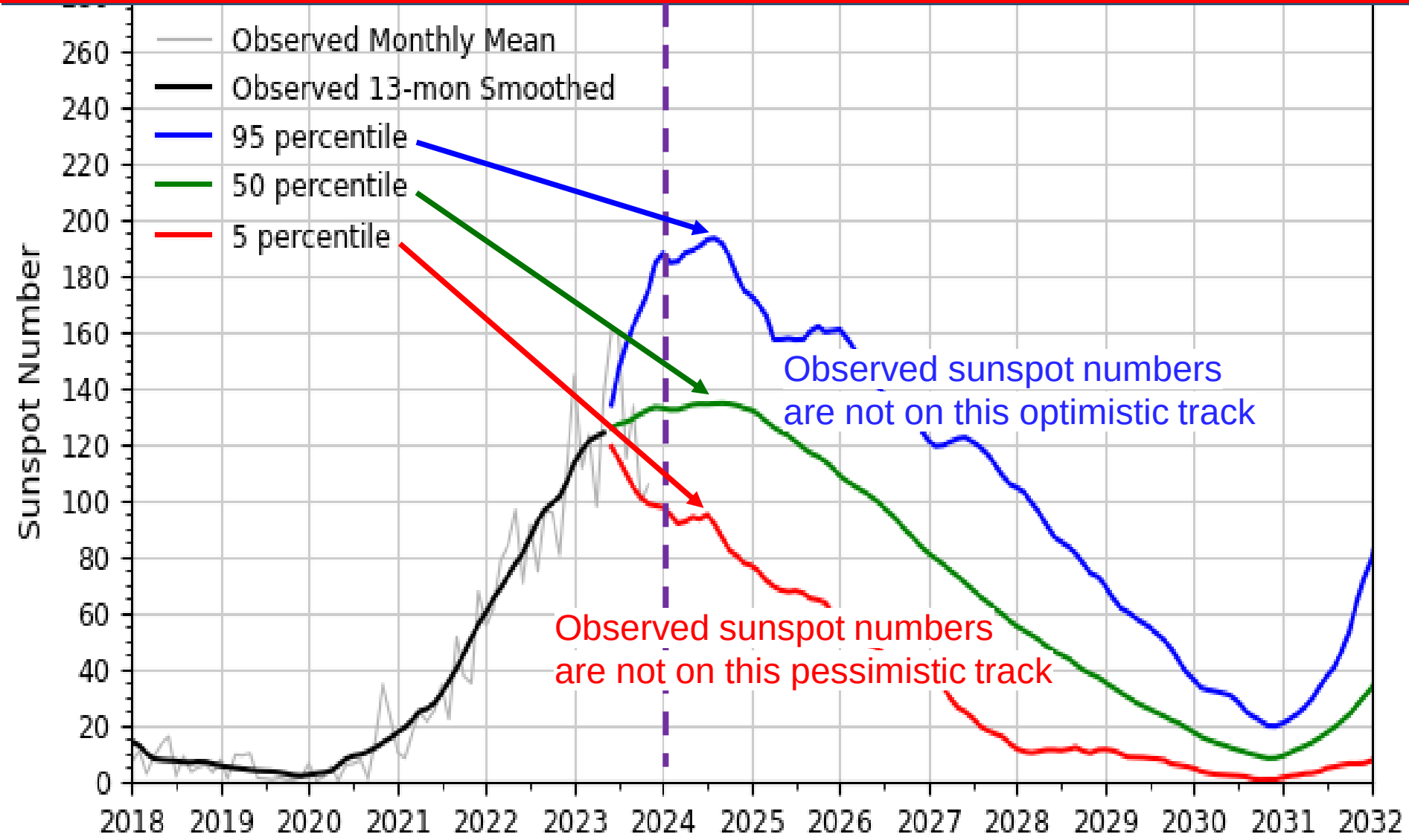
Solar cycle length varies from 9 to 14+ years

The Sun's northern and southern hemisphere solar cycles are sometimes offset by as much as two years

Propagation models use the 13 month smoothed SSN

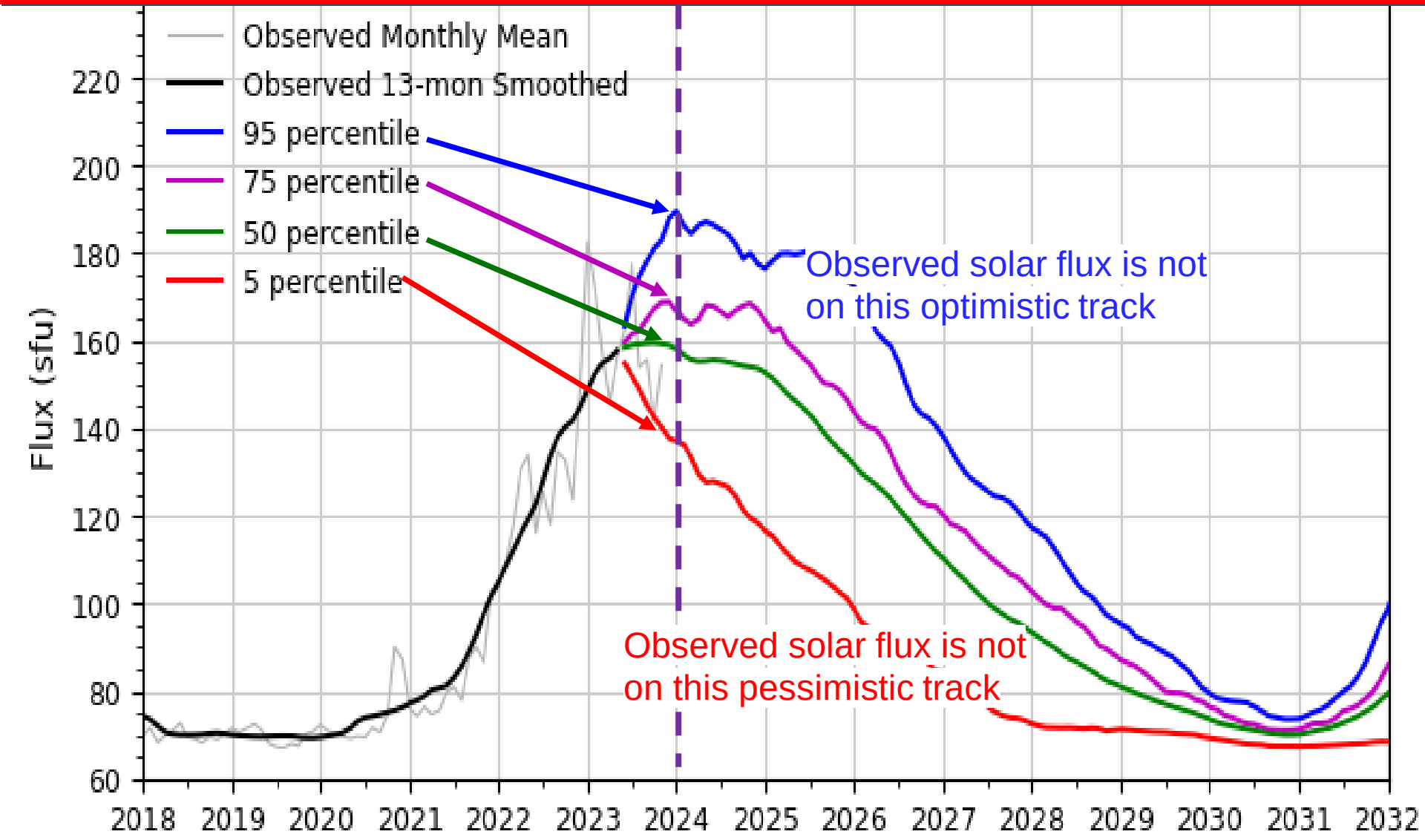


Solar Cycle 25 Smoothed Sunspot Number Forecast
NASA Marshall Space Flight Center - December 2023



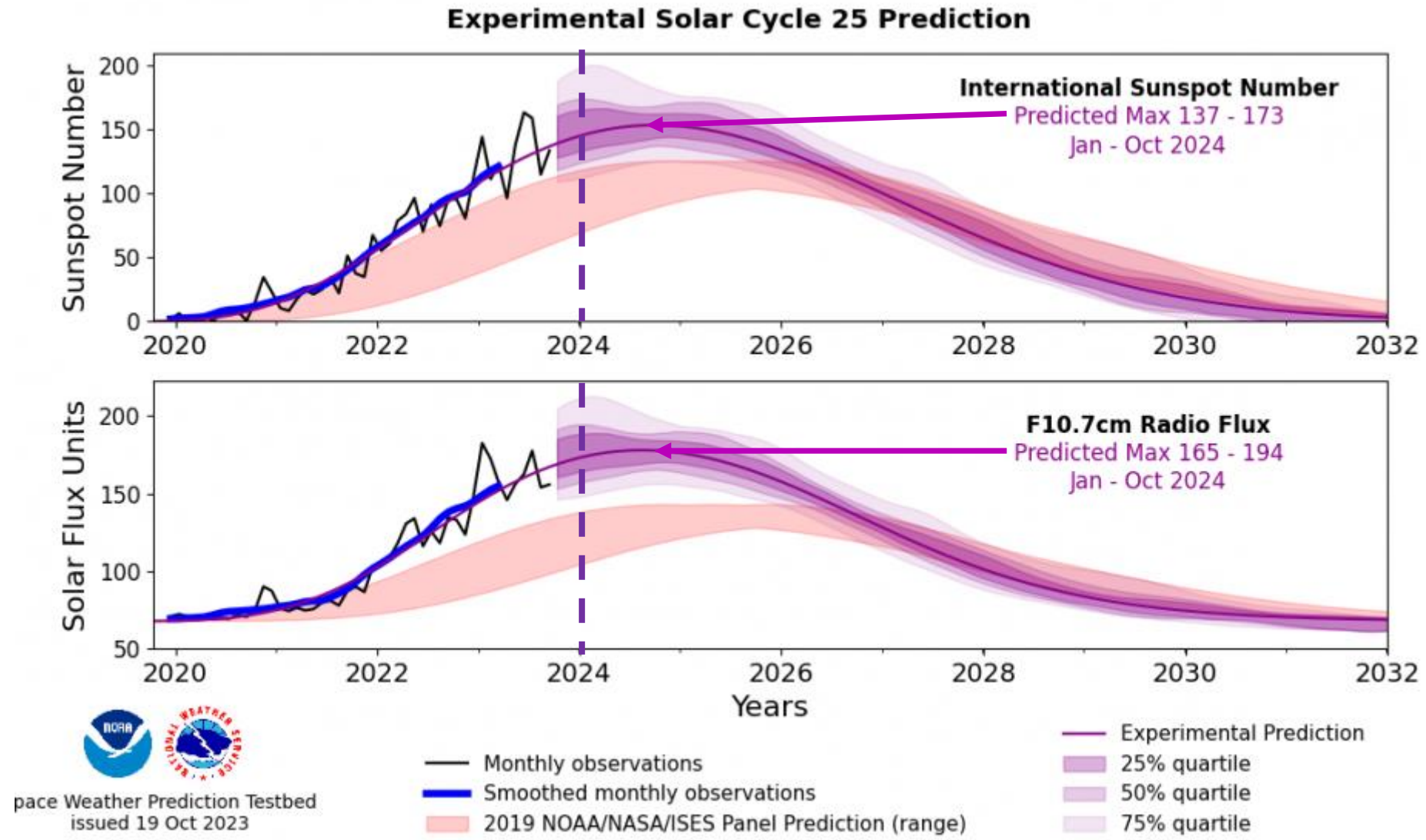
www.nasa.gov/msfcsolar

Solar Cycle 25 Solar Flux Index Forecast
NASA Marshall Space Flight Center - December 2023



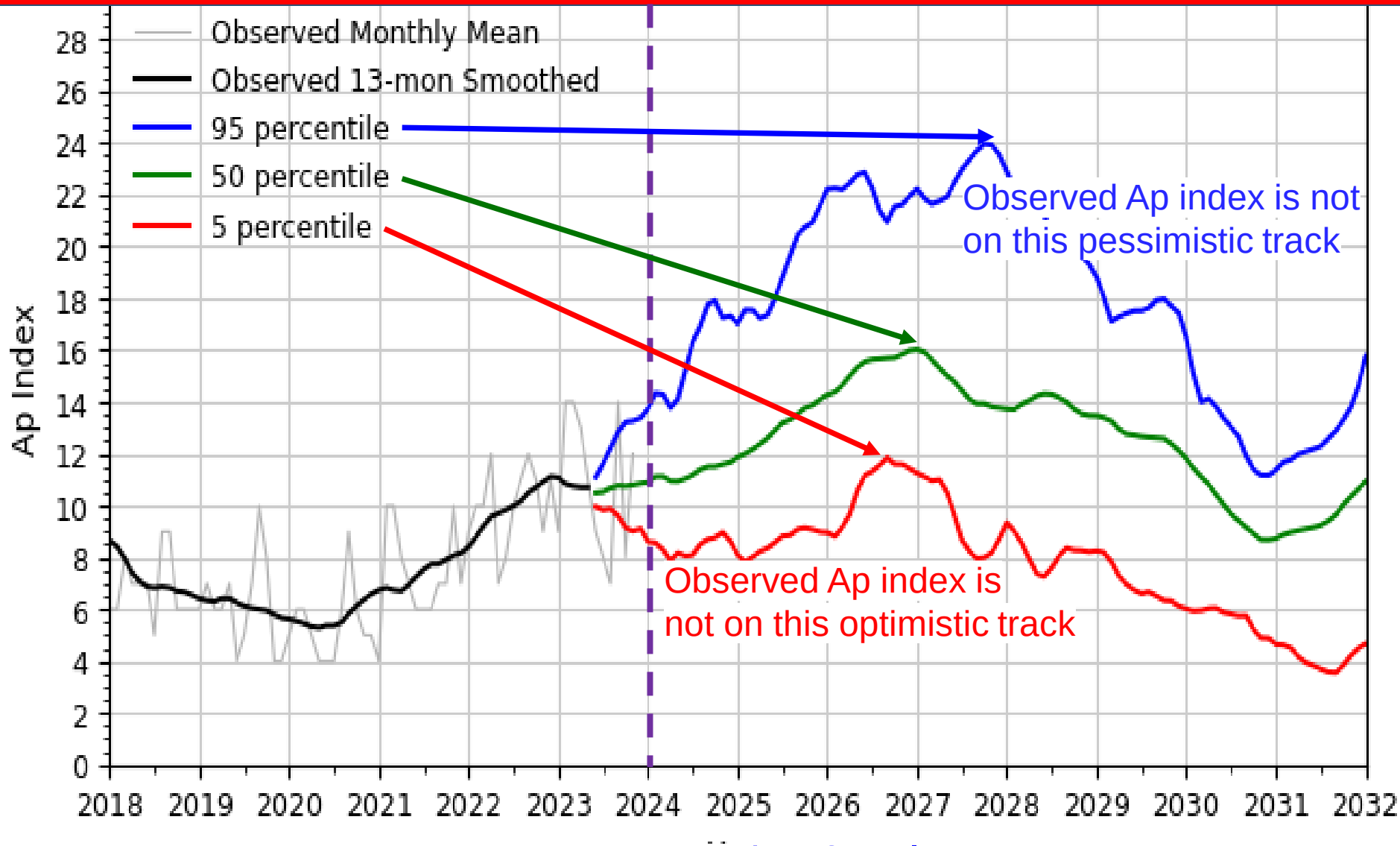
www.nasa.gov/mstcsolar

NOAA Solar Maximum Forecast: Jan-Oct 2024



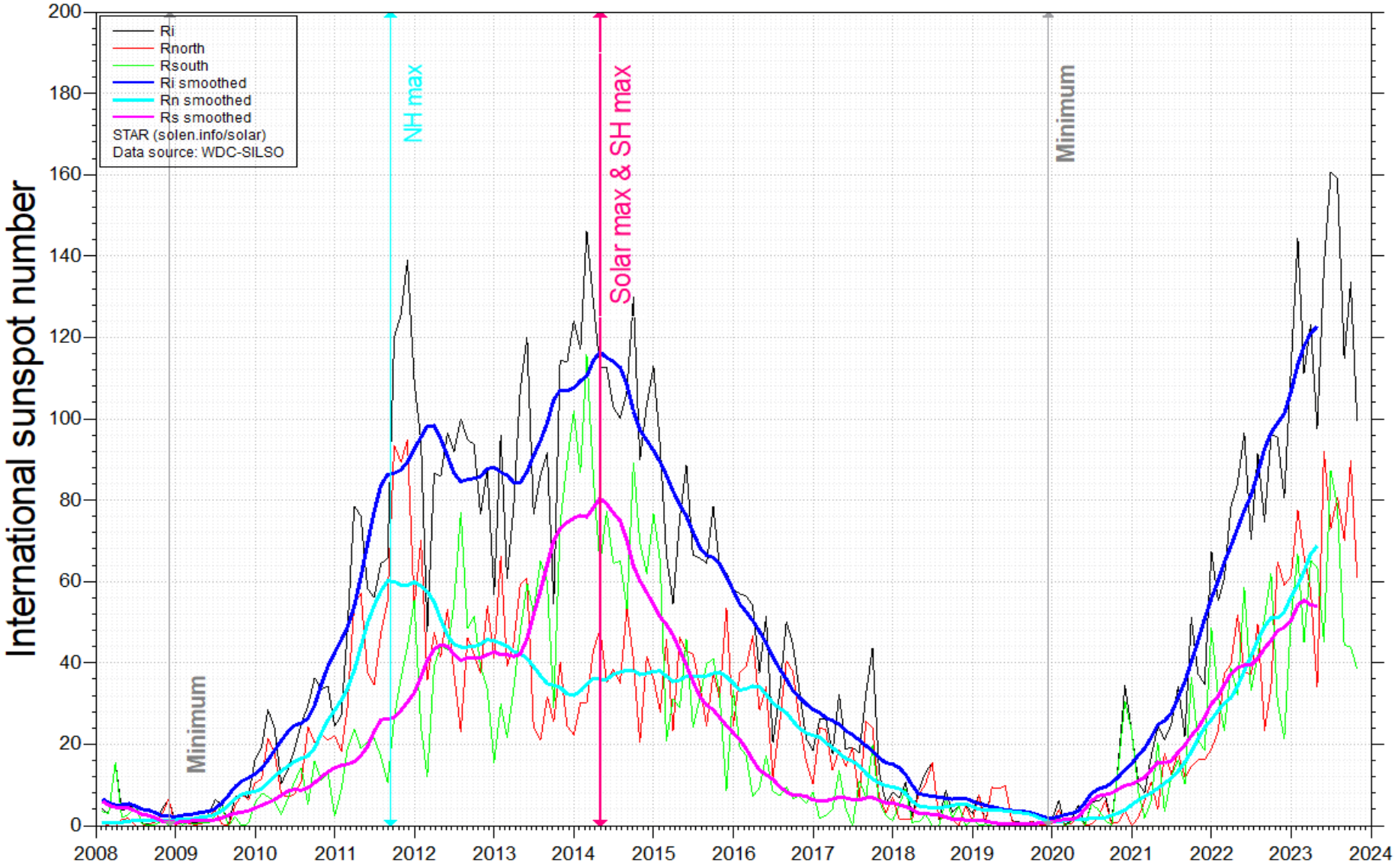
www.swpc.noaa.gov/news/noaa-forecasts-quicker-stronger-peak-solar-activity

Solar Cycle 25 Geomagnetic Ap Index Forecast
NASA Marshall Space Flight Center – December 2023



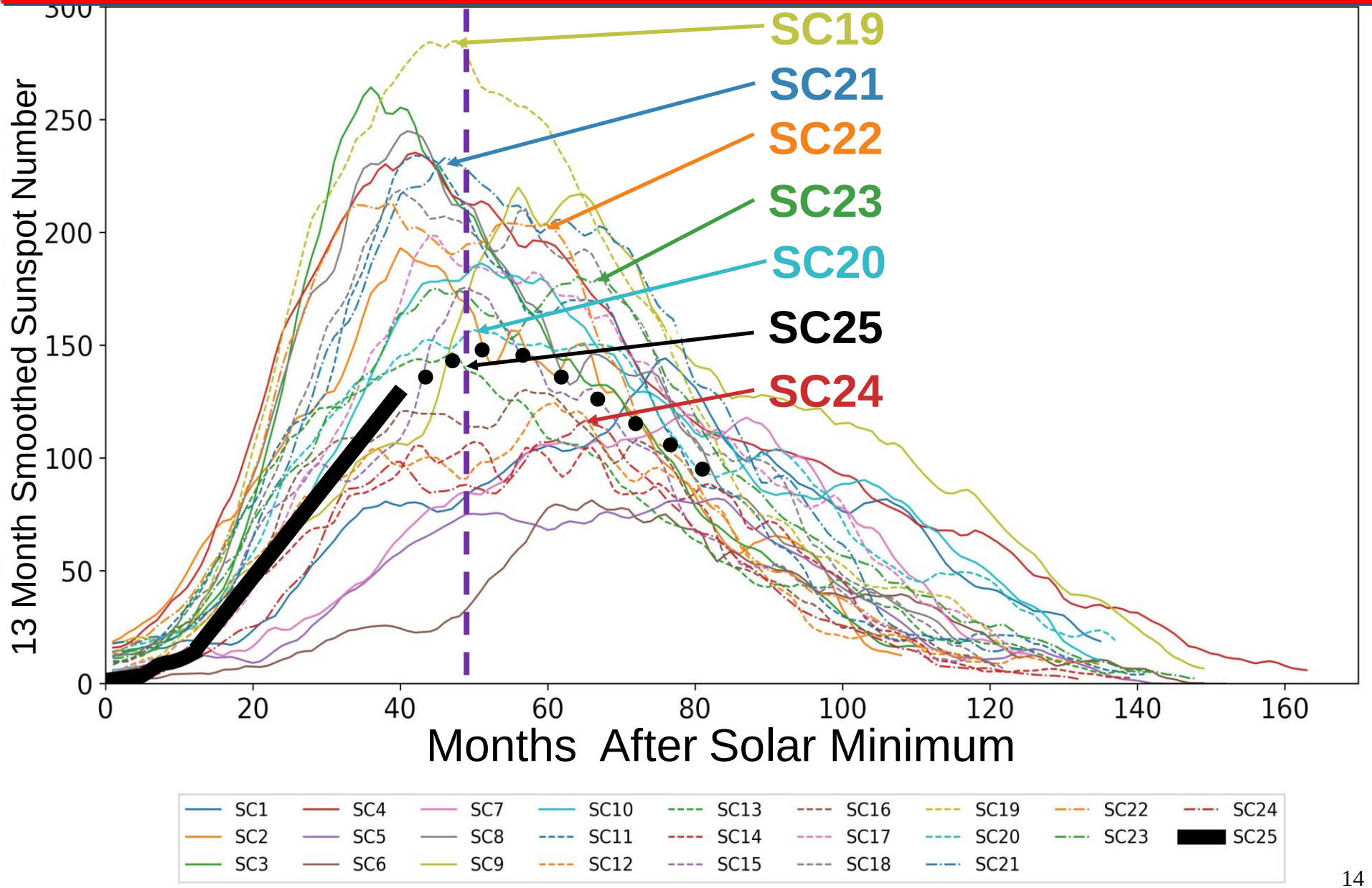
www.nasa.gov/msfcsolar

Solar Cycle 25 Progress vs Solar Cycle 24

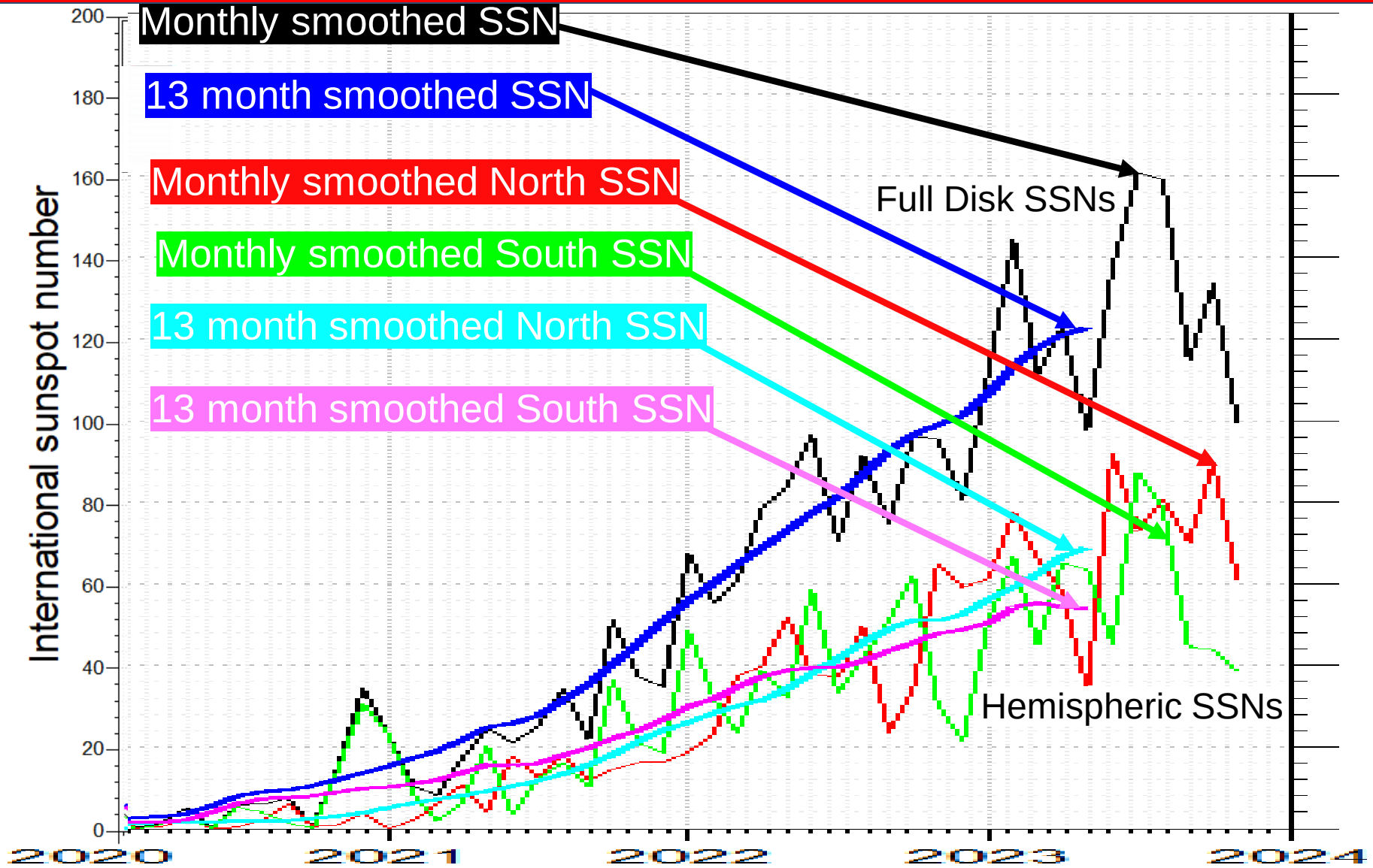


https://solen.info/solar/images/cycle24.png

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



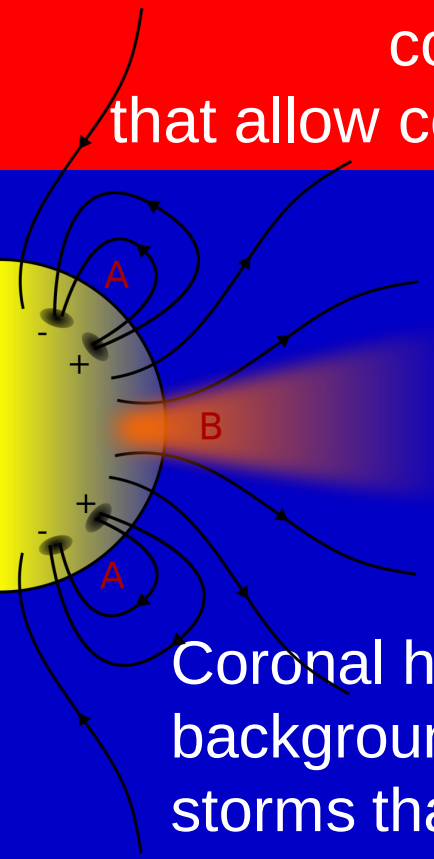
Solar Cycle 25 – Solar Hemisphere SSNs



https://solen.info/solar/images/cycle24.png

Coronal Hole High Speed Streams

Unlike the closed magnetic fields of sunspots,
coronal holes have open magnetic fields
that allow coronal plasma to escape and form the solar wind



Coronal hole high speed streams are the most common source of moderate geomagnetic storms that occur frequently during the declining phase of each solar cycle

Coronal hole high speed streams interact with the slower background solar wind often causing moderate geomagnetic storms that develop gradually over several hours mostly during the declining four years of each solar cycle

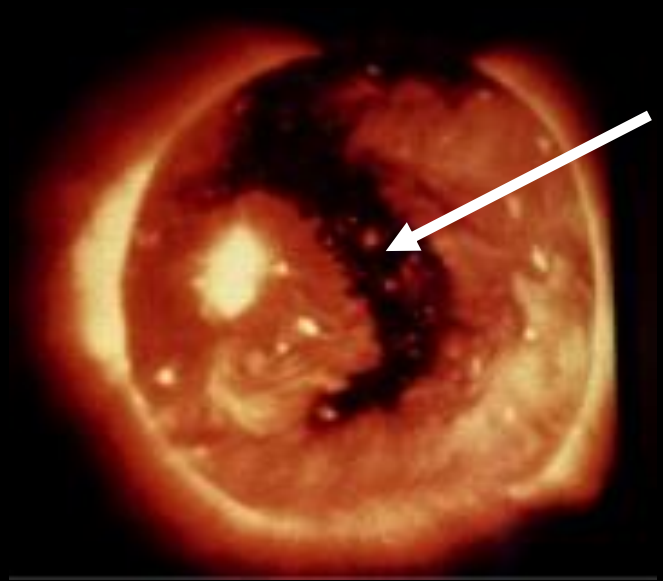
Conversely, fast CMEs from active regions sometimes cause intense geomagnetic storms that develop suddenly during the most active seven years of each solar cycle

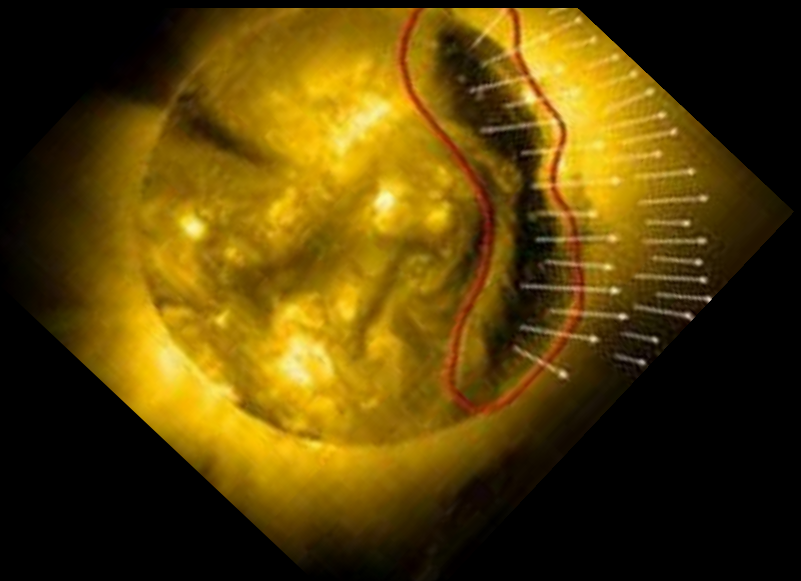
Disturbed Geomagnetic Conditions Caused by Coronal Hole High Speed Streams

Energetic charged particles and their magnetic fields flow from coronal holes forming the fast solar wind and the interplanetary magnetic field

Coronal hole high speed stream effects cause mostly unsettled to active geomagnetic disturbances and occasional minor geomagnetic storms but rarely cause strong geomagnetic storms

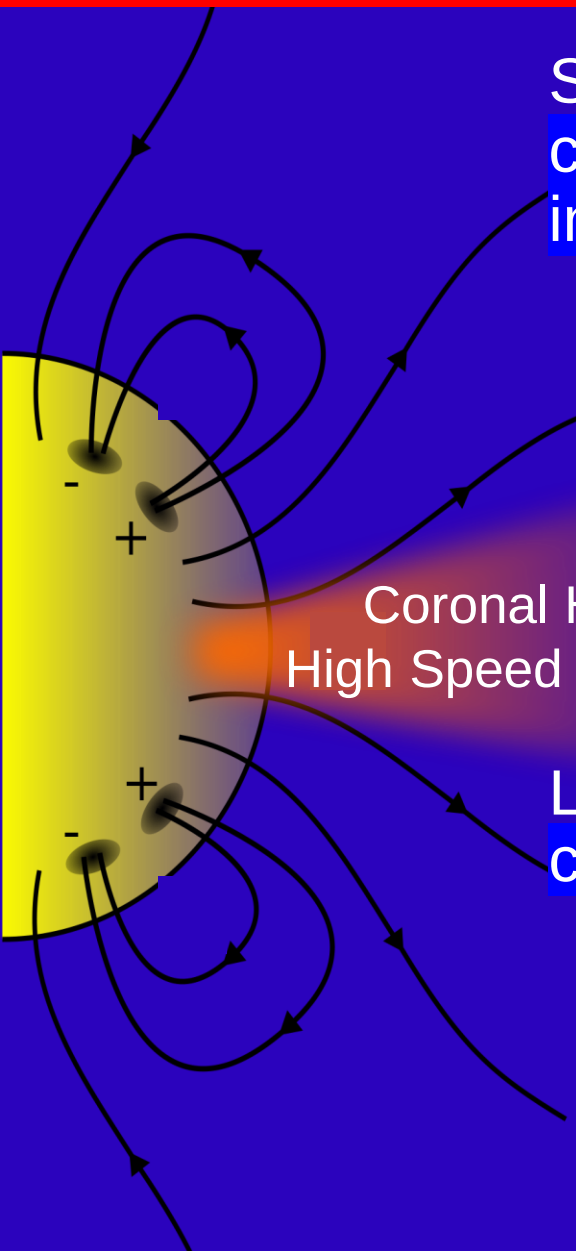
Disturbed geomagnetic activity caused by coronal hole high speed streams becomes less frequent as we approach solar maximum





Minor Geomagnetic Storms

more frequently degrade propagation after solar maximum



Coronal Hole
High Speed Stream

Short duration minor geomagnetic storms caused by coronal hole high speed stream interactions within the slow solar wind

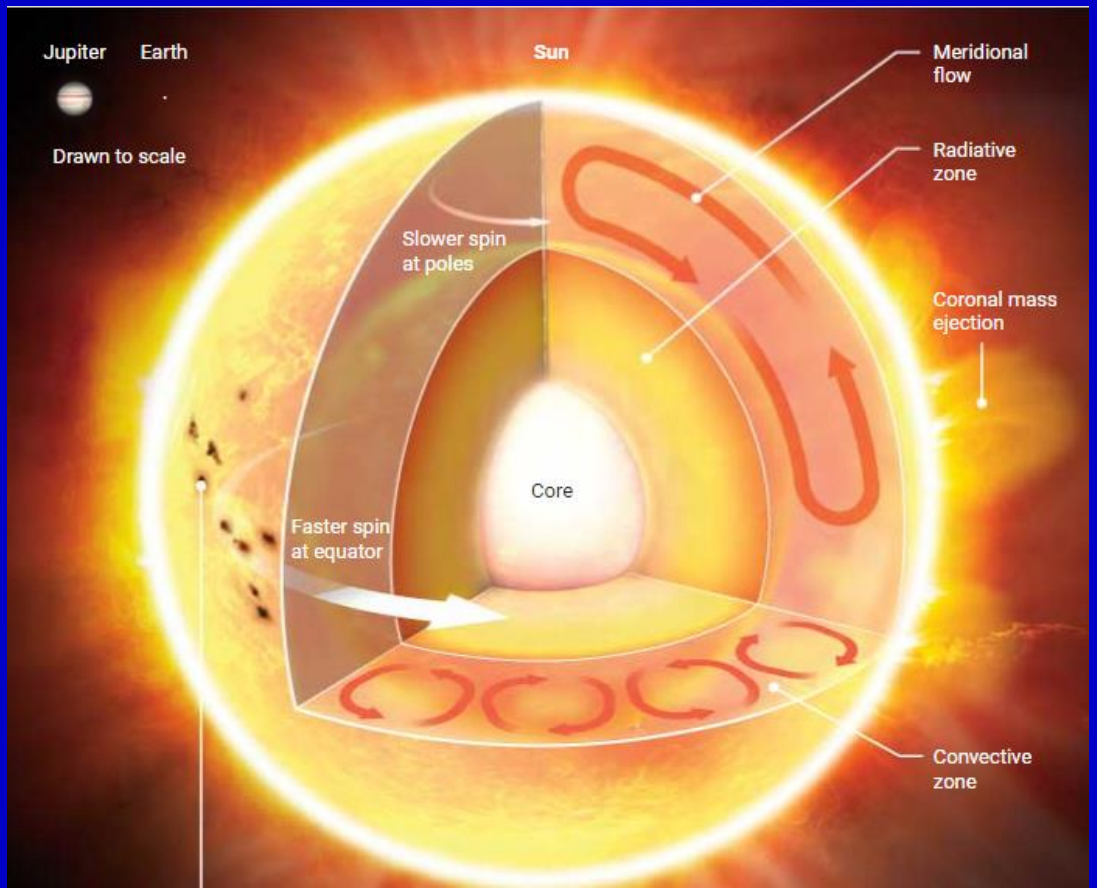
- very frequent during the declining phase of the solar cycle after solar maximum
- occur about half as frequently during the years near solar maximum

Longer duration minor geomagnetic storms caused by fast coronal mass ejections

- very infrequent near solar minimum
- much more frequent during the years near solar maximum
- but have little affect on HF propagation

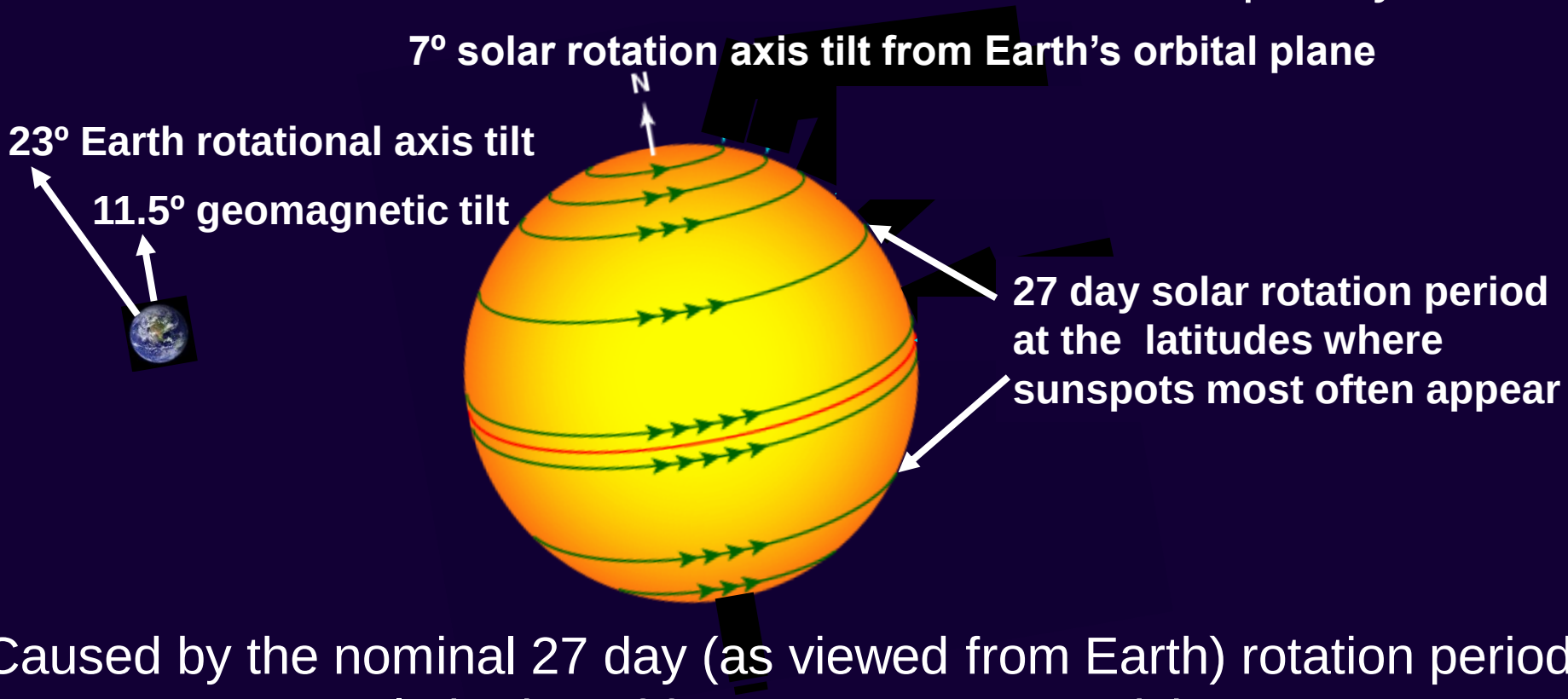
The Sun's Twisting Magnetic Field Produces Active Regions and their Sunspots, Solar Flares and Fast Coronal Mass Ejections

Differential rotation in the convective zone stretches, twists, tangles and strengthens the powerful submerged magnetic field which produces sunspots, solar flares and coronal mass ejections



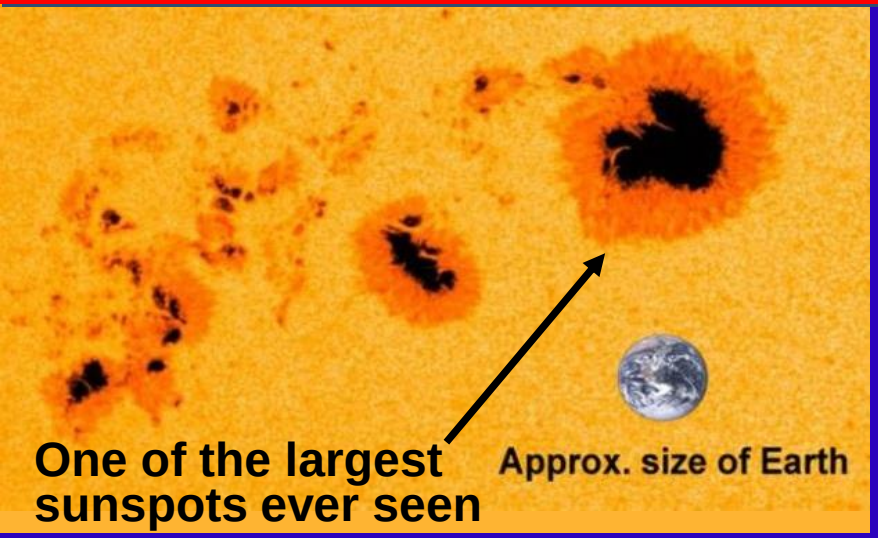
27 Day Recurrence of Sunspot Activity and Geomagnetic Disturbances

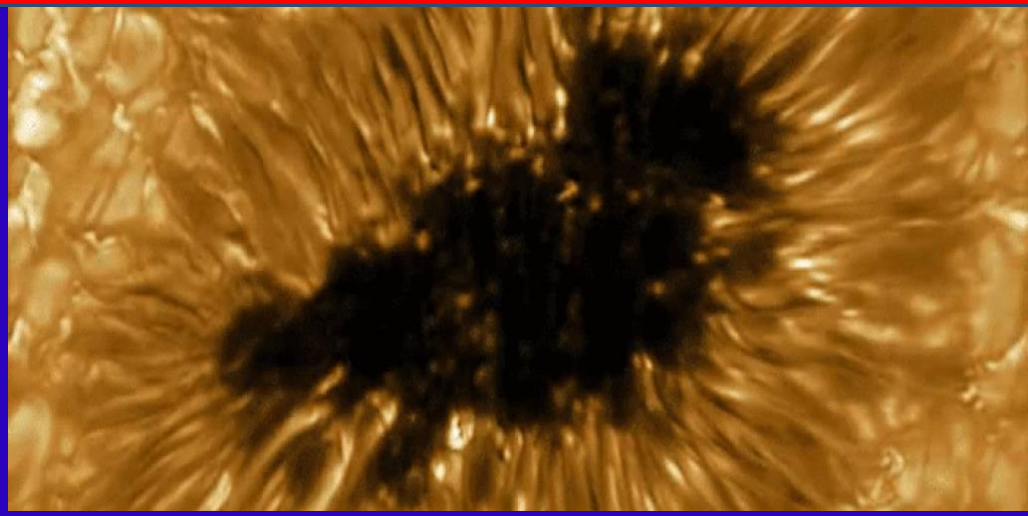
Geomagnetic disturbances often repeat every 27 days especially during the four years after solar maximum when recurrent coronal holes occur most frequently

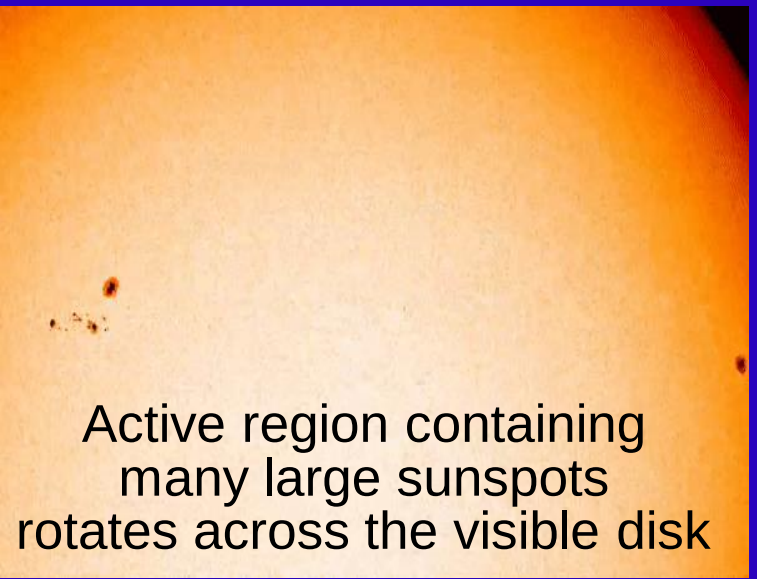


Caused by the nominal 27 day (as viewed from Earth) rotation period at latitudes of frequent sunspot activity

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






Active region containing many large sunspots rotates across the visible disk

During solar maximum active regions radiate:

- Stronger extreme ultraviolet radiation causing higher F_2 region MUFs
- Highly energetic plasma from fast CMEs causing more frequent geomagnetic storms
- Highly energetic hard x-rays from solar flares causing frequent daytime radio blackouts

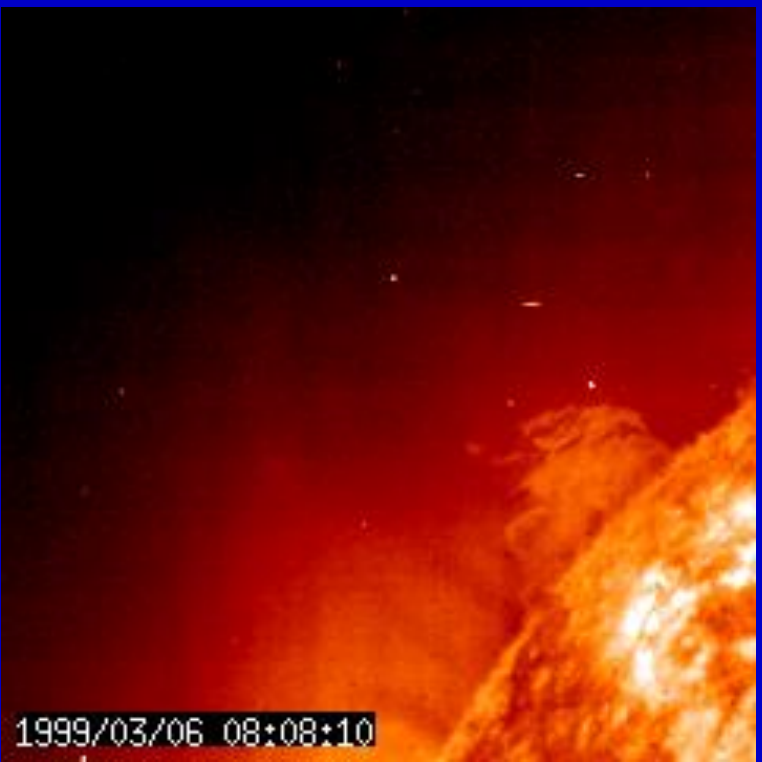
Solar Flares and their Associated CMEs

Massive explosions of X-rays and plasma from active regions

Most solar flares occur when the solar flux index is 90 or greater during the seven years of greatest solar activity during each solar cycle

Solar flares heat solar plasma to millions of degrees Fahrenheit

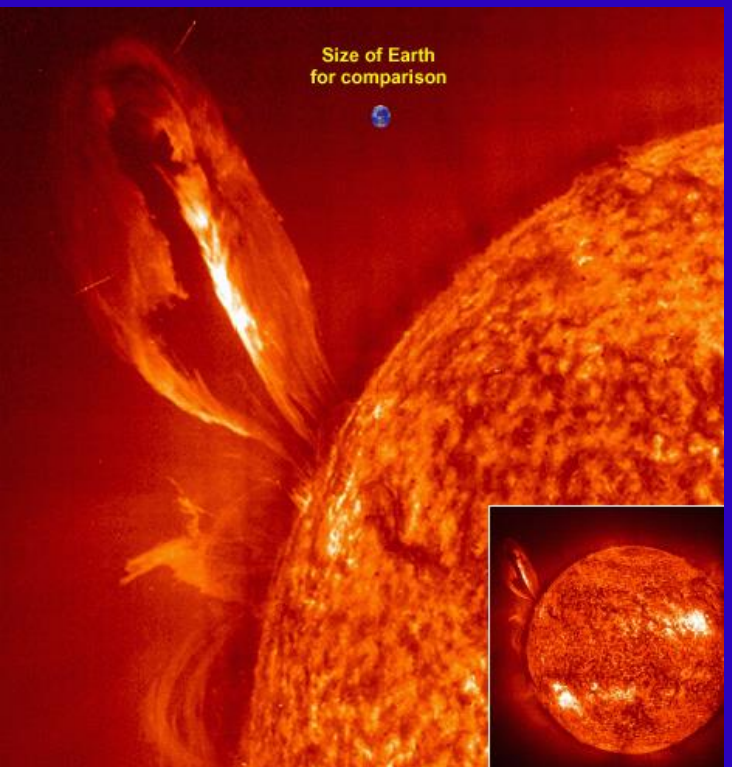
In just a few minutes a coronal mass ejection associated with a flare can release as much as ten billion tons of plasma travelling towards the planets at up to 3000 km/second

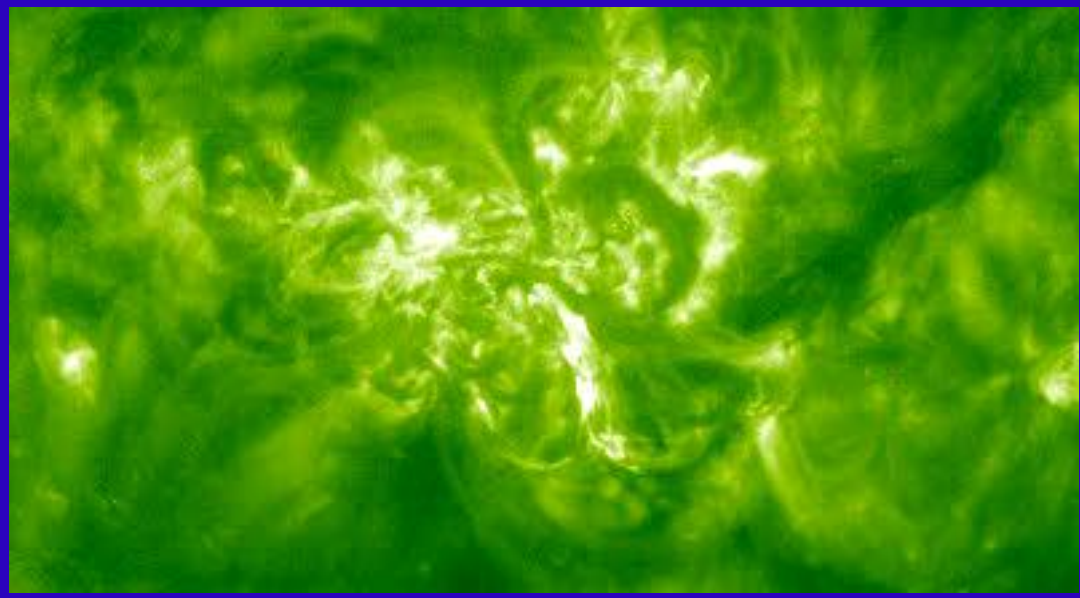


More Frequent X-Class and Strong M-Class Solar Flares

X-class and strong M-class flares are often associated with fast coronal mass ejections (CMEs) travelling faster than 700 km/second to as fast as 3000 km/second

95% of solar flares occur when the solar flux index is 90 or greater during the seven years of greatest solar activity during each solar cycle





Huge X20-class solar flare
28 October 2003

Daytime HF Radio Blackouts Caused by X-Class and M-Class Solar Flares Mostly During the Years Near Solar Maximum

Radio blackouts affect *only* propagation crossing daylight regions

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

After an hour or two HF ionospheric propagation gradually returns to near pre-blackout levels.

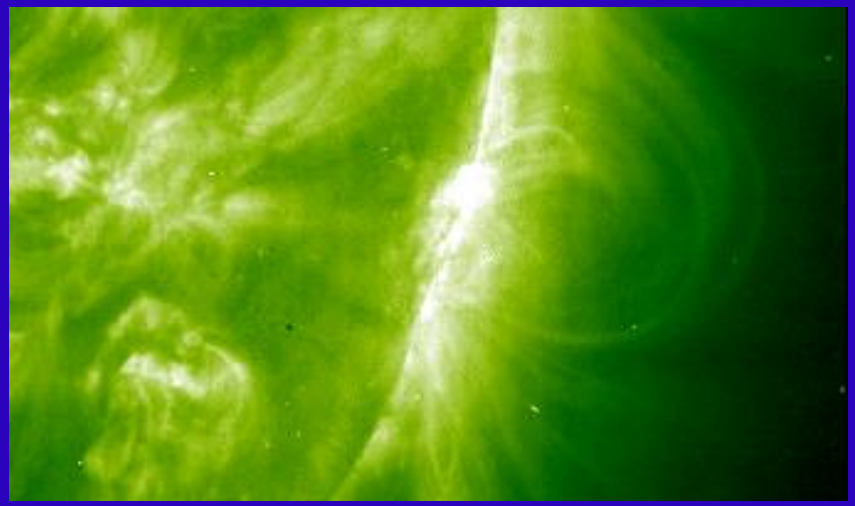
Reduced absorption begins at higher frequencies

Powerful X-Class Solar Flares
severely impact daytime HF ionospheric propagation

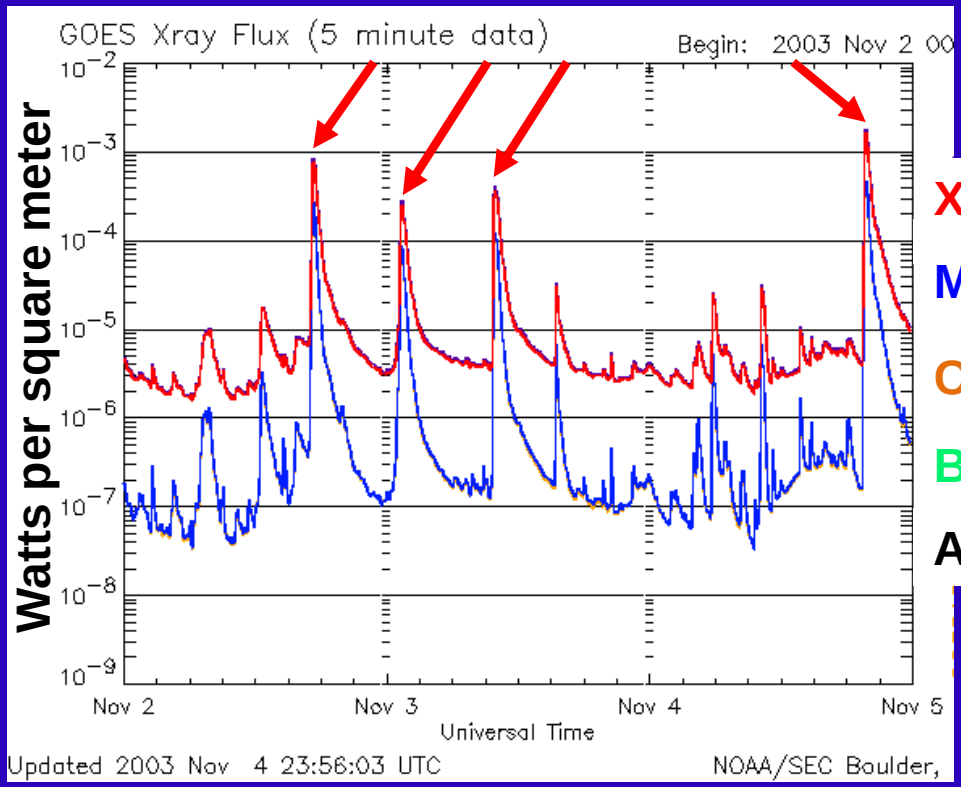
X10-Class – extreme flares produce long duration hemisphere-wide radio blackouts

X-Class – major flares produce hemisphere- wide radio blackouts and severe geomagnetic storms mostly during the four most active years near solar max

Strong M-Class – medium flares produce polar region radio blackouts and degrade HF ionospheric propagation mostly at high latitudes during the seven most active years of the solar cycle



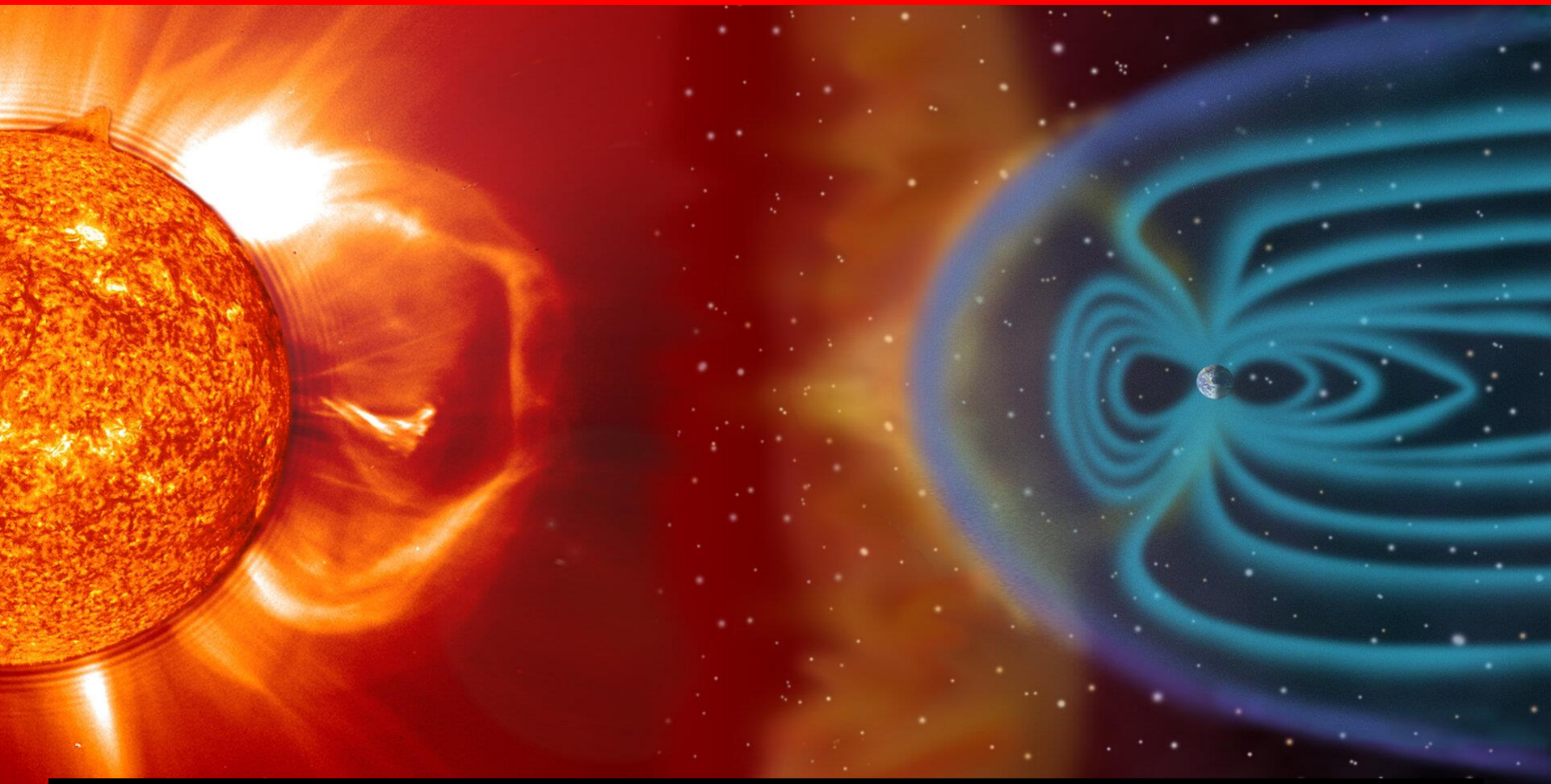
X28 flare -- the largest ever recorded erupts on November 4, 2003



Four X-class flares
2-5 November 2003

Flares are classified on a logarithmic scale according to their x-ray brightness

More Frequent Fast Coronal Mass Ejections Through 2026

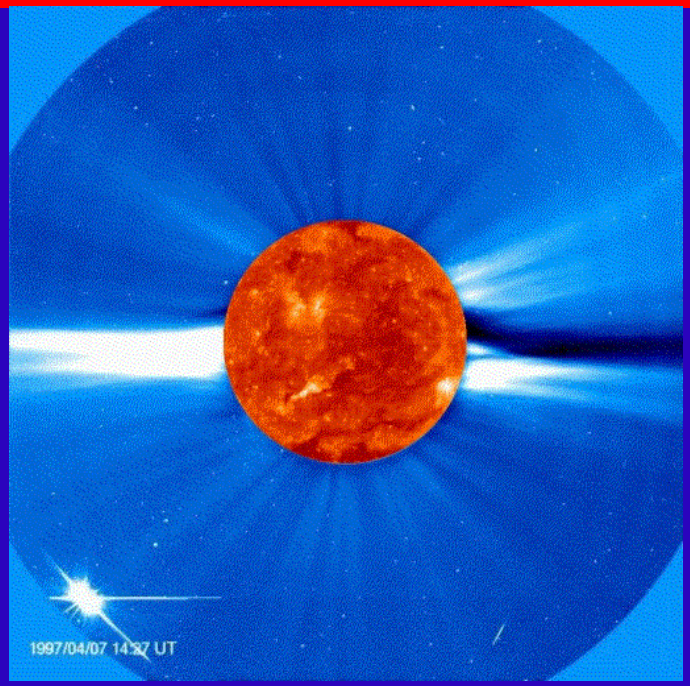


Fast CMEs cause more frequent and longer lasting moderate and severe geomagnetic storms

Steele Hill/NASA

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

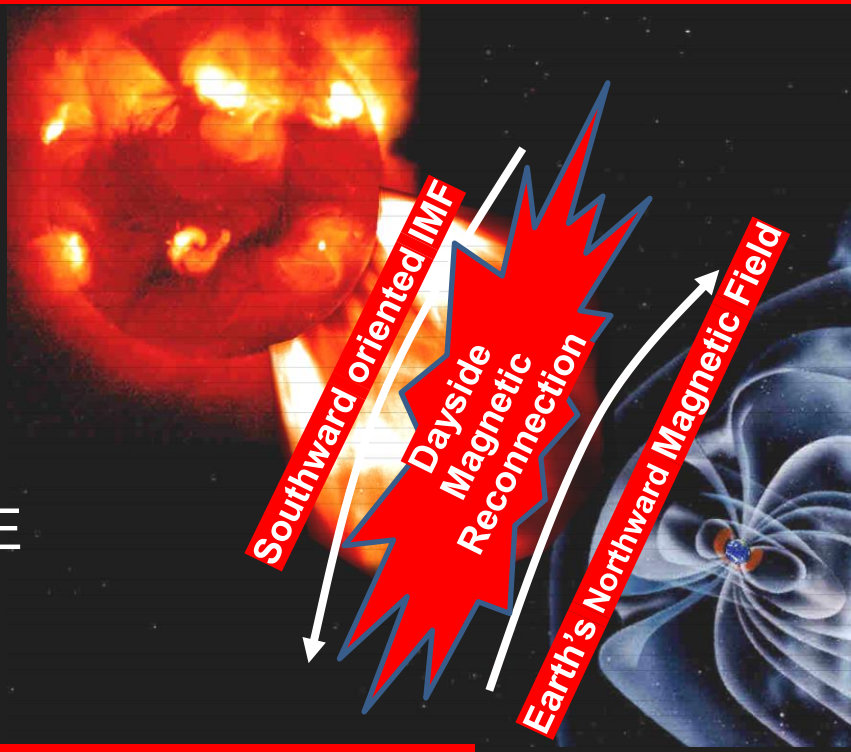
Fast CMEs from solar active regions are the dominant cause of moderate to severe HF propagation disturbances caused by geomagnetic storms



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 it persists in a southward orientation for an extended period of time when enhanced by a fast CME



Fast CMEs occur more 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, and
- when directed from +/- 30º longitude from the Sun's central meridian

High Level Overview of HF Propagation Through 2026

- Solar maximum propagation conditions began in January 2023 and continue through 2026
- 10, 12 and especially 15 and 17 meter worldwide propagation persists later into the night through 2026
- 10 and 12 meter DX propagation continues through 2026
- 20, 30 and 40 meter DX propagation continues throughout the night through 2026
- Geomagnetic disturbances become more frequent as 2026 approaches
- Sunspot activity begins to steadily decline after 2026 until solar minimum in about 2031

What HF Bands Should I use for DXing Through 2026?

- Each band has its unique advantages and disadvantages
- 17, 15, 12 and 10 meters provide reliable daytime worldwide propagation from September through May
- 20 meters provides reliable daytime and nighttime worldwide propagation throughout the year
- 40 meters provides reliable nighttime worldwide propagation throughout the year
- 80 meters usually provides good nighttime worldwide propagation from October through April

How Solar Maximum Affects 12 and 10 Meter Propagation Through 2026

- Worldwide 10 meter propagation improved dramatically since January 2023
  - almost every day from mid-September through late April
  - huge run rates to Europe from sunrise to early afternoon
  - excellent propagation to Japan and Asia after 2130Z sometimes for as long as three or four hours
- Propagation between northern hemisphere locations will continue to be infrequent during most days from May through mid-September
  - Sporadic-E is the dominant May to mid-August propagation
- Excellent 10 meter propagation is likely to continue through 2026

How Solar Maximum Affects 17 and 15 Meter Propagation Through 2026

- Worldwide propagation improved dramatically since 2022
  - almost every day from September through May
  - big run rates to Europe from before sunrise to mid-afternoon
  - excellent propagation to Japan and Asia after 2130Z sometimes for as long as four hours or more
- Propagation between northern hemisphere locations begins later and is shorter in duration from June to August
  - Sporadic-E is sometimes the dominant 15 meter propagation mode from mid-May to mid-August

How Solar Maximum Affects 20 Meter Propagation Through 2026

- Nighttime propagation improved dramatically since January 2023
  - now almost 24 hour per day worldwide propagation
    - but not during summer mid-day hours
  - excellent nighttime run rates to Europe from 0700-0900Z
  - excellent run rates resume about an hour before sunrise
  - most of the DX activity switches to 15 and 10 meters after about 1200Z
- Propagation to Japan and Asia is strongest from Asian sunrise through the night until several hours after our sunrise
- Summer midday 20 meter DX propagation is very poor from June through August

How Solar Maximum Affects 40 and 30 Meter Propagation Through 2026

- Propagation throughout the nighttime hours has become more reliable and more long lasting since 2022
  - good run rates to Europe start about an hour before sunset
  - continuing throughout the night until a few hours after European sunrise when Europeans QSY to higher bands
  - the best European propagation and activity is often around European sunrise (0600-0800Z)
- Mid-afternoon propagation to Europe is weaker since 2022
  - most of DX activity is still on the higher bands
- Propagation from the east coast to Japan and Asia is more reliable since 2022 starting at sunset in Japan (0800Z) until about 30 minutes after our sunrise

How Solar Maximum Affects 80 Meter Propagation Through 2026

- 80 meter propagation has become less reliable since 2022
  - weak and unreliable DX propagation begins at sunset
  - good run rates to Europe start several hours after sunset
  - the best European activity is often just before their sunrise
    - continuing until just after European sunrise when most Europeans QSY to higher bands

- 80 meters will steadily improve after 2026

How Solar Maximum Affects 160 Meter Propagation Through 2026p

- 160 meter propagation has become very unreliable since 2022
  - weak unreliable DX propagation begins after sunset
  - propagation to Europe often improves around midnight for a few hours or much less

- 160 meters will begin to slowly improve after 2026

Nowcasting using the Reverse Beacon Network

80 Meters European CQs heard in North America 0500Z

630m 160m 80m 60m 40m 30m 20m 17m 15m 12m 10m 6m 4m 2m

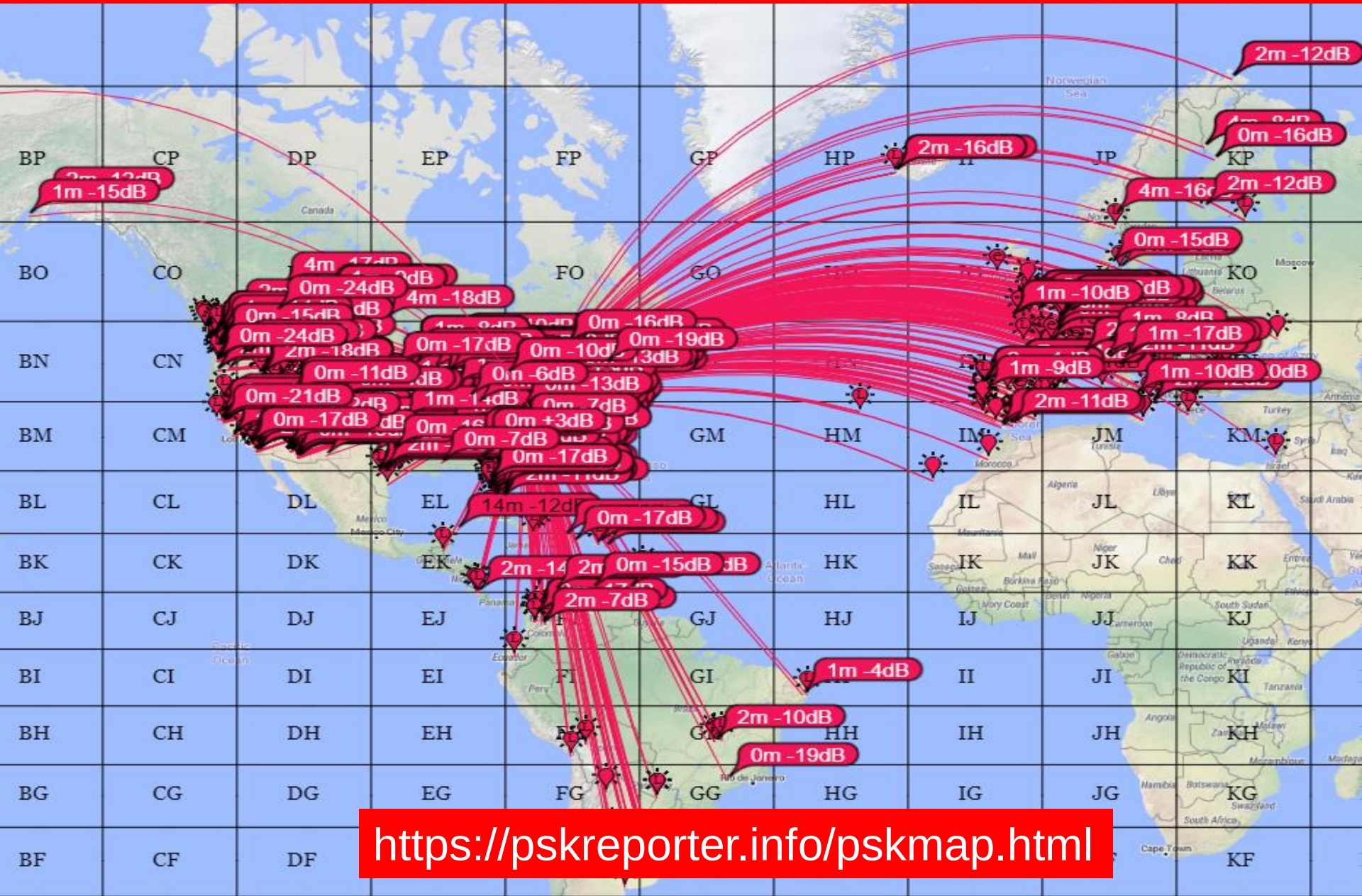
cw rtty psk31 psk63

	● Spotter (de)	● Spotted (dx)
callsign	spotter-callsign	spotted-callsign[,spotted-callsign]
dxcc	any	any
itu zone	any	any
cq zone	any	any
continent	NA - North America	EU - Europe

http://beta.reversebeacon.net/main.php

Nowcasting using PSK Reporter

20 Meters Worldwide PSK heard in North America 2200Z



https://pskreporter.info/pskmap.html