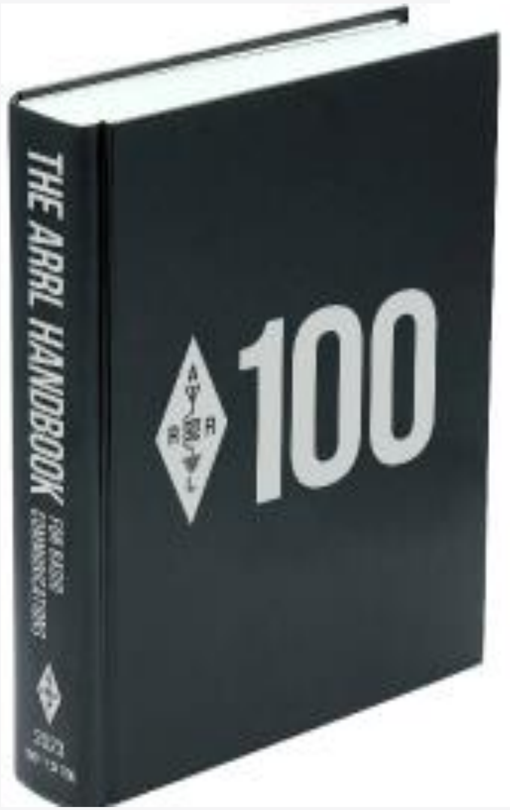
How the Increasing Dynamics of HF Propagation During the Declining Phase of Solar Cycle 25 Affect Contest Strategy and Execution

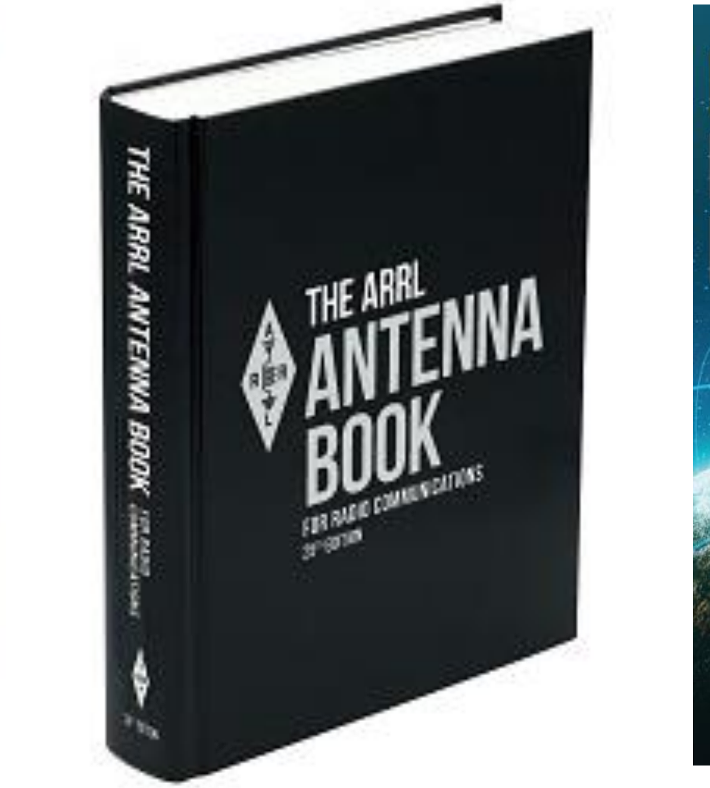
Frank Donovan
W3LPL
donovanf@erols.com

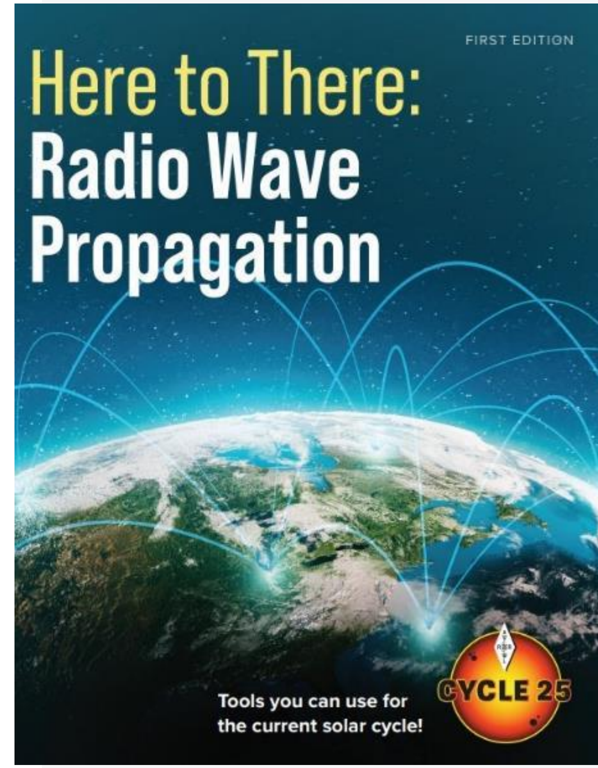
CTU CONTEST UNIVERSITY

ICOM

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







home.arrl.org/action/Store/Product-Details/productId/2009938479
home.arrl.org/action/Store/Product-Details/productId/2012451093
home.arrl.org/action/Store/Product-Details/productId/2010547491

All HF Propagation Originates from the Sun's Intensely Dynamic Magnetic Field

Solar Magnetic Field: source of active regions & the IMF

Active Regions: sunspots, CMEs and solar flares

Sunspots: source of extreme ultraviolet radiation

CMEs: cause almost all strong geomagnetic storms

Coronal Holes: source of the high speed solar wind

High Speed Solar Wind: minor geomagnetic storms

IMF: the Sun's magnetic field extended far into space

IMF orientation: affects geomagnetic storm intensity

Solar Flares: cause daytime HF propagation dropouts

Key Features of HF Propagation Dynamics During the Declining Phase of Solar Cycle 25

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

Ionizing Extreme Ultraviolet Radiation Ten times more radiation during the solar maximum phase improves HF propagation

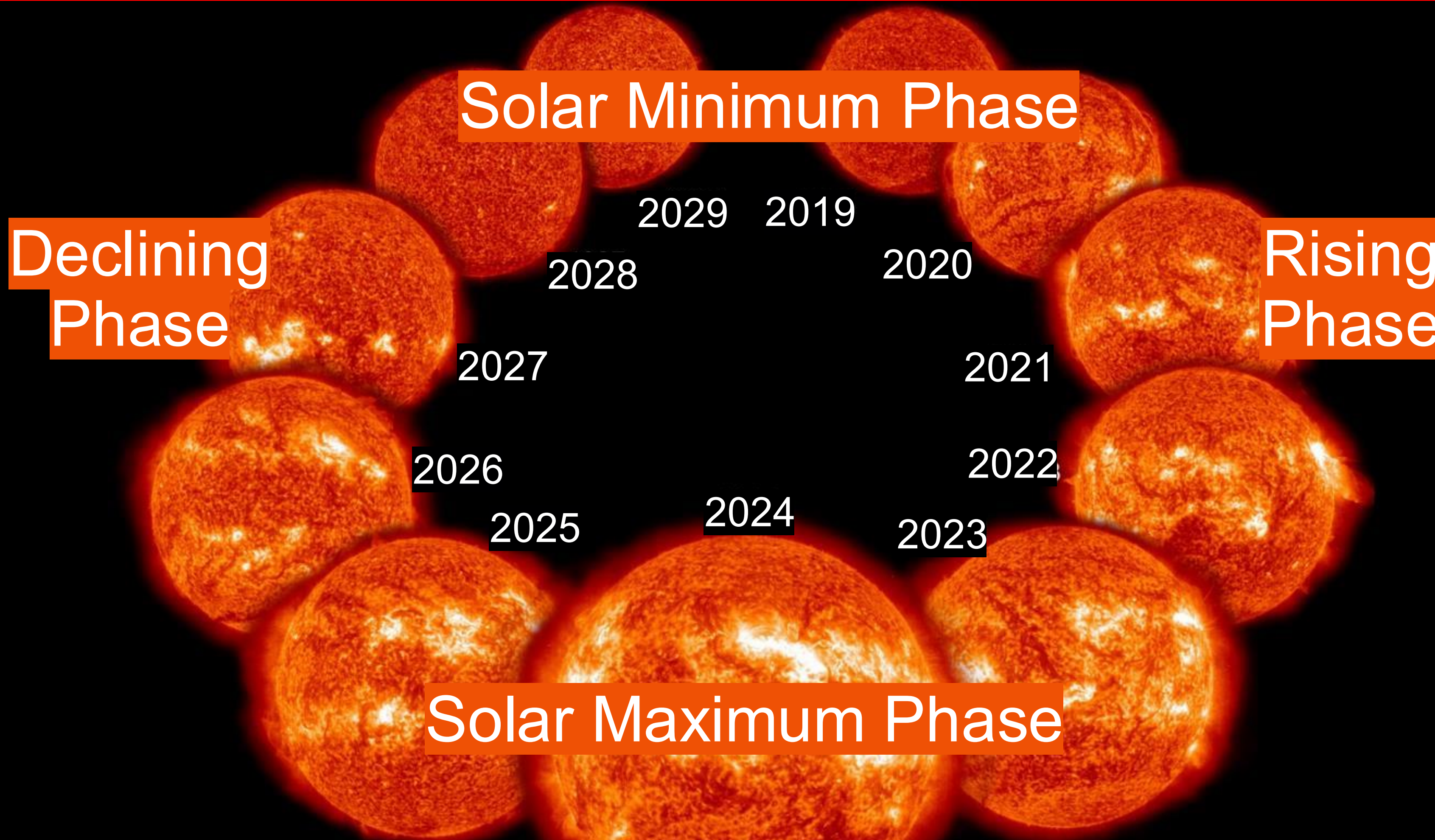
Coronal Mass Ejections (CMEs) large expulsions of highly energetic plasma with embedded magnetic field from the sun's corona

Solar Flares large explosions near active regions emit intense bursts of electromagnetic radiation that black out daytime HF propagation for up to two hours with no warning

Geomagnetic Storms Strong to severe storms are triggered by highly energetic plasma from CMEs. Minor storms are triggered by high speed solar wind originating in coronal holes and by weak CME effects

Seasonal Variability Earth's 23.5º tilted axis increases the intensity and frequency of geomagnetic storms during spring and fall and decreases their intensity and frequency during summer and winter

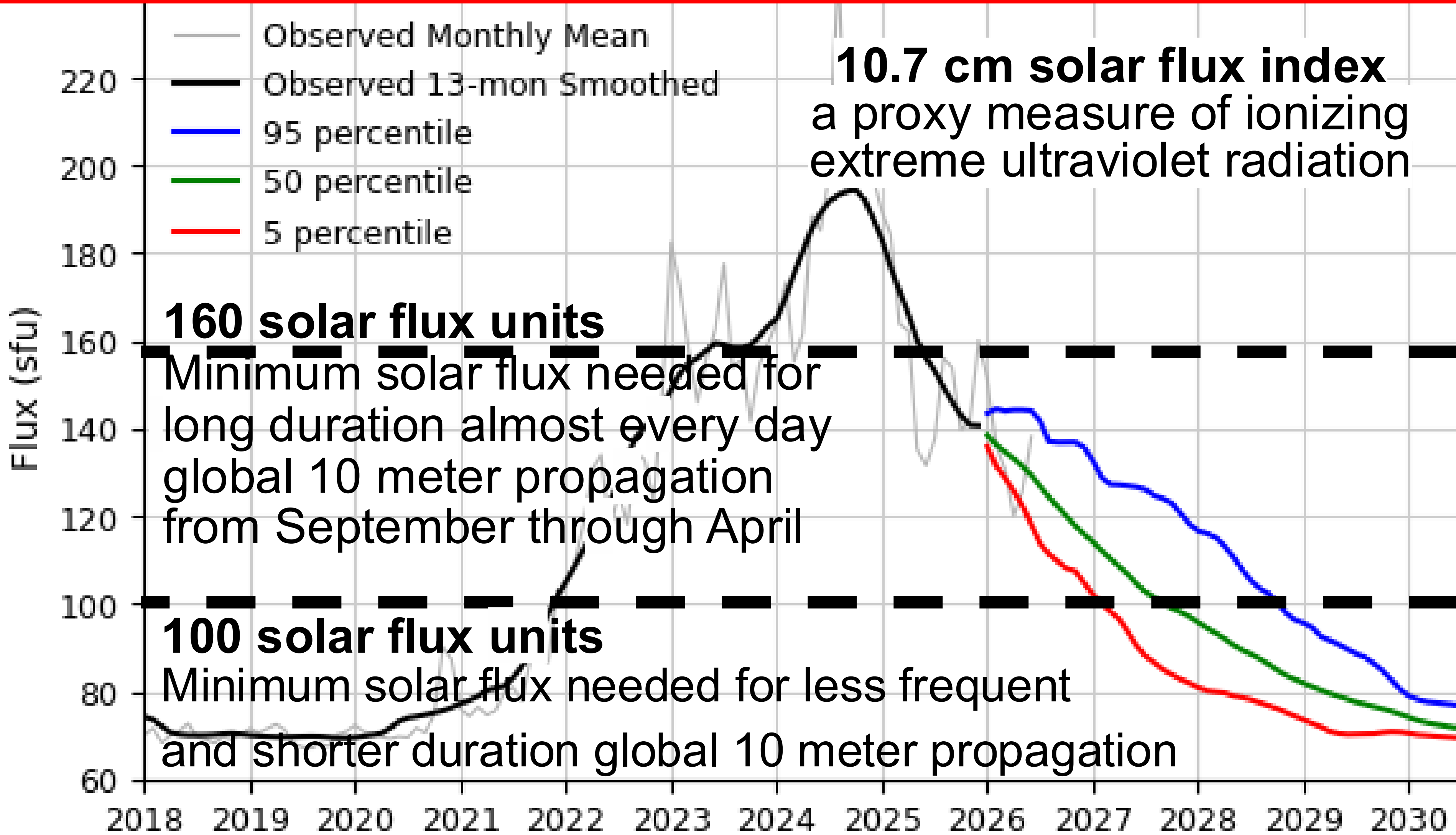
More Frequent Earth Facing Large Coronal Holes and Geoeffective CMEs Greatly Affect HF Propagation Through 2027



Earth Facing Equatorial Coronal Holes Occur Much More Frequently During the Declining Phase of Every Solar Cycle

Earth directed high speed solar wind from equatorial coronal holes produce much more frequent minor geomagnetic storms during the declining phase of every solar cycle

The Declining Phase of Solar Cycle 25 will Transition to the Solar Minimum Phase in 2028



NASA Marshall Space Flight Center - 3 Jul 2026 www.nasa.gov/msfcsolar

Seasonal Variability of the F2 and F1 Regions

The F2 region is the only region providing 24x7x365 long distance HF propagation

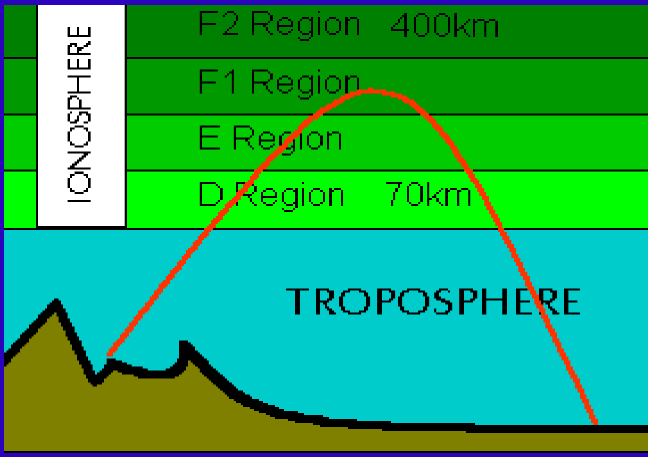
F2 ionization is greatest during the day

F2 ionization declines steadily at night causing significantly reduced MUFs especially during the winter and during solar minimum

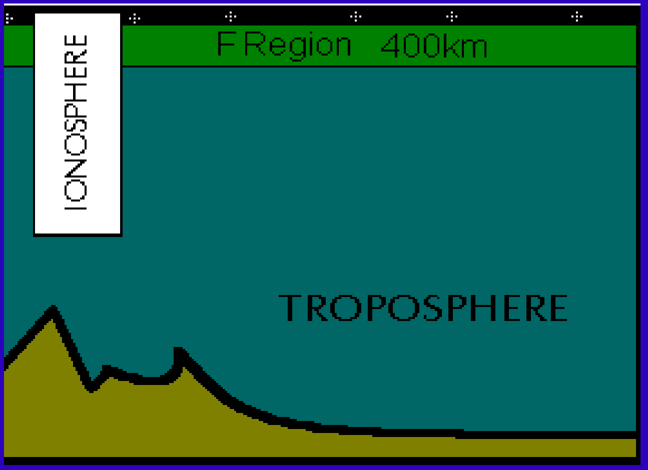
F2 ionization varies greatly with time of day, season, geomagnetic storms
and during the four phases of the solar cycle - rising, maximum, declining, minimum

The F1 region is mostly a summer daytime region that blankets daytime low angle 20 meter long distance propagation

The F1 and F2 regions merge after sunset



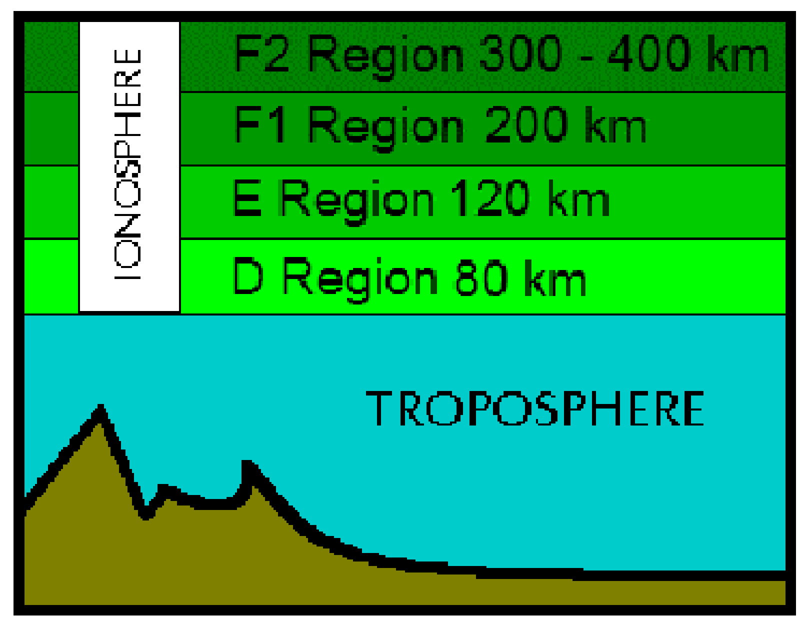
Day



Night

The Seasonal Variability of 20 Meter Mid-Latitude F2 Propagation

E region and F1 region blanketing of F2 long distance summer propagation ends several hours before sunset

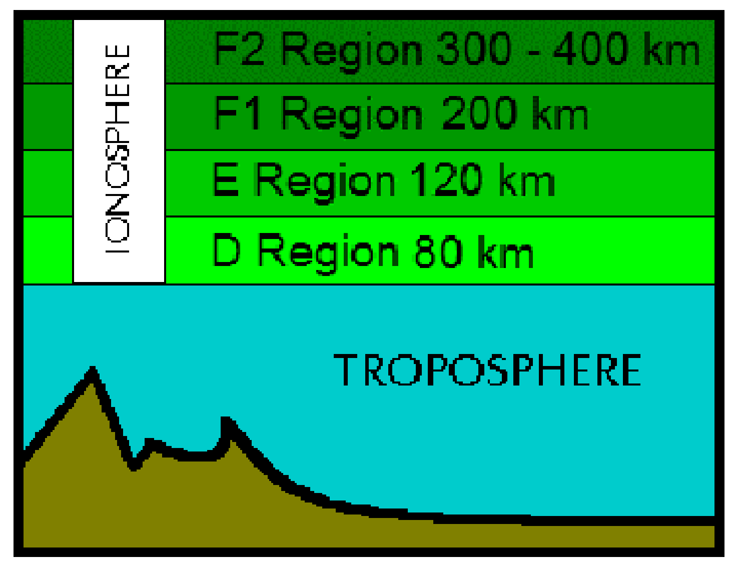


Soon after sunset, the F1 region combines with the F2 region producing a lower altitude, less densely ionized nighttime F2 region at 250 to 300 km altitude

The nighttime winter F2 region is much less densely ionized and has somewhat much lower MUFs than the daytime F2 region

The nighttime summer F2 region is less densely ionized but has much higher MUFs than the nighttime winter F2 region

Blanketing (screening) of 20 Meter Summer Mid-Latitude Long Distance F2 Propagation

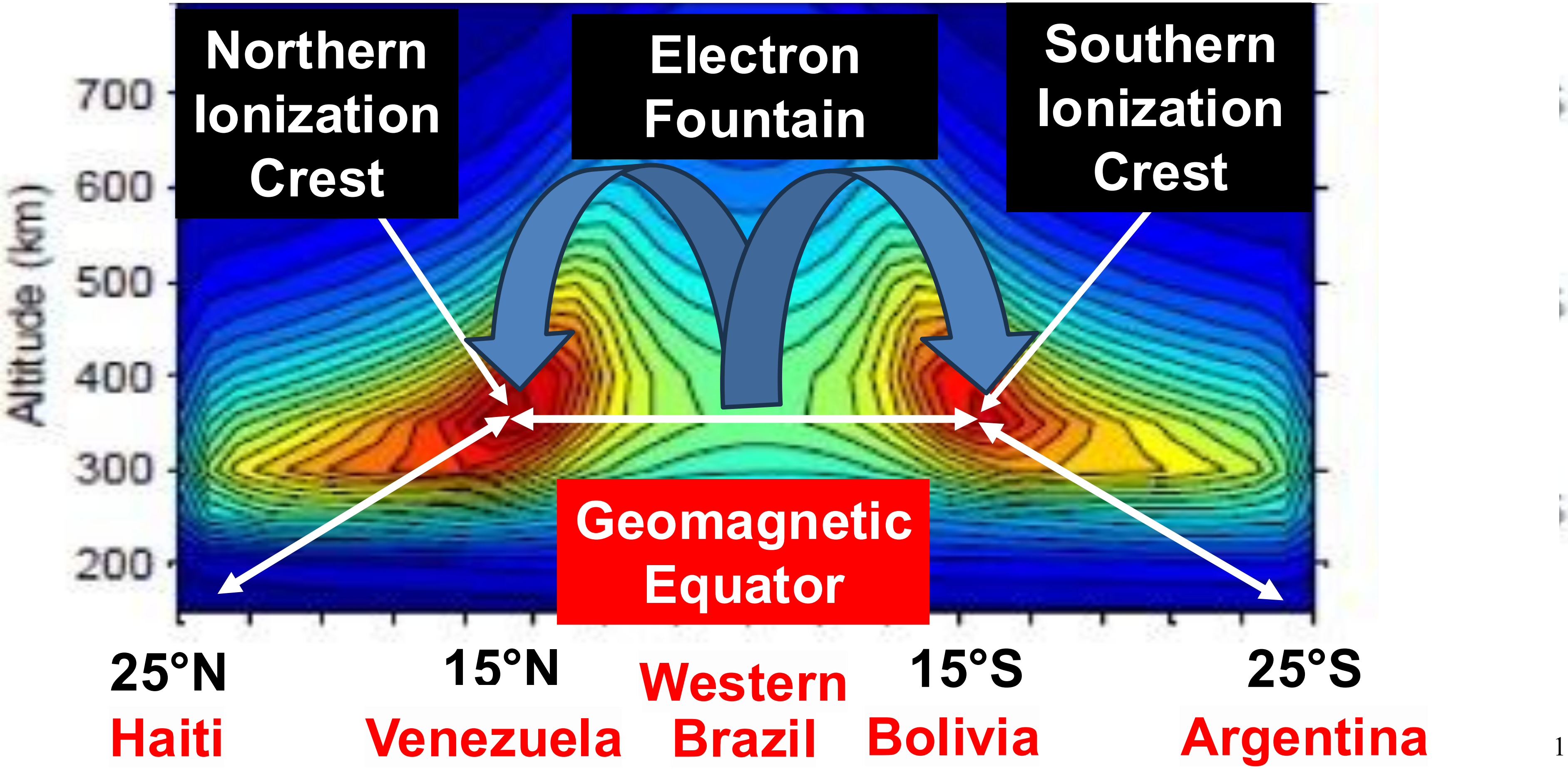


The E and F1 regions cause geographically widespread severe degradation of 20 meter long distance F2 propagation almost every day during midday hours mostly from May to September by blanketing (i.e. screening) F2 propagation

Sporadic-E causes locally severe but unpredictable blanketing of 20 and 15 meter long distance F2 propagation mostly from May through September from about mid-morning through late evening

The Amazing Dynamics of 6 and 10 Meter Trans-Equatorial Propagation (TEP)

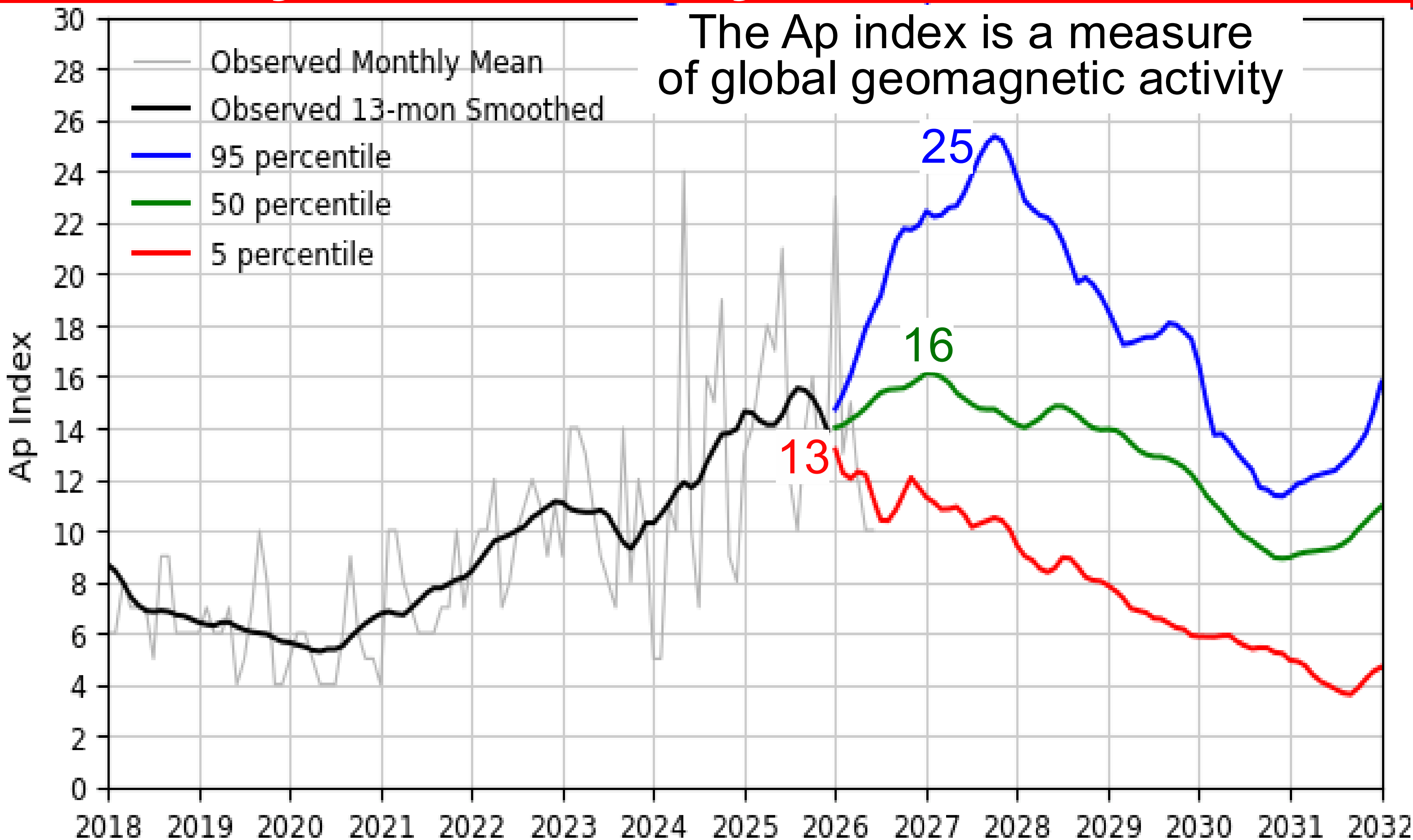
MUF enhancing TEP occurs most often during the spring and fall at about 1500-1900 local solar time at the reflection points between mid-latitude locations each roughly 2000 to 2500 miles north and south of the ***geomagnetic*** equator



15 and 10 Meter Long Path Propagation Will Become Less Frequent and Less Widespread After 2027

Because the solar flux index remains mostly above 100 during the declining phase of each solar cycle, frequent long distance F2 propagation continues between widely separated points near the daylight-darkness terminator

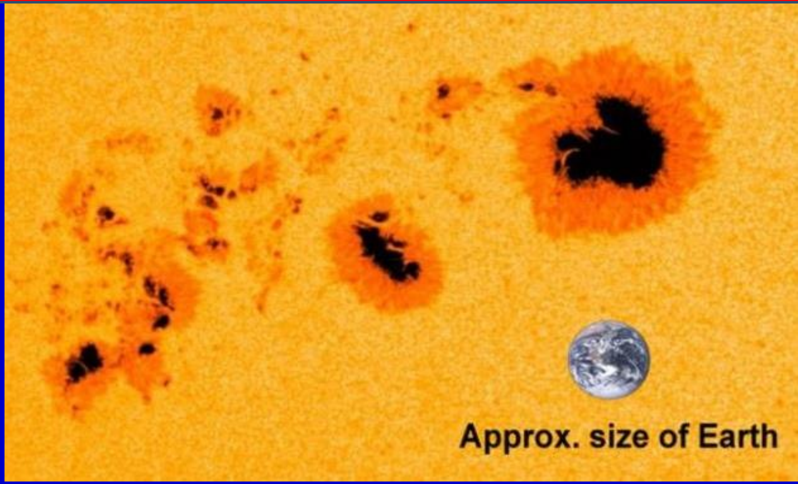
Degradations Caused by Geomagnetic Activity will Gradually Decline After 2026



NASA Marshall Space Flight Center – 2 July 2026 www.nasa.gov/msfcsolar

Active Regions Produce Frequent Solar Flares and Coronal Mass Ejections Throughout the Declining Phase of the Solar Cycle

An active region containing one of the largest sunspots ever seen

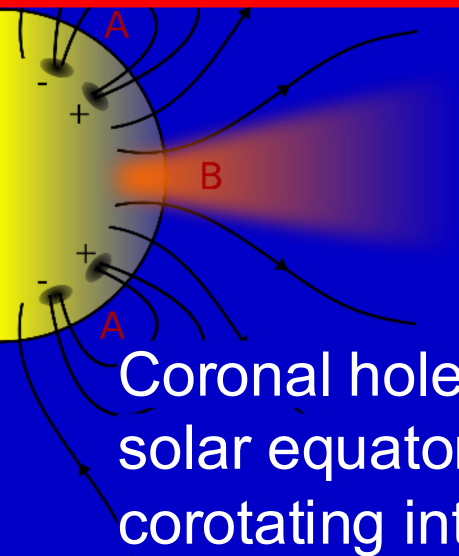


During the declining phase of every solar cycle:

- Highly energetic magnetized plasma from geoeffective fast CMEs cause frequent strong, long lasting geomagnetic storms
- High speed streams of hot plasma from equatorial coronal holes cause frequent, short duration minor geomagnetic storms
- Highly energetic hard x-rays from solar flares cause frequent daytime radio blackouts that can last for several hours

Coronal Hole High Speed Streams from Equatorial Coronal Holes

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



Coronal hole high speed streams are the most frequent source of minor geomagnetic storms especially during the declining and solar minimum phases of each solar cycle

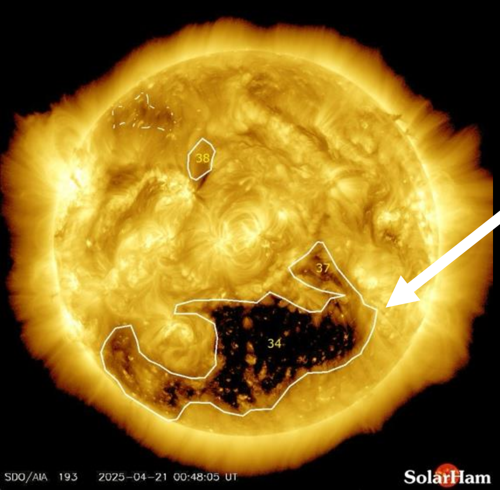
Coronal hole high speed streams originating near the solar equator interact with the slow ambient solar wind forming corotating interaction regions (CIRs) that often cause minor geomagnetic storms developing gradually over several hours, most frequently during the declining four years of each solar cycle

Conversely, geoeffective fast CMEs originating in active regions during the declining phase of each solar cycle sometimes cause sudden strong and severe geomagnetic storms

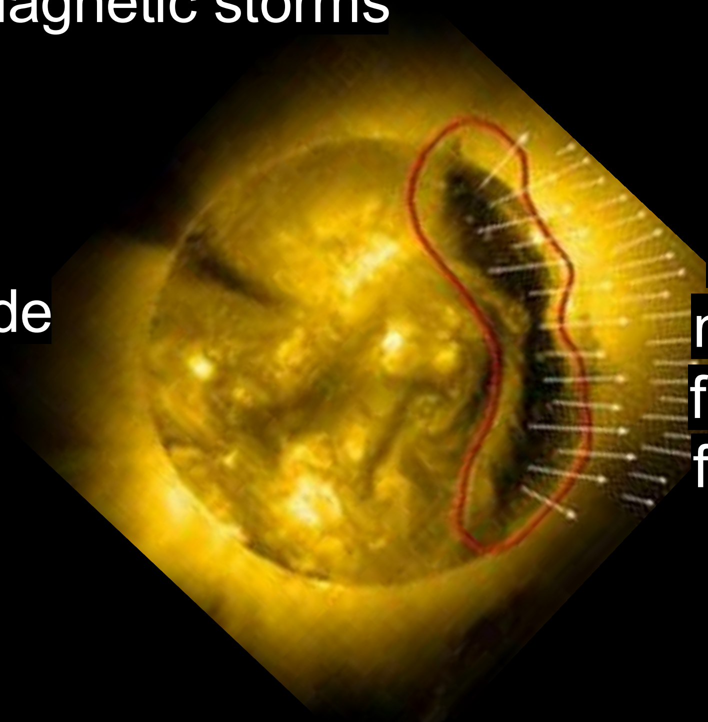
The Dynamics of Equatorial Coronal Hole High Speed Streams

Small equatorial coronal holes allow magnetized plasma to escape the Sun's gravity forming the ambient slow solar wind and its embedded interplanetary magnetic field

During the declining phase of each solar cycle, more frequent coronal hole high speed streams originating from large Earth facing equatorial coronal holes cause more frequent minor geomagnetic storms

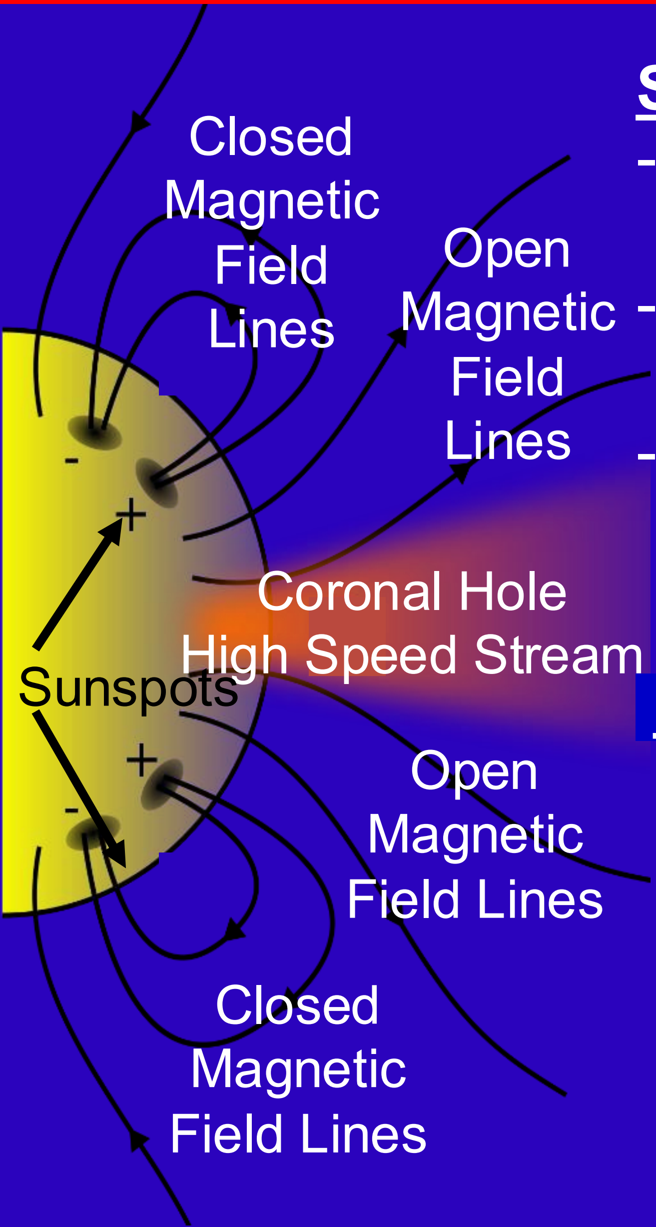


450,000 mile wide Earth facing coronal hole April 21 2025



Open unipolar magnetic field lines flow from coronal holes

Short and Long Duration Minor Geomagnetic Storms



<u>Short duration</u> minor geomagnetic storms

- caused by coronal hole <u>high speed stream</u> interactions with the ambient slow solar wind
- cause minor HF propagation degradation during the declining phase of the solar cycle
- but they are the most frequent cause of minor HF propagation degradations during the solar minimum phase of the solar cycle

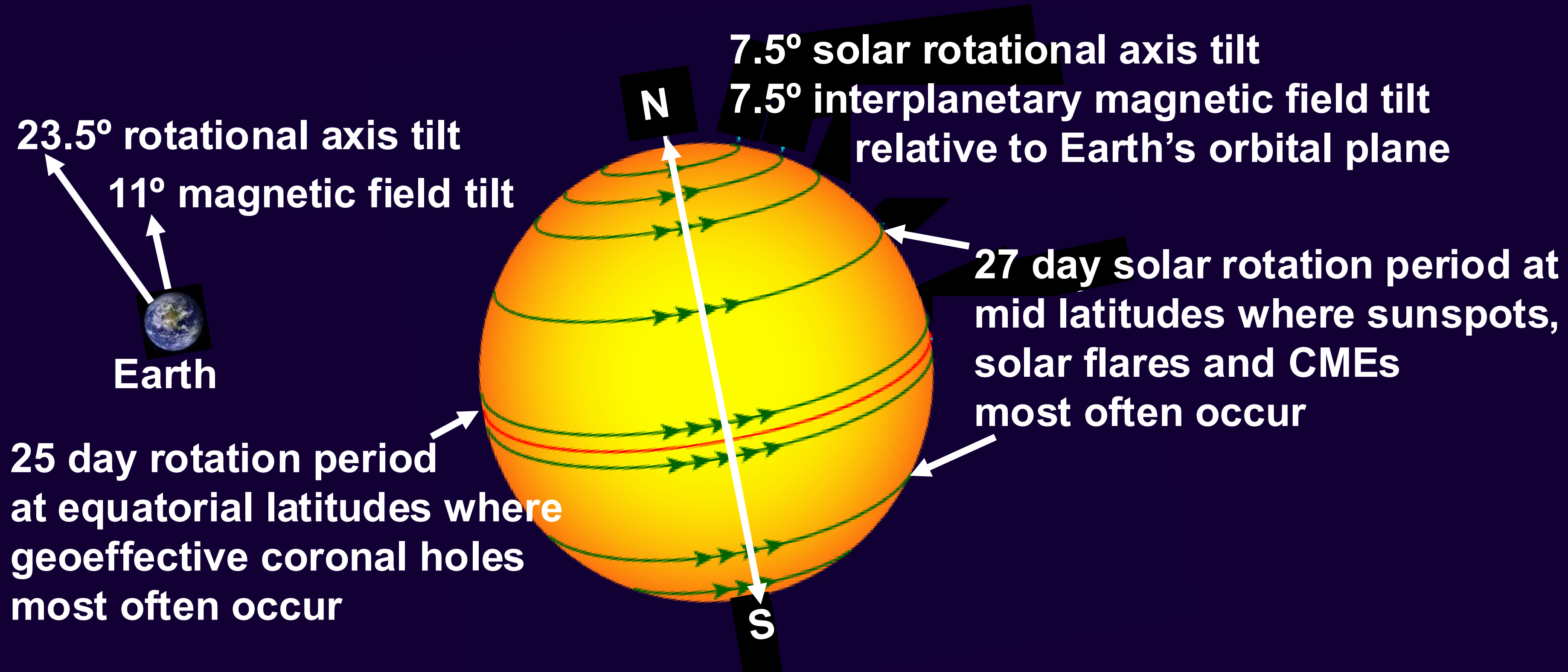
<u>Long duration</u> minor geomagnetic storms

- caused by near misses and weak CMEs
- cause minor HF propagation degradation during the declining phase of the solar cycle
- occur about twice as frequently during the declining phase of the solar cycle

27 Day Recurrent Large Active Regions and Large Equatorial 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



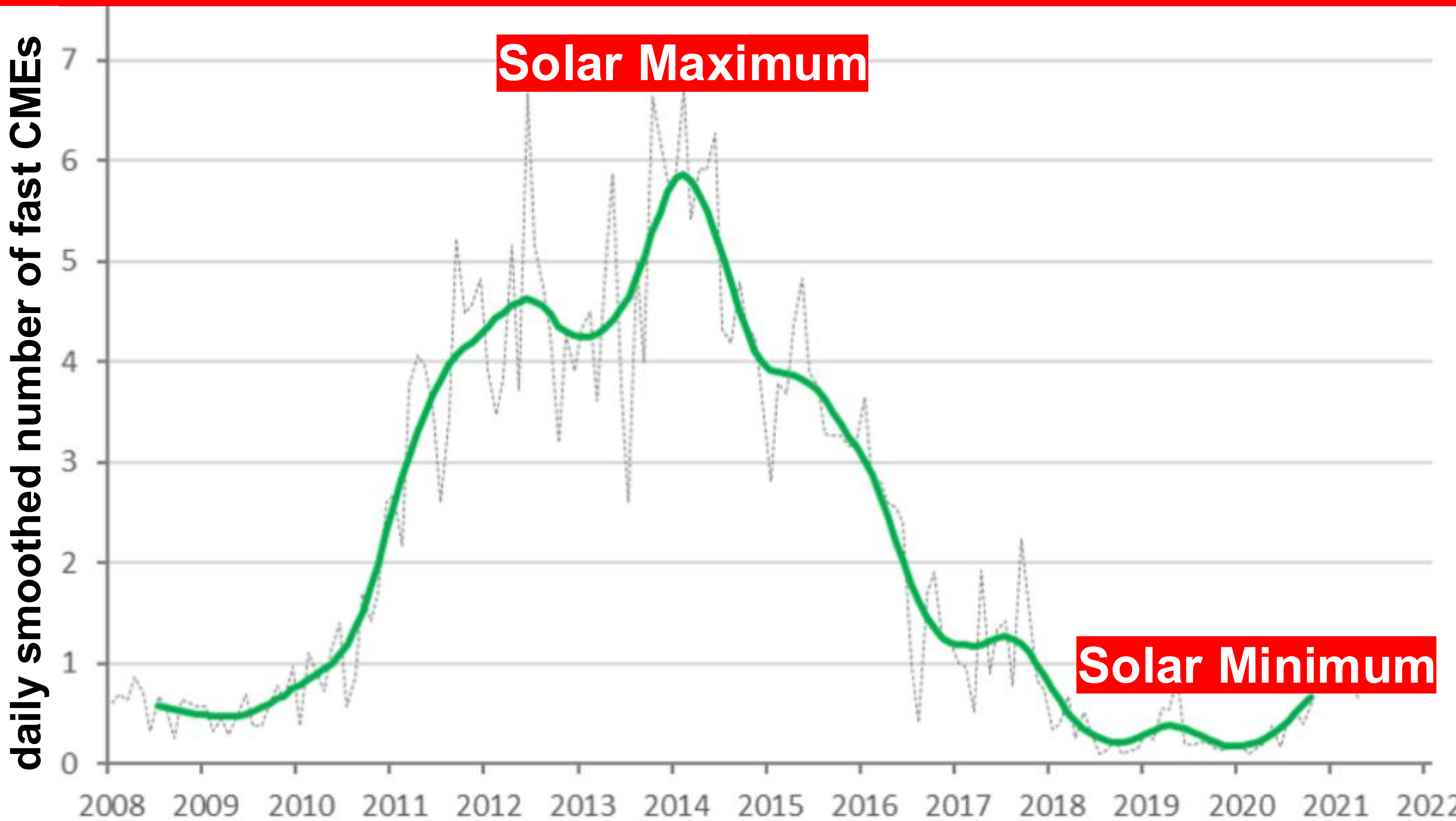
27 day solar rotation period where large active regions most often occur
25 day solar rotation period where equatorial coronal holes occur

Frequent CMEs and Associated Solar Flares During the Declining Phase Each Solar Cycle

95% of solar flares occur when the solar flux index is 90 or greater during solar maximum and early declining phase of each solar cycle

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

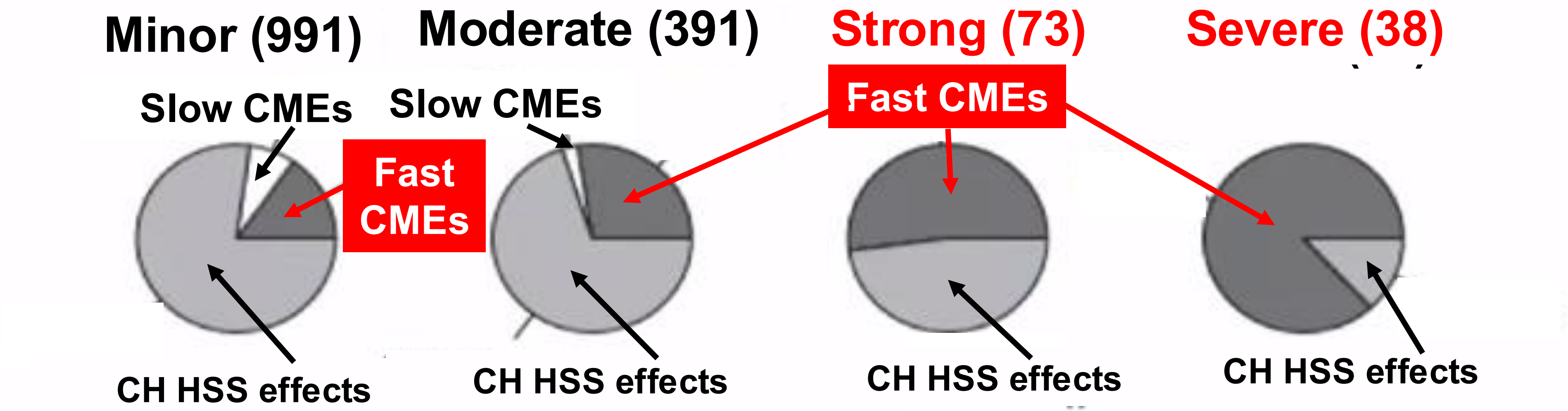
Fast Coronal Mass Ejections (CMEs) By Far the Dominant Cause of Strong to Severe Geomagnetic Storms



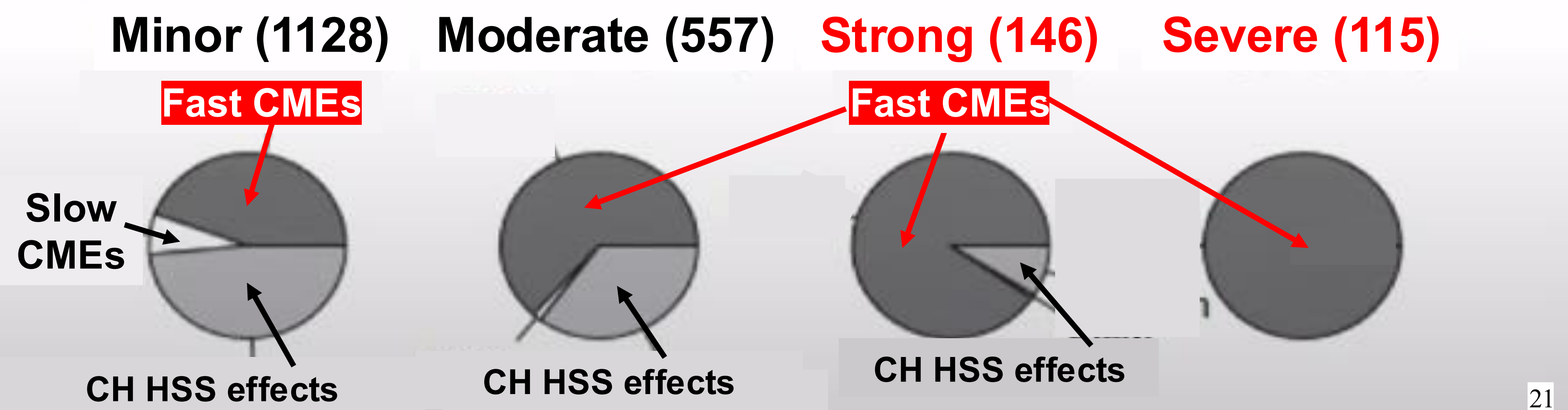
Geoeffective Fast CMEs

Dominant cause of strong to severe geomagnetic storms

Coronal hole high speed streams cause most storms near solar minimum



Fast CMEs cause most storms of all sizes near solar maximum

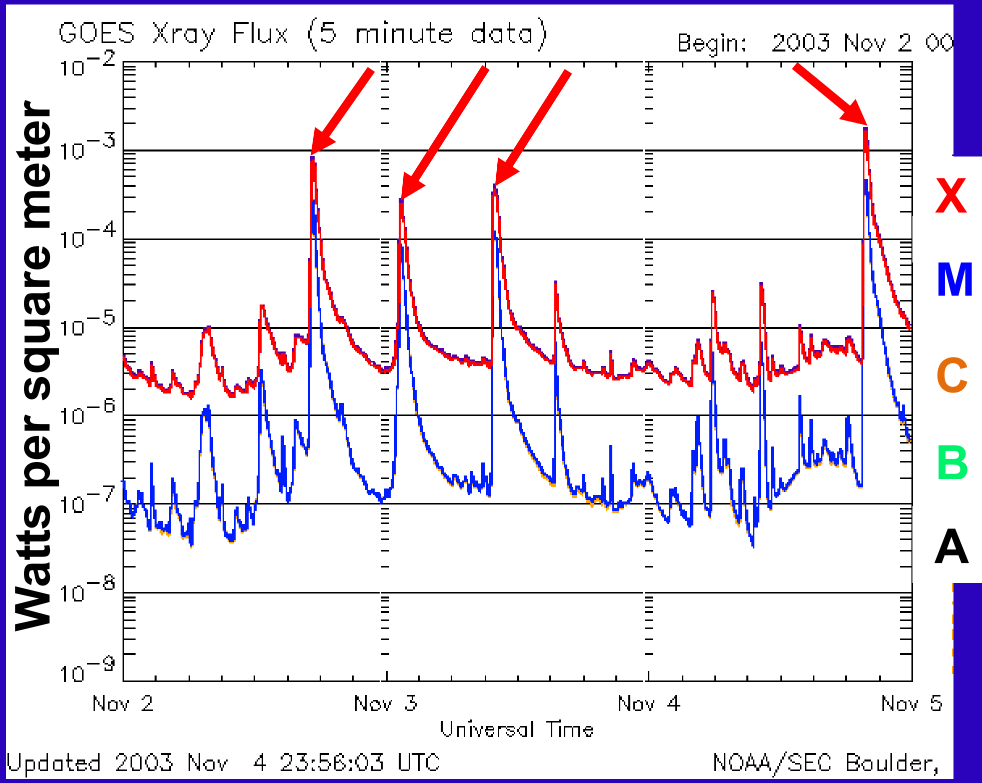


X-Class Major and Extreme Solar Flares Severely Degrade Daytime HF Propagation

Extreme X10-Class flares produce long duration hemisphere-wide daytime radio blackouts especially during the solar maximum phase

Major X-Class flares produce hemisphere-wide daytime radio blackouts during the solar maximum phase and less often during the declining phase of each solar cycle

Strong M-Class flares less severely degrade daytime HF propagation mostly at high latitudes during the solar maximum and declining phases of each solar cycle



Four Major X-Class flares
2 to 4 November 2003

Solar 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 Mostly During the Solar Maximum Phase

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

Absorption decreases proportional to the square of frequency

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) are the By Far the Dominant Cause of Strong to Severe Geomagnetic Storms

Propagation degradations caused by geoeffective fast CMEs are greatly magnified when the interplanetary magnetic field (IMF) persists in a southward orientation -- opposite to the Earth's magnetic field -- for more than a few hours

Fast CMEs rarely cause geomagnetic storms when the IMF is not oriented southwards

Forecasts of the southward orientation of the IMF are notoriously inaccurate

Strong to Severe Geomagnetic Storms

Always Caused by Persistent Southward IMF Orientation

Persistent Southward Oriented
Interplanetary Magnetic Field (IMF)

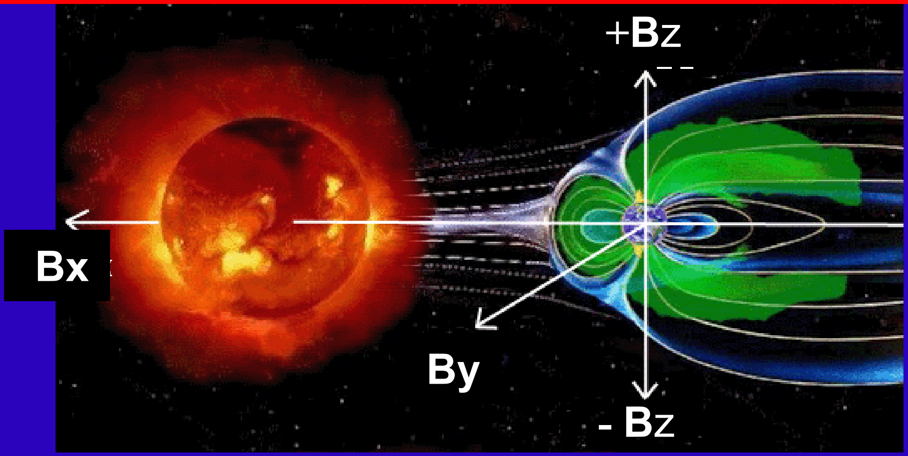
causes strong to severe geomagnetic storms
when the IMF persists in a southward orientation
for at least several hours
when enhanced by a geoeffective fast (>500 km/sec) CME

Fast CMEs occur most frequently during the solar maximum and declining phases of each solar cycle

Strong to severe geomagnetic storms occur most often when

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

Persistent Southward Orientation of the Interplanetary Magnetic Field (IMF)



When the north-south (Bz) component of the IMF turns southward:
- magnetic reconnection with the Earth's oppositely polarized magnetic field converts its magnetic into kinetic energy, accelerating the solar wind
- accelerated plasma precipitates into the ionosphere on a global scale
- persistent southward oriented Bz often causes severe geomagnetic storms

Storm level	Kp Index	-Bz field strength	- Bz Persistence
Severe	8	100-200 nT	> 4 hours
Strong	7	50-100 nT	3-4 hours
Moderate	6	3-50 nT	2-3 hours
Minor	5	<3 nT	1-2 hours

Geomagnetic Storm Propagation Impacts

Geomagnetic storms are caused by geoeffective fast CMEs and by interaction between coronal hole high speed streams and slower solar wind mostly during the four years near solar minimum

Kp=9 **four days or less per solar cycle**

Impossible HF ionospheric propagation in many areas for at least two days

-- occurs only during the two years near solar maximum --

Kp=8 **about 100 events (60 days) per solar cycle**

Sporadically available HF ionospheric propagation in many areas for one or two days

Kp=7 **about 200 events (130 days) per solar cycle**

Sporadically available HF ionospheric propagation at high latitudes for one or two days

Kp=6 **about 600 events (360 days) per solar cycle**

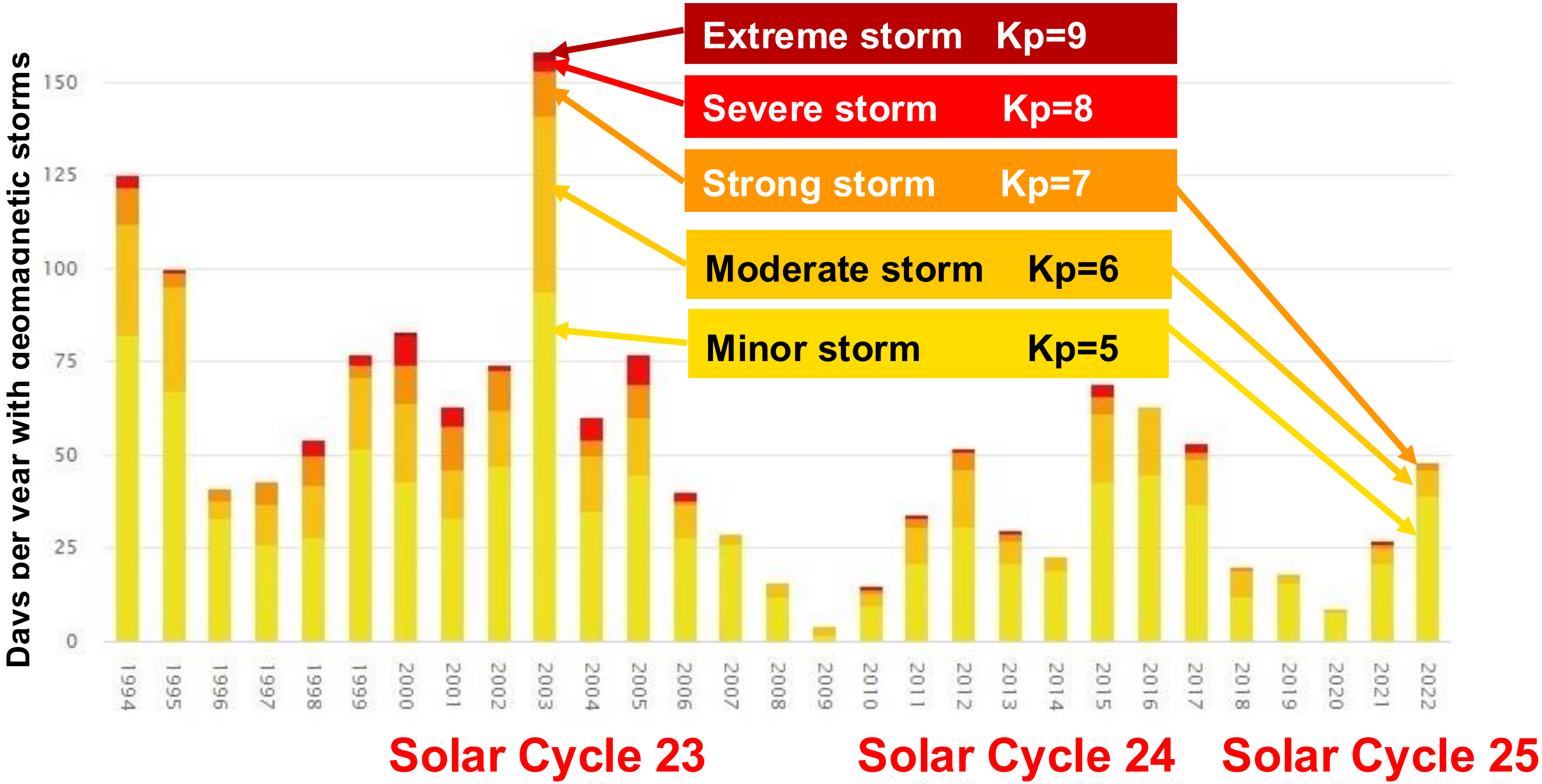
Unstable HF ionospheric propagation at high latitudes for many hours

Kp=5 **about 1700 events (900 days) per solar cycle**

Unstable HF ionospheric propagation at high latitudes for a few hours

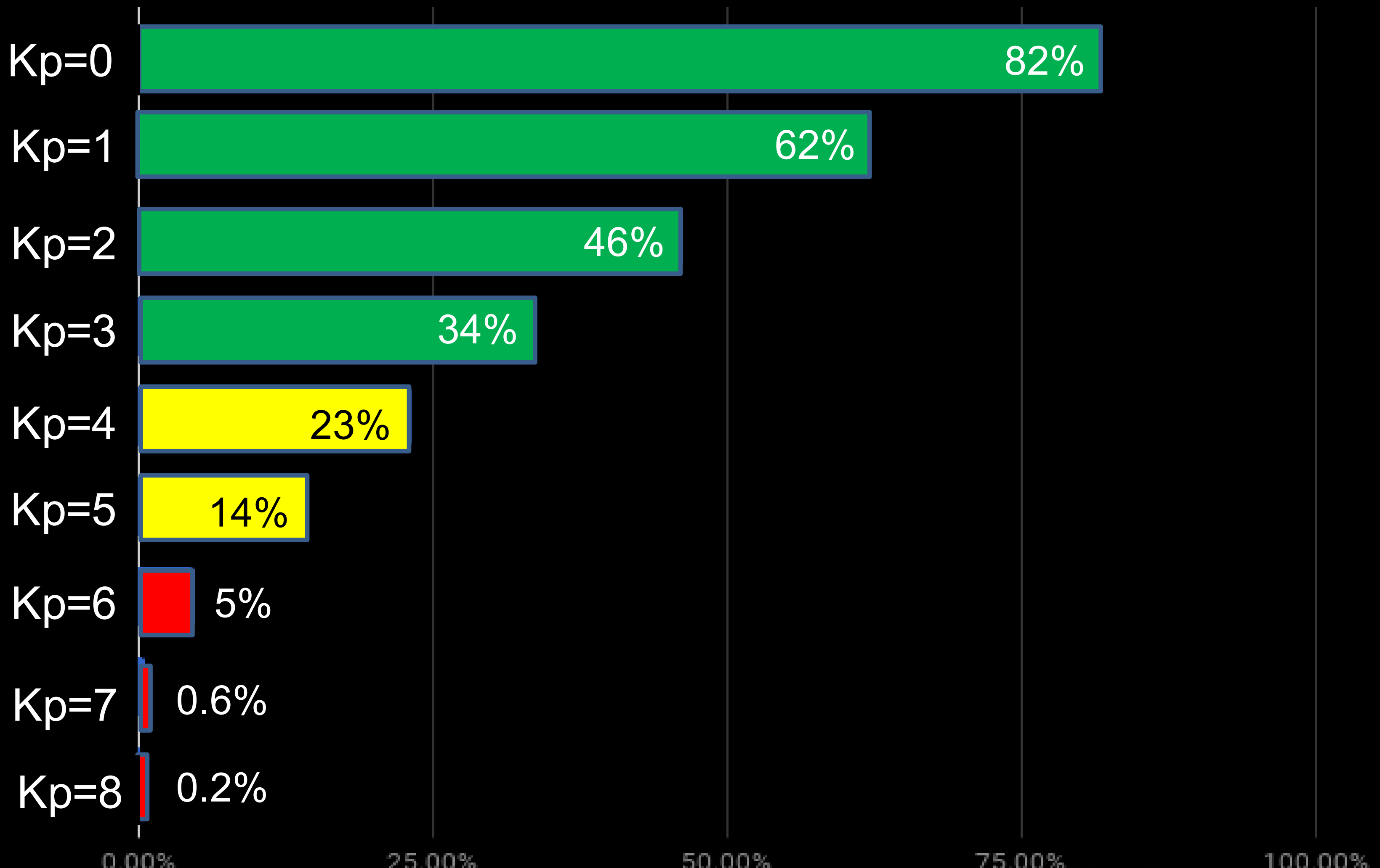
Days per Year with Geomagnetic Storms

There have been many fewer geomagnetic storms since Solar Cycle 23 in 2003



Daily Likelihood of Geomagnetic Disturbances

Likelihood on any given day that Kp will exceed:

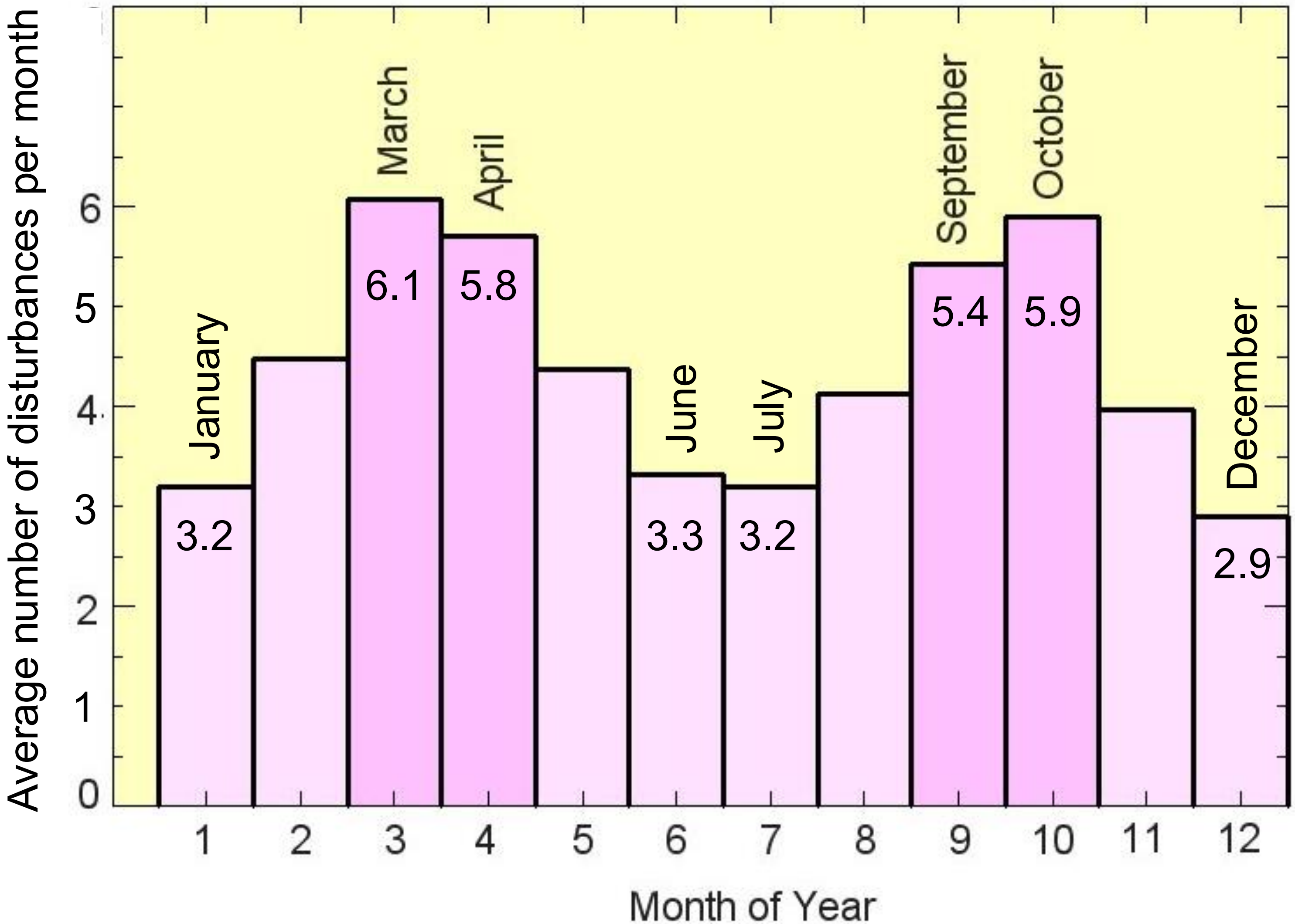


Data Source: British Geological Survey

SeeTheAurora.com

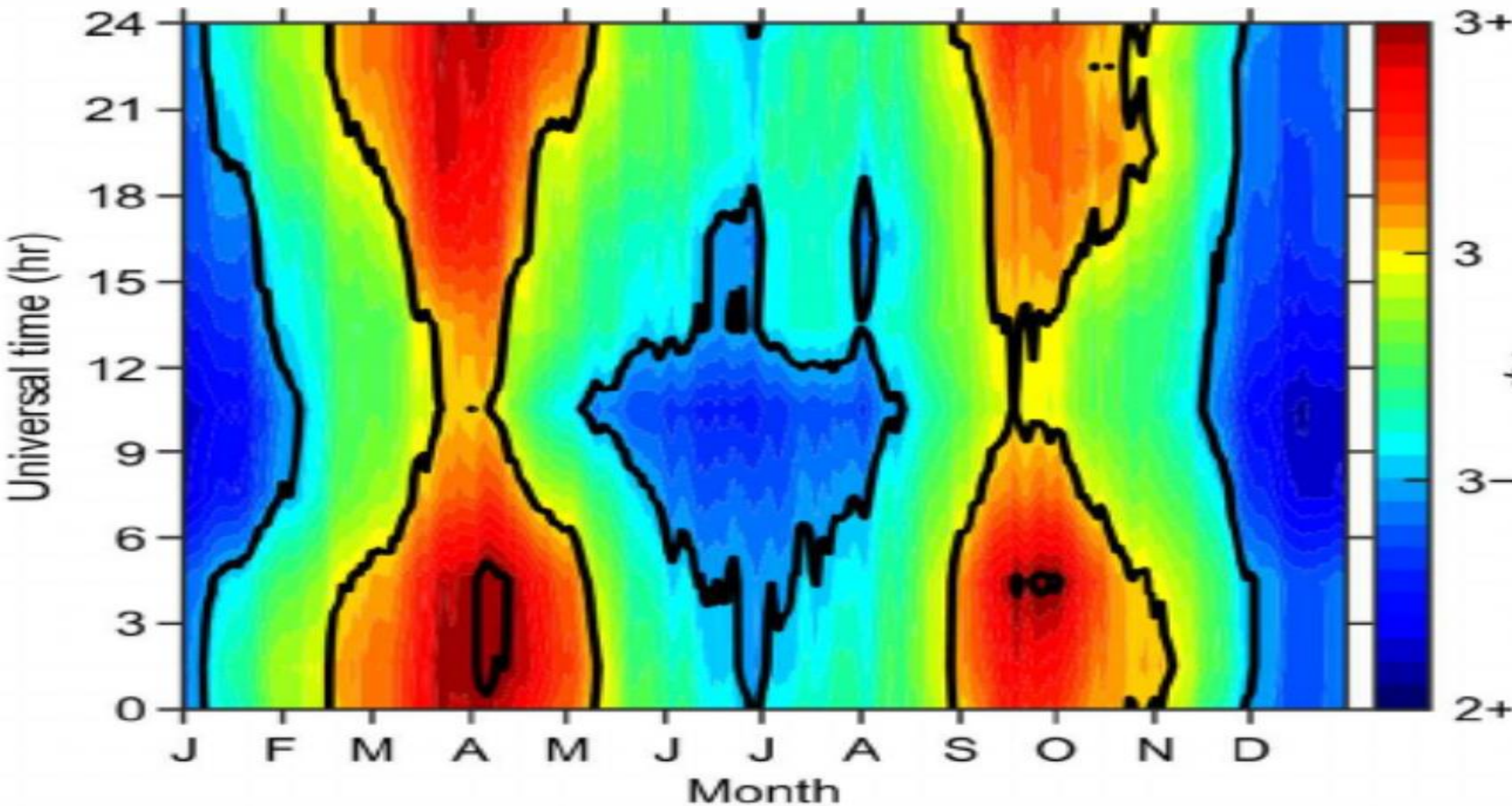
Seasonal Variability of Geomagnetic Disturbances

Geomagnetic disturbances (Kp=4+) occur about twice as often during spring and fall compared to summer and winter



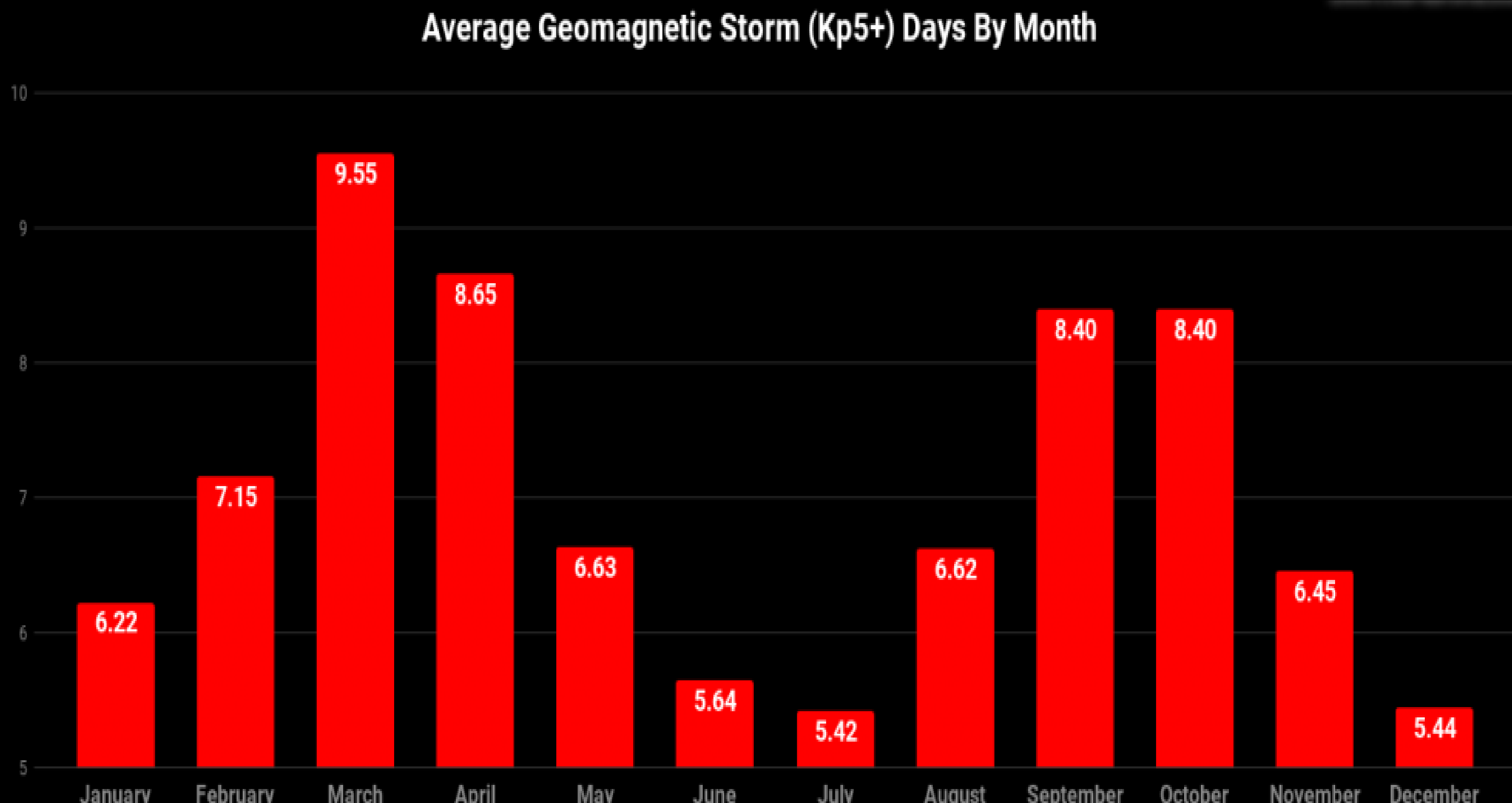
Seasonal and Minor Hourly Variability of the Northern Hemisphere Kp Index

Minor Kp index hourly (UTC) variability is caused by Earth's 24 hour daily rotation which varies the coupling between Earth's magnetosphere-ionosphere system and the solar wind



Seasonal Variability of the Likelihood of Geomagnetic Storms

Geomagnetic storms are almost twice as likely during March, April, September and October compared to June, July, December and early January

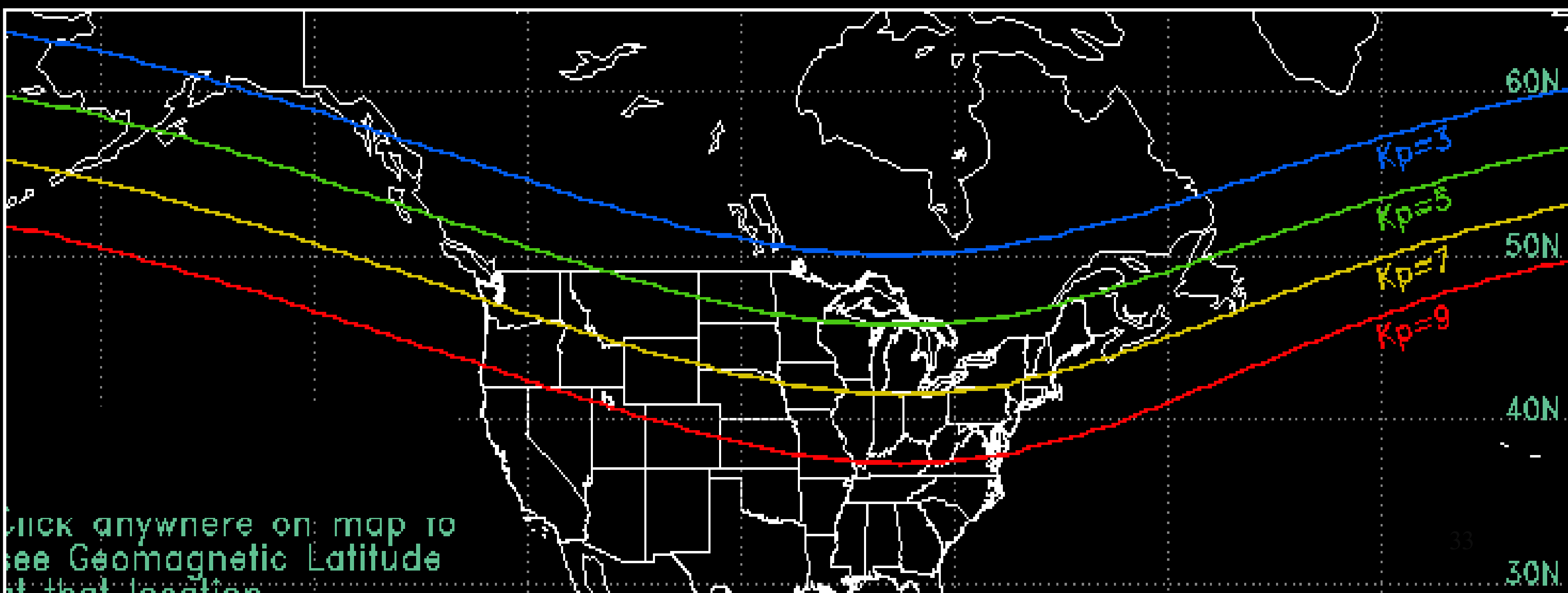


Intense Post-Midnight Auroral Absorption is Caused by Strong Geomagnetic Storms

Auroral absorption intensity, latitude, north-south width and duration depend on the strength of the triggering geomagnetic storm

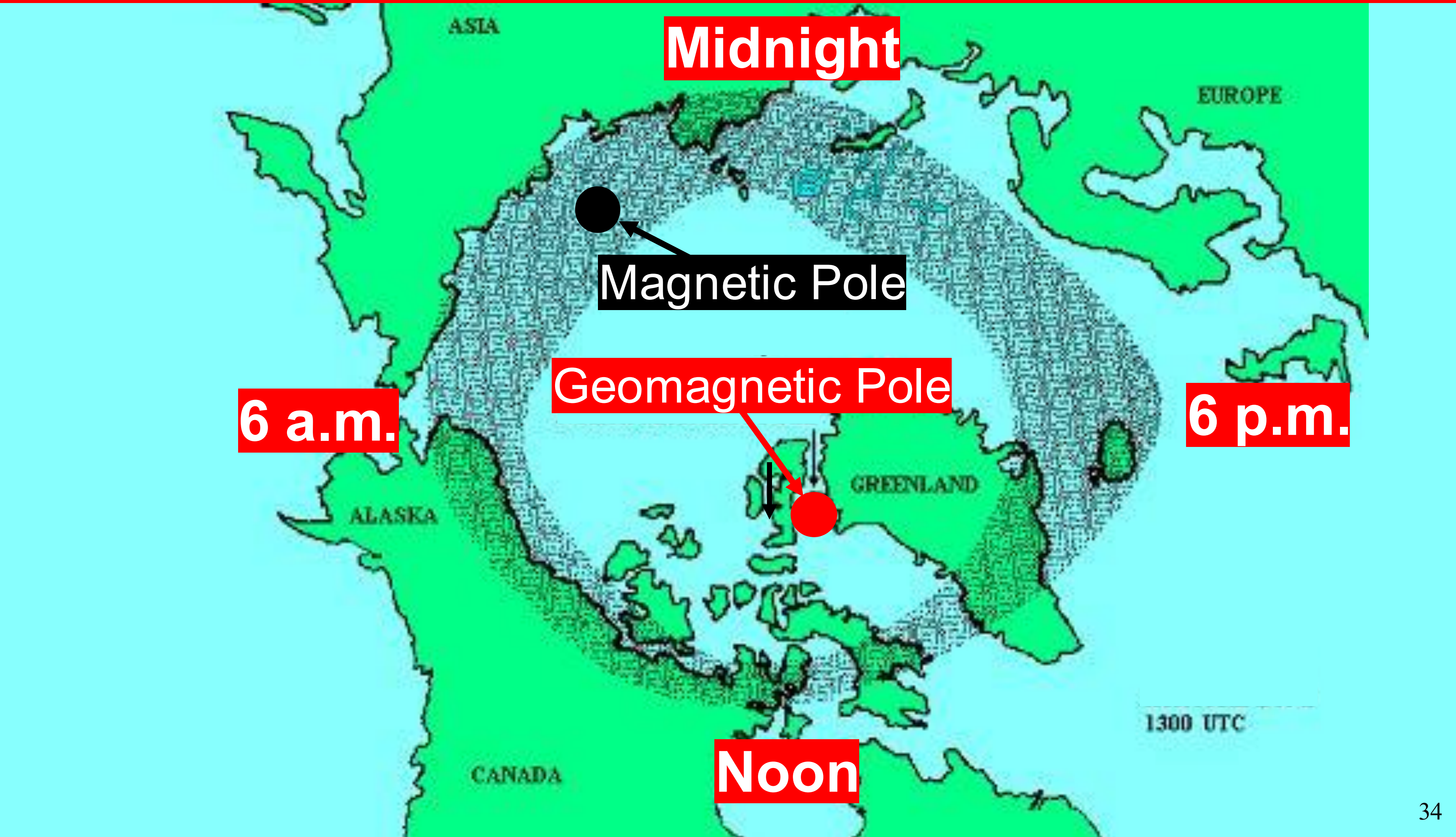
Aurora occurs much more frequently during the solar maximum and declining phases of each solar cycle

Aurora occurs about twice as often during spring and fall than during summer and winter



Position and Width of the Auroral Oval During Quiet Geomagnetic Conditions

Planetary Kp index = 0, 1 or 2



Increased Absorption in the Auroral Oval Caused when Geomagnetic Storms Occur After Midnight

The nighttime auroral oval moves equator-wards and its width expands during geomagnetic storms:

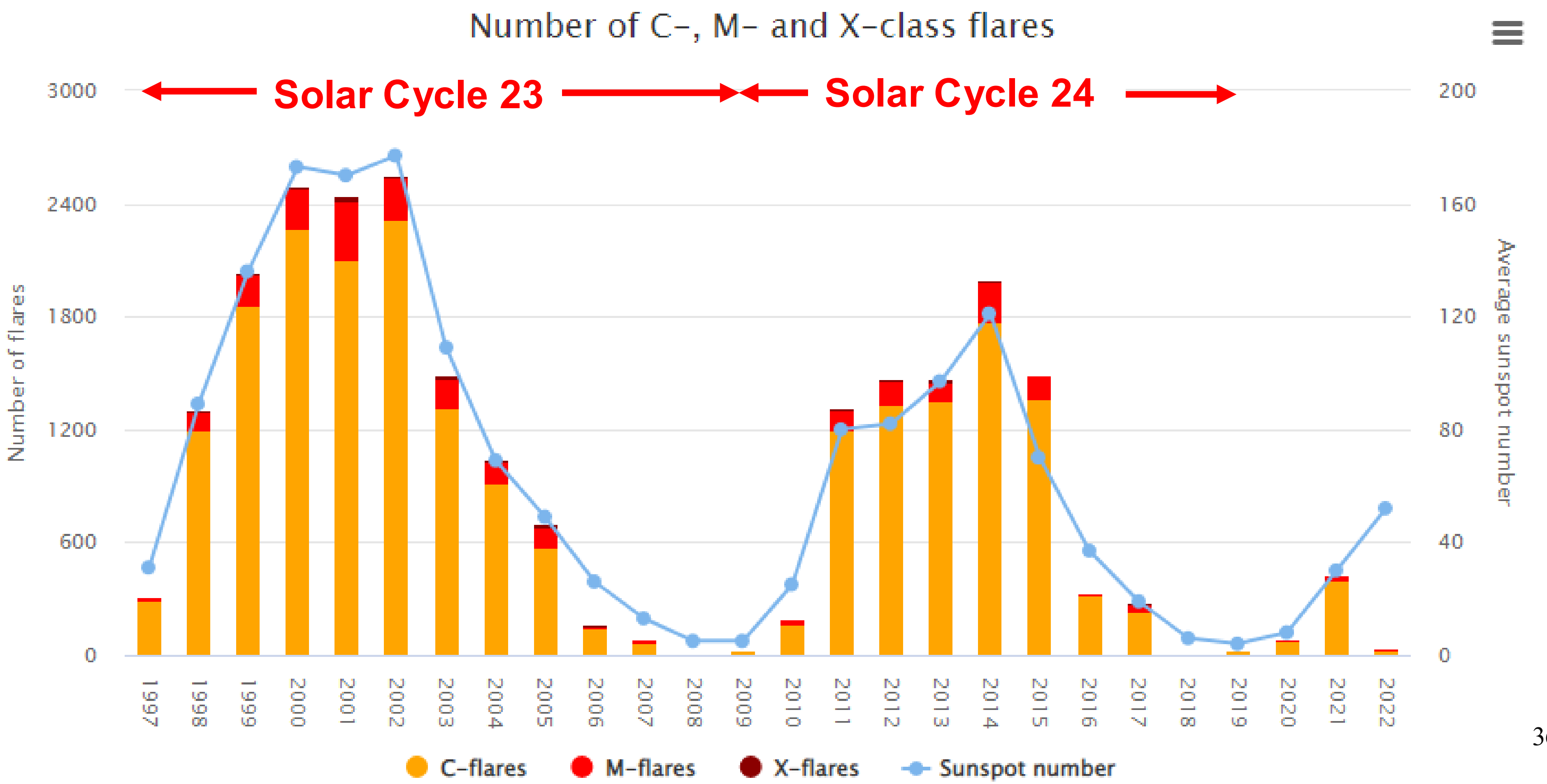
- enhanced solar wind during geomagnetic storms pulls the Earth's nightside open magnetic field lines further toward the equator
- which shifts the nighttime auroral oval closer to the northern U.S. border during the hours near midnight

Enhanced absorption in the auroral oval caused by geomagnetic storms begins at about midnight local solar time at propagation reflection points in the auroral oval

Normal daytime D region absorption caused by ionizing solar radiation is almost always stronger than auroral absorption caused by geomagnetic storms after sunrise at the propagation reflection points in the auroral oval

Varying Frequency of C, M and X-Class Solar Flares During Solar Cycle 23 and 24

More than 2000 M-class flares and less than 200 X-class flares occurred during Solar Cycle 24



Daytime HF Ionosphere Propagation Blackouts Caused by Solar Flares

Radio blackouts affect *only* propagation that crosses daylight regions

Hard x-ray radiation from X10-class solar flares increases the ionization of the D region by one or two orders of magnitude, causing dramatically increased or near total absorption of HF ionospheric propagation below 30 MHz

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

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

Reduced absorption begins at higher frequencies first

X-Class Solar Flares
Cause the Most Severe and Long Lasting Blackouts

X20-class **fewer than one event per solar cycle lasting several hours**
Completely blacks out HF propagation on the entire sunlit side of the Earth
- occurs only during the most active 2-3 years of the solar maximum phase

X10-class **8 events (8 days) per solar cycle lasting one or two hours**
Blacks out HF propagation on most of the sunlit side of the Earth
- X10 and X20 class solar flares also cause polar cap absorption

X1-class **175 events (140 days) per solar cycle lasting about an hour**
Briefly blacks out high latitude HF propagation on the sunlit side of the Earth

M5-Class **350 events (300 days) per cycle lasting tens of minutes**
Possibly blacks out high latitude HF propagation on the sunlit side of the Earth

M1-class **2000 events (950 days) per solar cycle lasting a few minutes**
Briefly degraded high latitude HF propagation on the sunlit side of the Earth

High Level Overview of HF Propagation During the Declining Phase Solar Cycle 25

- Solar maximum propagation conditions began in Dec 2022 and continued into mid 2026
- Almost daily 10 meter DX propagation ended in April 2026
- 15 meter worldwide propagation will frequently persist well into the night until at least April 2027
- 20 meter DX propagation will often persist throughout most of the night through 2027
- 40 meter DX propagation will frequently persist throughout the night through 2028
- Minor geomagnetic storms continue to occur frequently as large equatorial coronal holes occur frequently through 2027
- Sunspot activity will steadily decline until solar minimum conditions begin to dominate propagation by 2029

What HF Bands Should I Use for Contesting Through Early 2027?

- Each band has unique advantages and disadvantages
- 15 and 10 meters provides daytime worldwide propagation during most days from September through April
  - 10 meters is much 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 reliable nighttime worldwide propagation from October through April especially during the hours near midnight

The Declining Phase of Solar Cycle 25 Supports Shorter, Less Frequent 10 Meter Global Propagation Through 2027

- Frequent global propagation continues through April 2026
  - Many days from September through April
  - Many days of excellent propagation to Europe from shortly after sunrise through late morning or early afternoon
  - Some days to Japan and east Asia after 2130Z for a few hours or less

- Worldwide sporadic-E propagation between northern hemisphere locations during many days from mid-May through early August
  – Sporadic-E is the often dominant 10 meter propagation mode from mid-May to early August

The Declining Phase of Solar Cycle 25 Supports 15 Meter Global Propagation Through 2028

- Global propagation continues through 2028
  - Almost every day from September through May
  - Excellent propagation to Europe from sunrise or before until early to mid-afternoon
  - Many days to Japan and east Asia after 2130Z for several hours
- Global 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 mid-May through early August

The Declining Phase of Solar Cycle 25 Supports 20 Meter Nighttime Global Propagation Through 2028

- Worldwide nighttime propagation continues through 2028
  - 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 often switches to 17, 15 and 10 meters shortly after our sunrise
- Propagation to Japan and east Asia is strongest for several hours after 2130Z, weaker throughout about midnight then improves for several hours after local USA sunrise
- 20 meter DX propagation within a few hours of local noon is always very poor from June through August because of E region and sporadic-E blanketing of F2 region propagation

The Declining Phase of Solar Cycle 25 Supports Early Evening and Nighttime 40 Meter Global Propagation Through 2028

- Global propagation throughout the night continues to be reliable through 2028
  - 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 best around European sunrise (0600-0800Z)
- Mid-afternoon propagation to Europe gradually improves although most DX activity remains on the higher bands
- Propagation from east coast USA to Japan and east Asia starts at sunset in Japan (about 0830Z) until about 30 minutes after local USA sunrise

The Declining Phase of Solar Cycle 25 Gradually Improves 80 Meter Worldwide Propagation After 2026

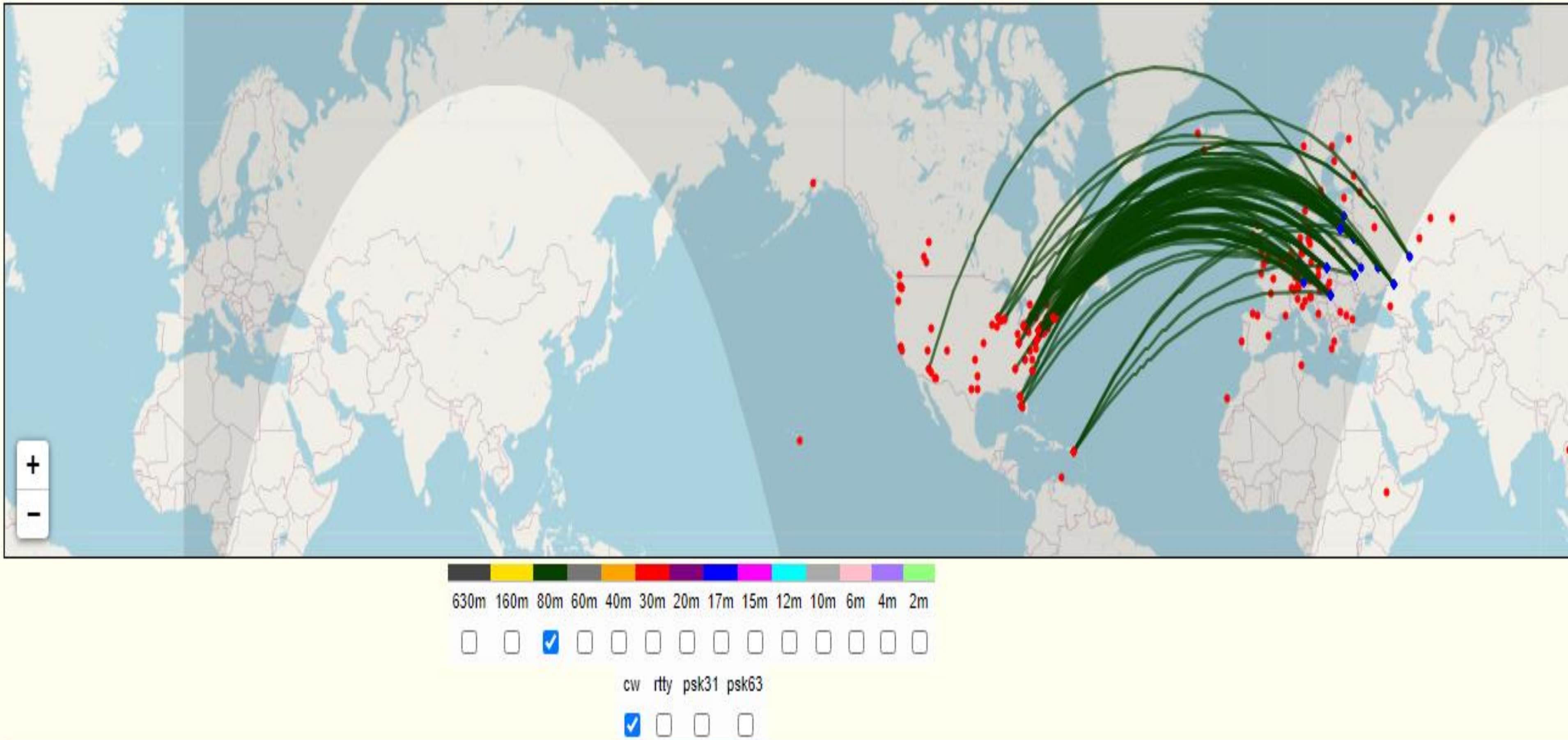
- 80 meter DX propagation will be longer in duration after 2026
  - weak and less reliable DX propagation begins at USA sunset
  - stronger European propagation usually starts a few hours after local USA sunset
  - the greatest European activity is often during a few hours after USA sunset and near European sunrise at 0600-0800Z
    - most Europeans shift their operating to higher frequency bands at or before their sunrise
  - 80 meter global propagation will steadily improve after 2026

The Declining Phase of Solar Cycle 25 Slowly Improves 160 Meter Worldwide Propagation After 2027

- 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 2027

Nowcasting using the Reverse Beacon Network

80 Meters European CW CQs heard in North America 0500Z

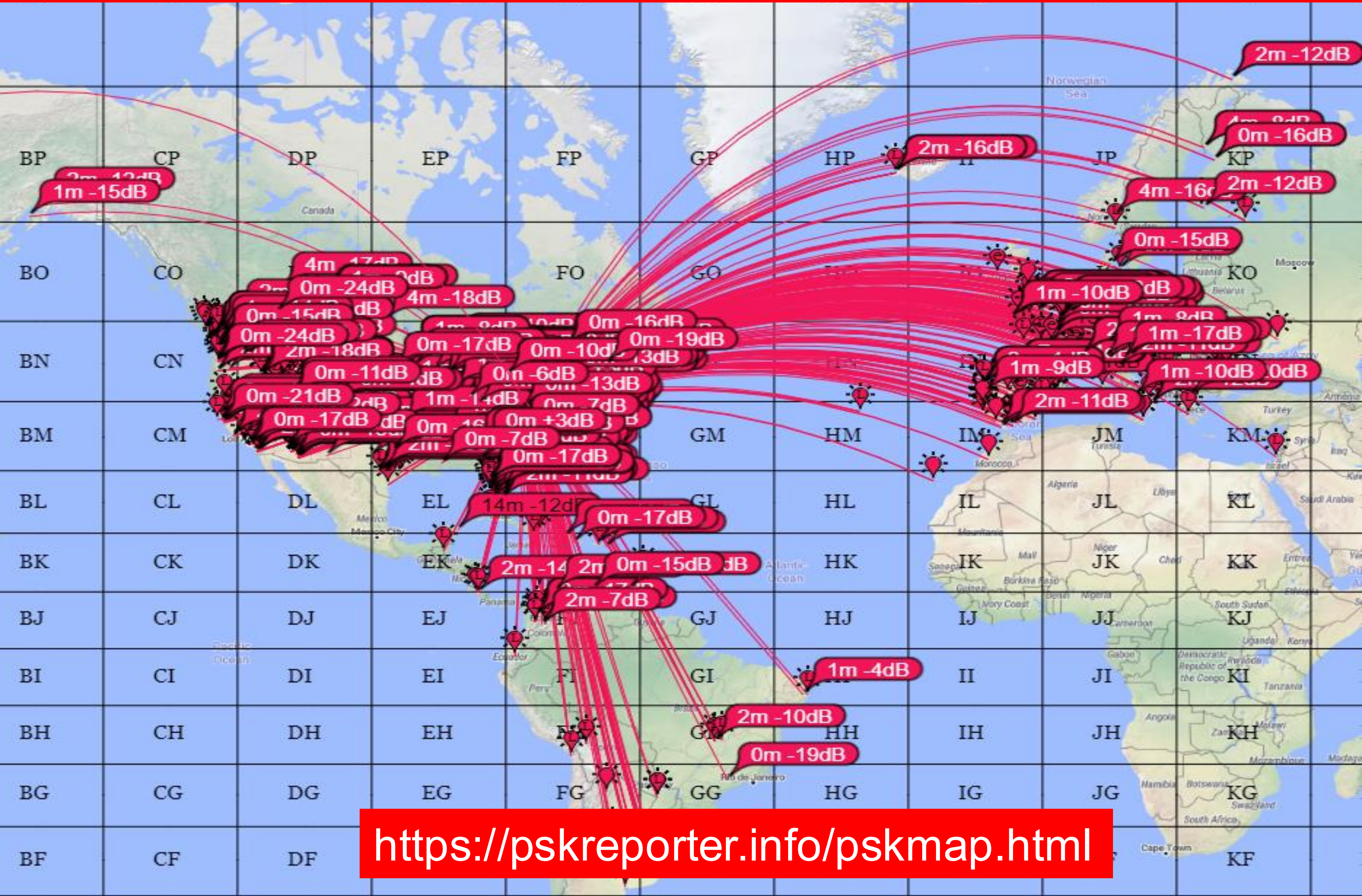


	● Spotter (de)	● Spotted (dx)
callsign	spotter-callsign	spotted-callsign[,spotted-callsign]
dxcc	any	any
itu zone	any	any
cq zone	any	any
continent	NA - North America	EU - Europe

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

Nowcasting using PSK Reporter

20 Meters Worldwide FT8 heard in North America 2200Z



https://pskreporter.info/pskmap.html