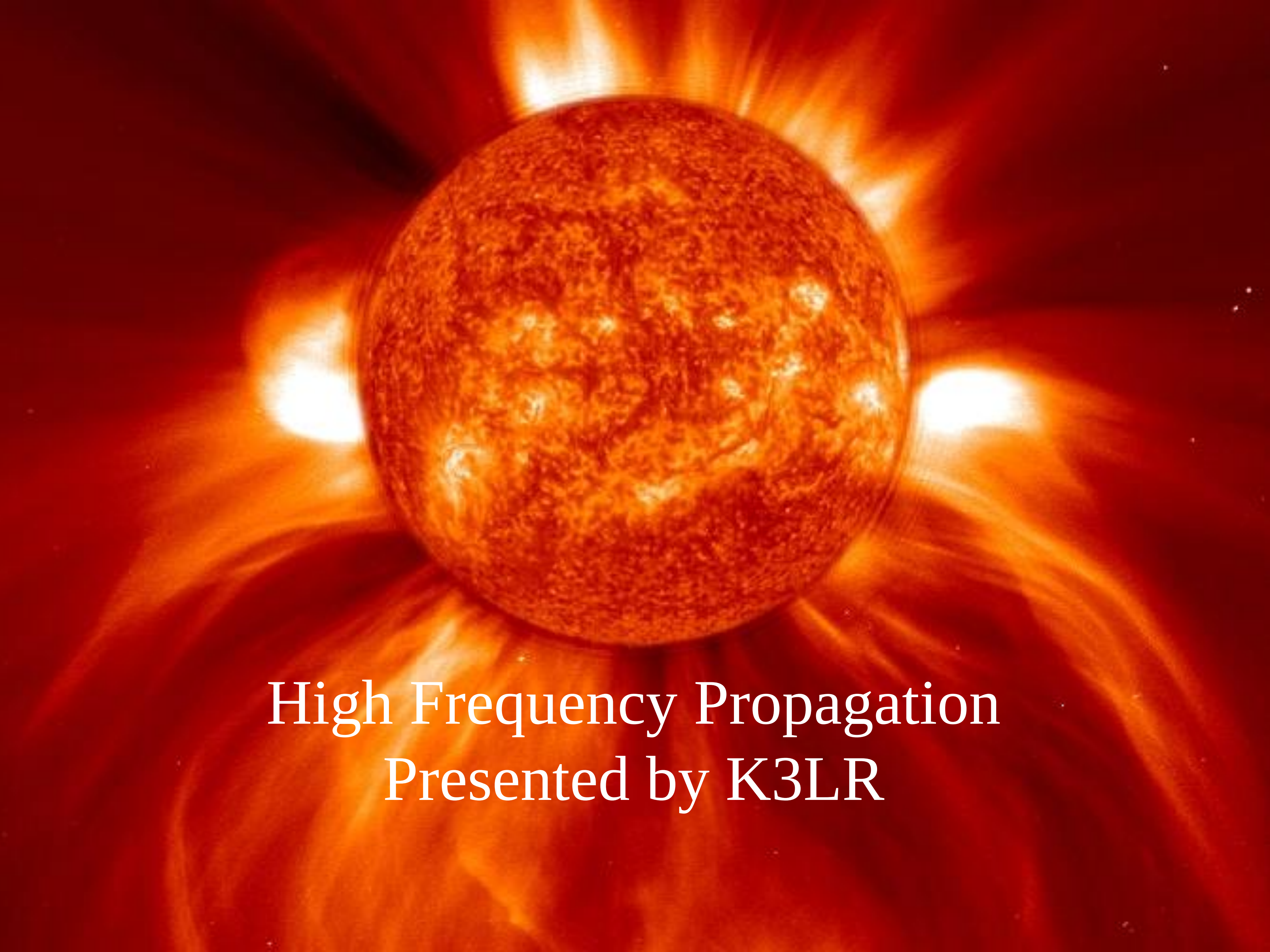
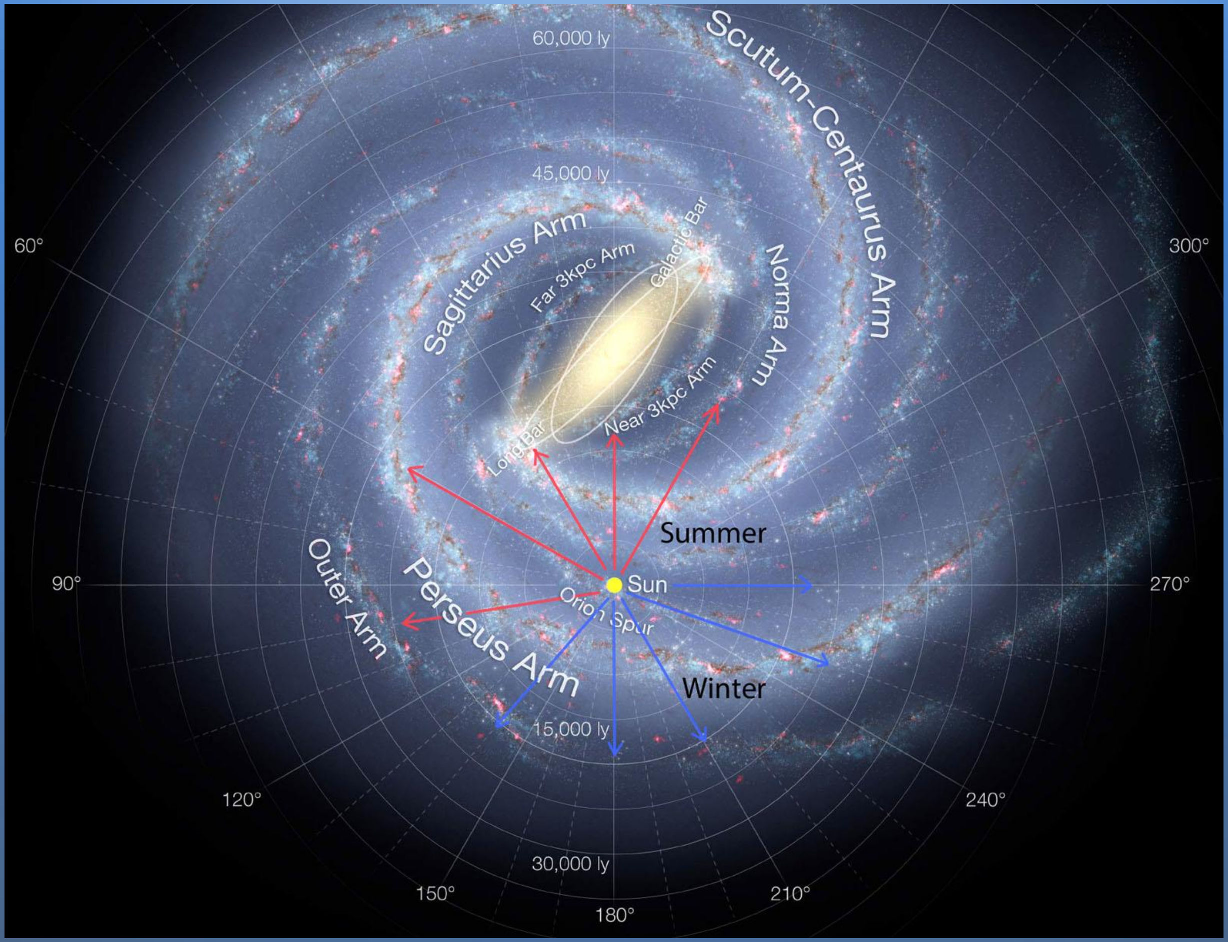


High Frequency Propagation

Presented by K3LR

The Sun's Place in our Galaxy

Our Sun is just one of hundreds of billions of stars in the Milky Way



Our Sun resides about 28,000 light years from the super massive black hole at the Milky Way's galactic center

Overview of Propagation-Related Solar Effects

- Sunspots

  More sunspots during the sunspot peak improve 15, 12, 10 and 6 meter propagation especially from October through May

- Sunspot cycles vary in length from 9 to 14 years
  - Some cycles have longer lasting, more energetic maximums
  - Some cycles have longer lasting, deeper minimums
- Fast moving electromagnetic radiation from solar flares

  Ultraviolet radiation and X-rays arrive at Earth in only 8 minutes

- Particle emissions from coronal holes, solar flares and CMEs

  Energetic charged particles pulled into the Earth's polar regions by its magnetic field cause geomagnetic storms and aurora

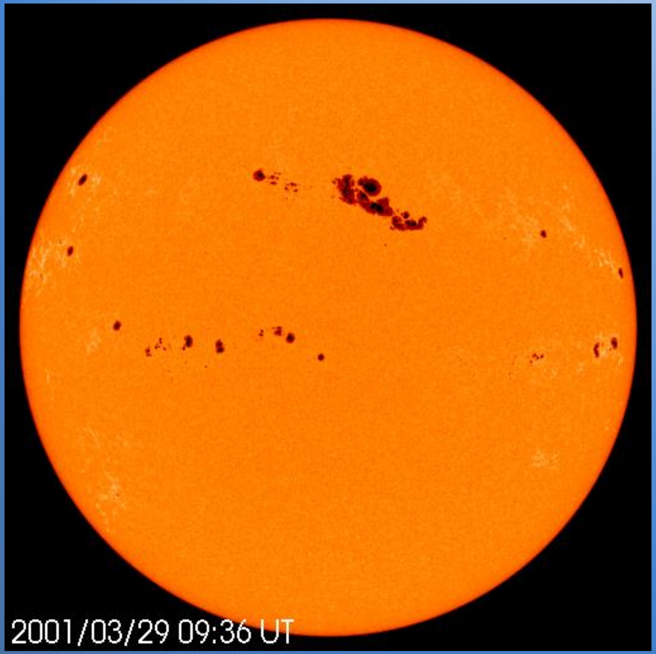
- Solar rotation causes repetitive and predictable solar events

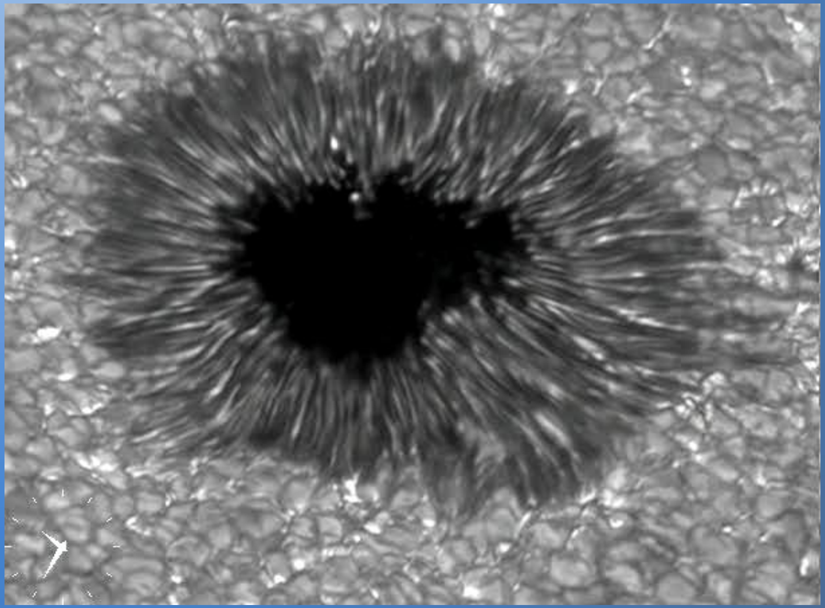
  Full rotation takes approximately 27 days

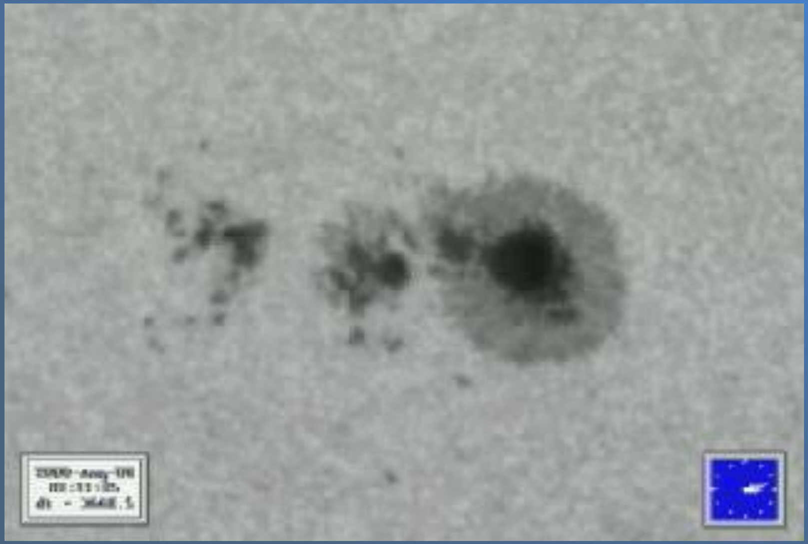
- Seasonal variations on Earth caused by its 23.5 degree tilt
  - The Earth's tilt varies the total amount of solar radiation received, especially in the Earth's polar regions
- Total solar radiation on Earth: 1.361 kilowatts per square meter

Sunspots and
the Sunspot Cycle

Sunspots







Sunspots are regions of strong magnetic fields

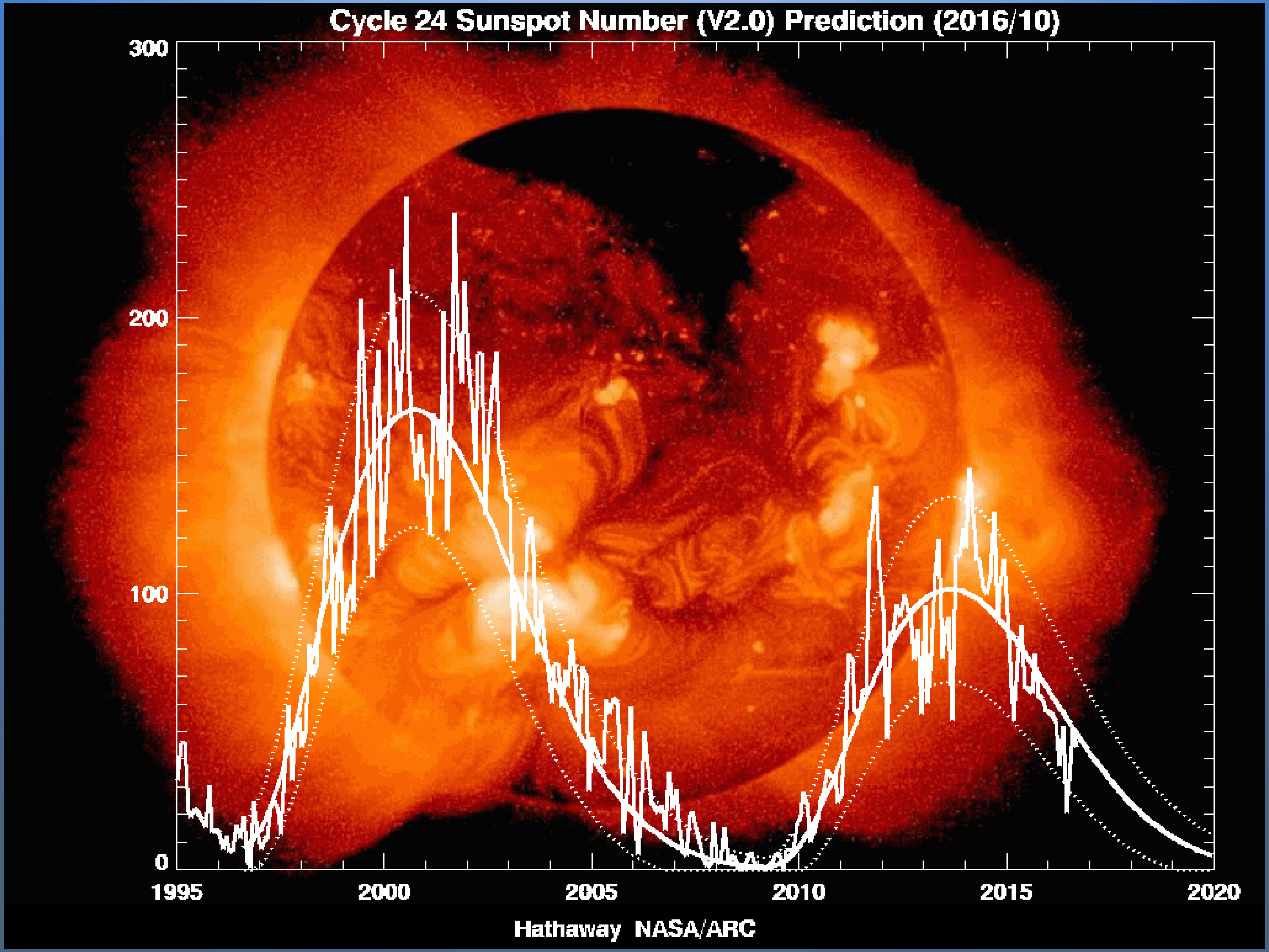
They appear dark because they are cooler than the surface

The Sunspot Number

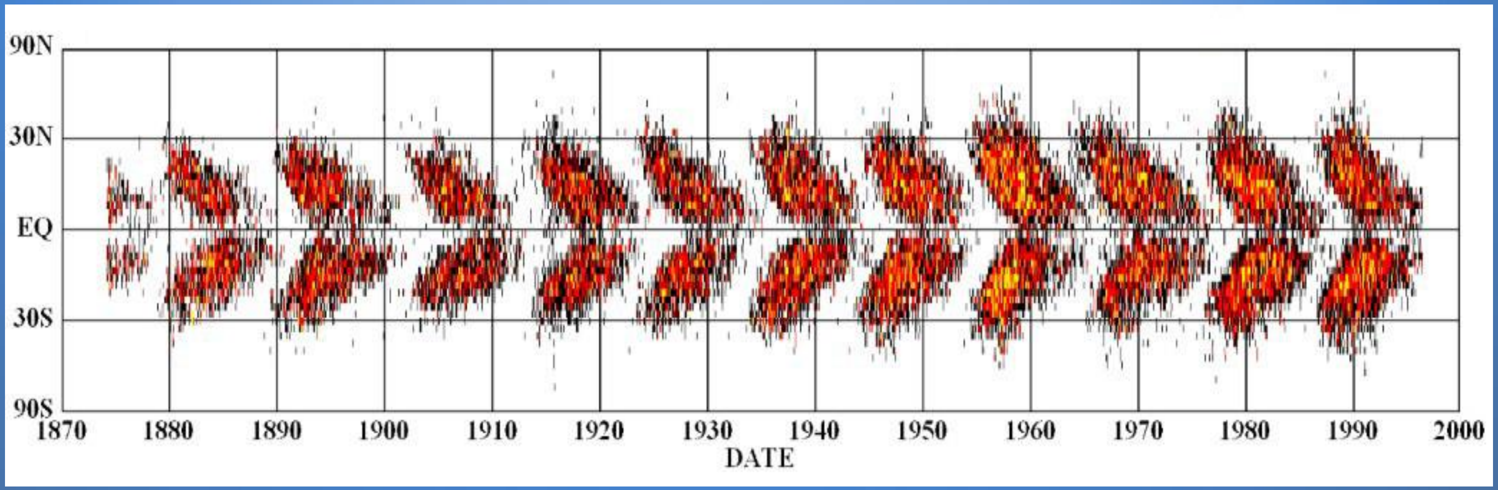
- The oldest measure of solar activity
- Continuous records since the early 19th century
- Computed by multiplying the number of observed sunspot groups by 10 and adding the number of individual spots observed
- Because the sun rotates and different areas of the sun are visible each day, average sunspot numbers are normally used
- The lowest possible sunspot number is 0
- Higher sunspot numbers equate to more solar activity
- The largest annual average sunspot number of 190.2 occurred in 1957

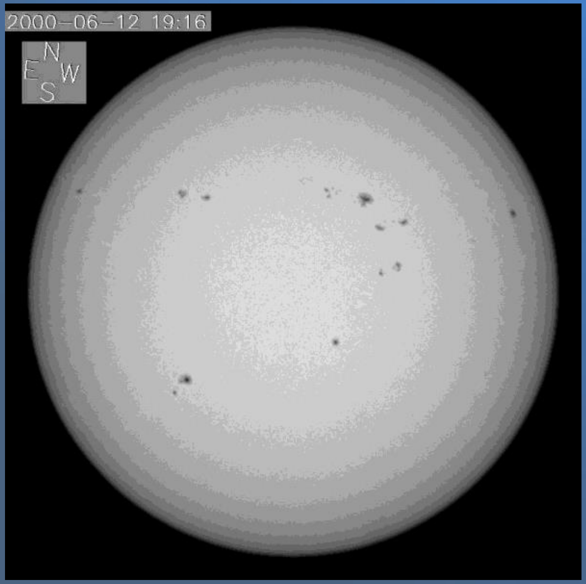
The 11 Year Sunspot Cycle

Actual solar cycle length varies from 9 to 14 years



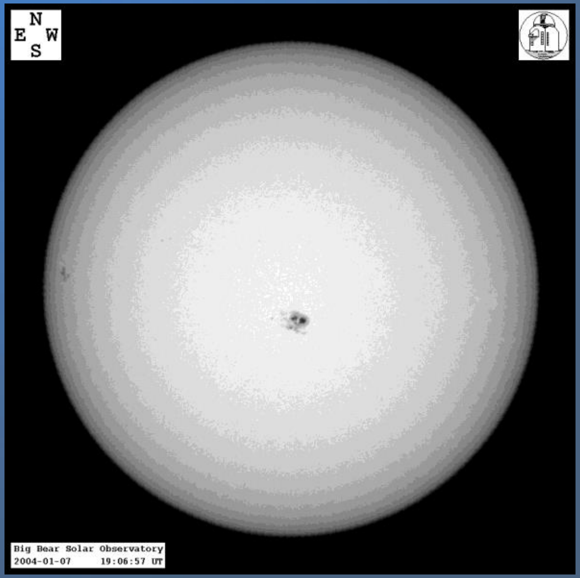
Sunspots appear at different latitudes throughout the solar cycle





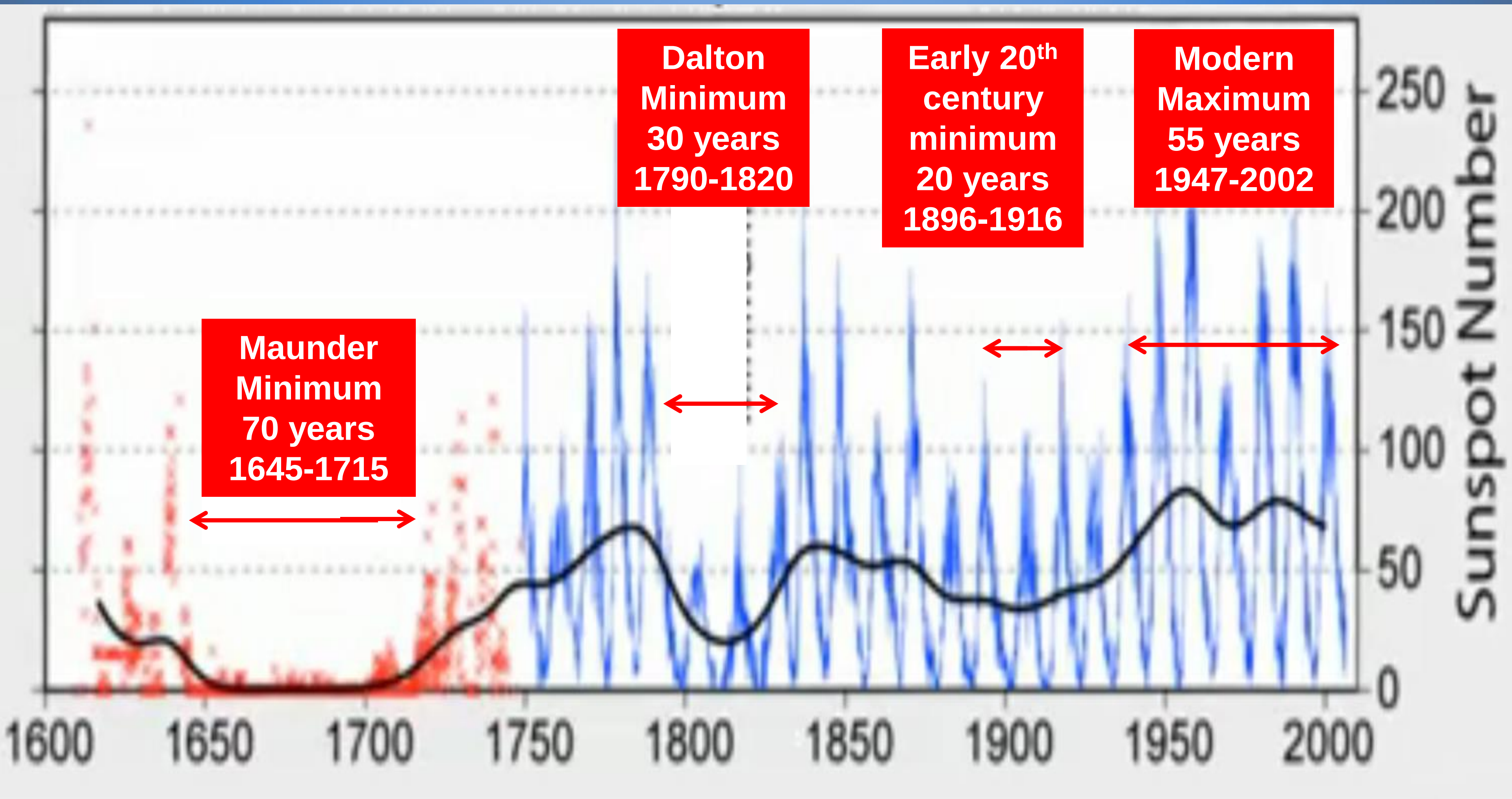
June 12, 2000

Jan 7, 2004

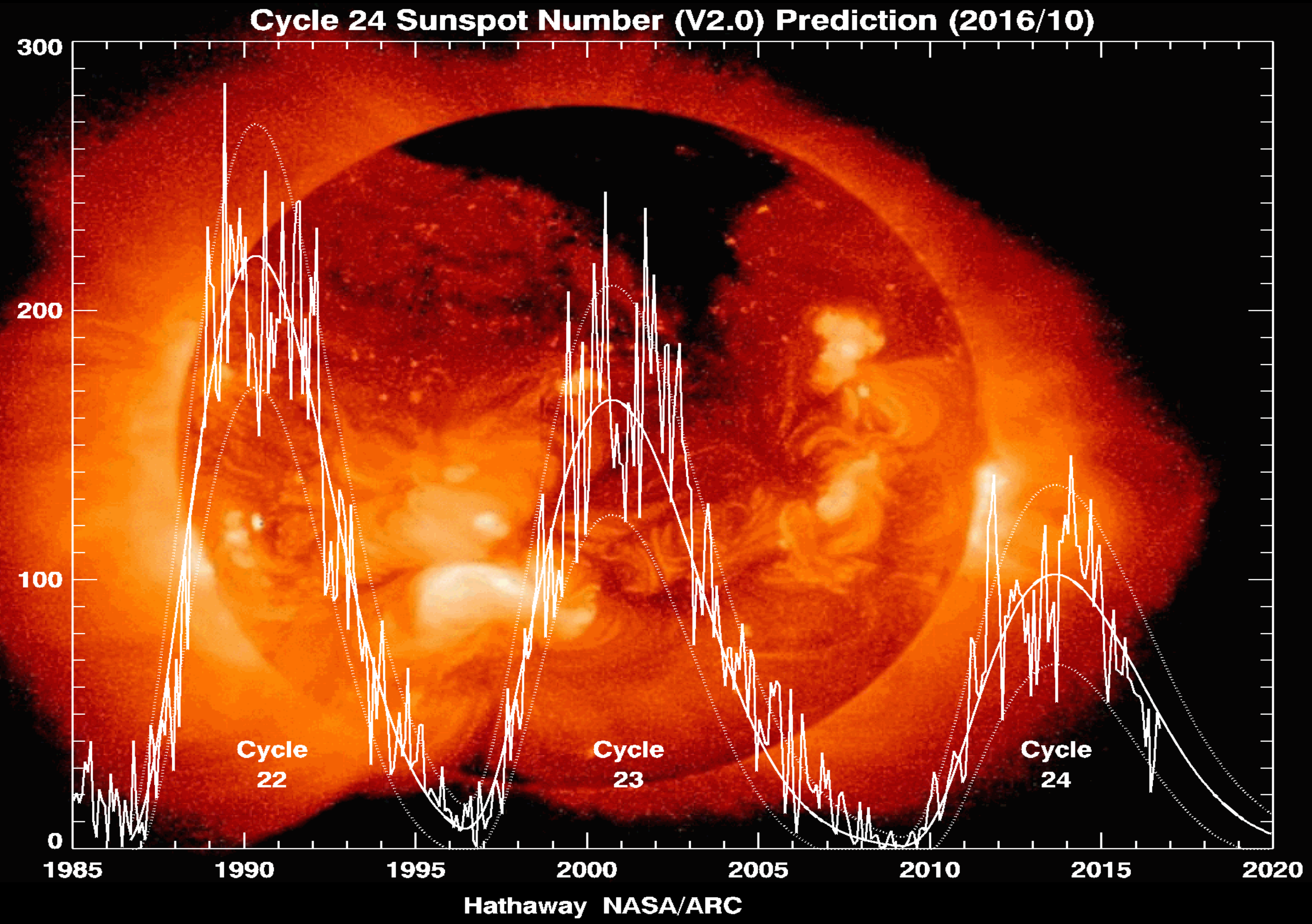


400 Years of Sunspot Observations

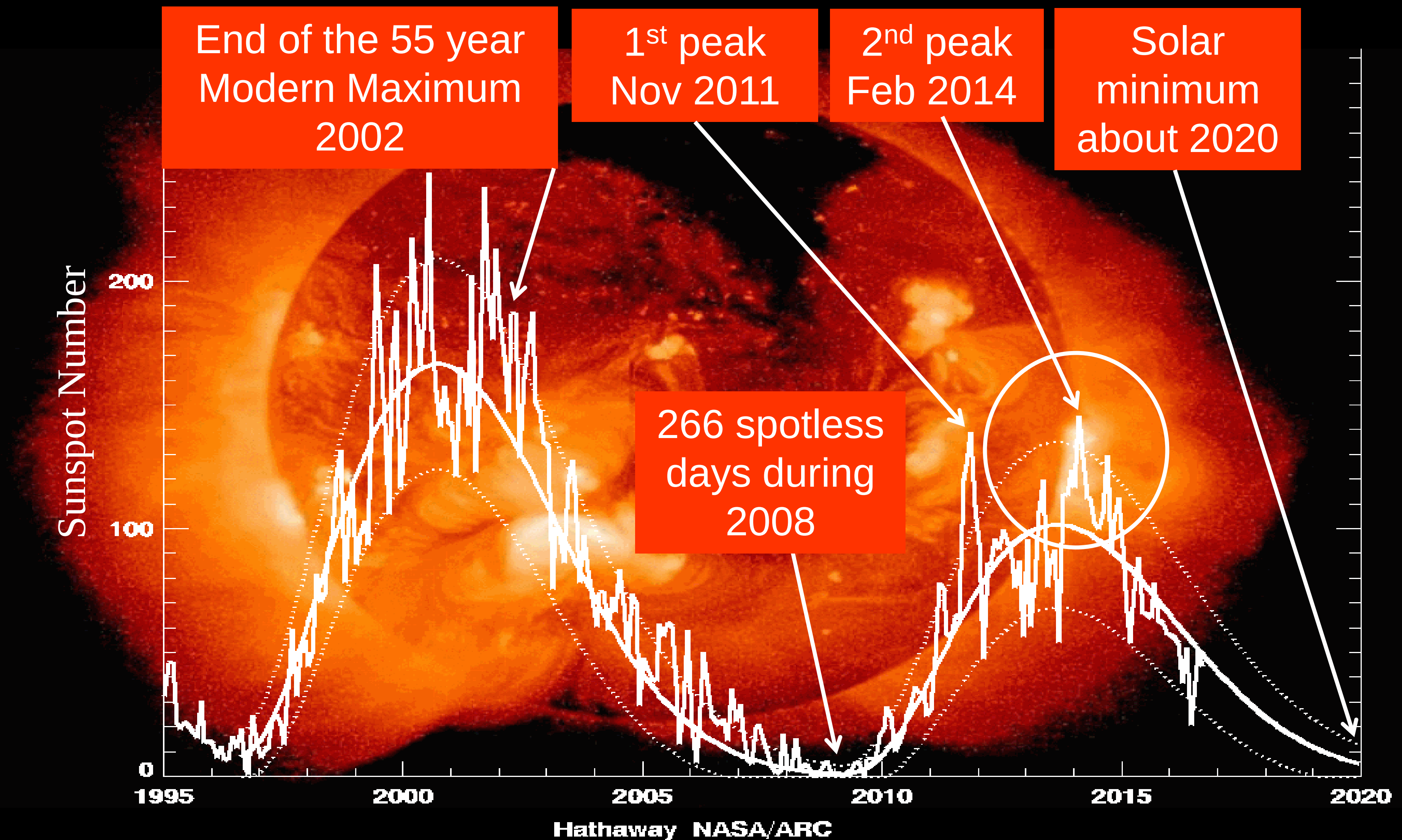
55 years of unusually high sunspot activity
1947 - 2002
ended with the decline of Solar Cycle 23 in 2002



Steadily Weakening Sunspot Activity Since Solar Cycle 22



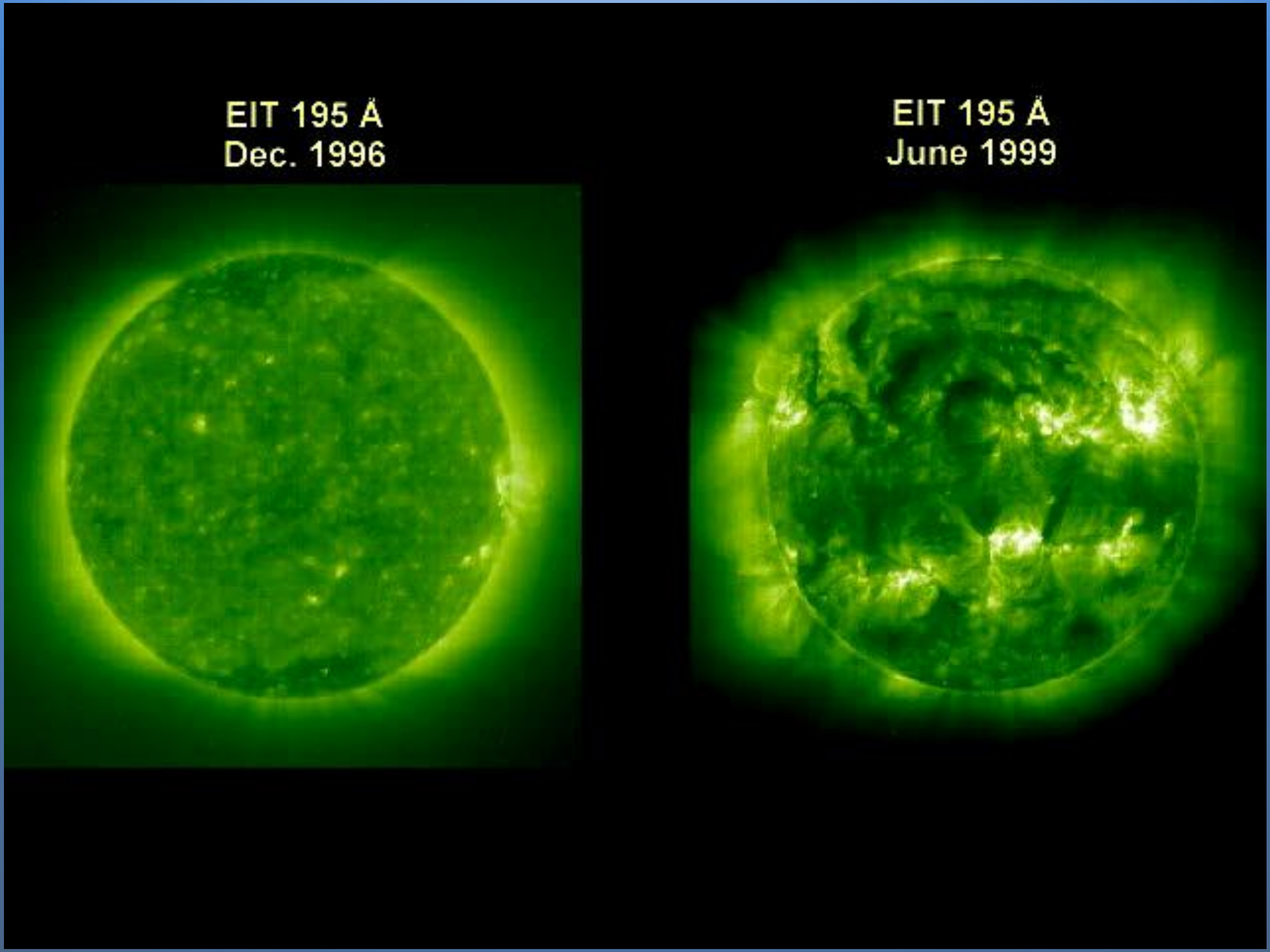
Solar Cycle Progress
Since the Solar Cycle 23 Maximum



Solar Radiation and Emissions

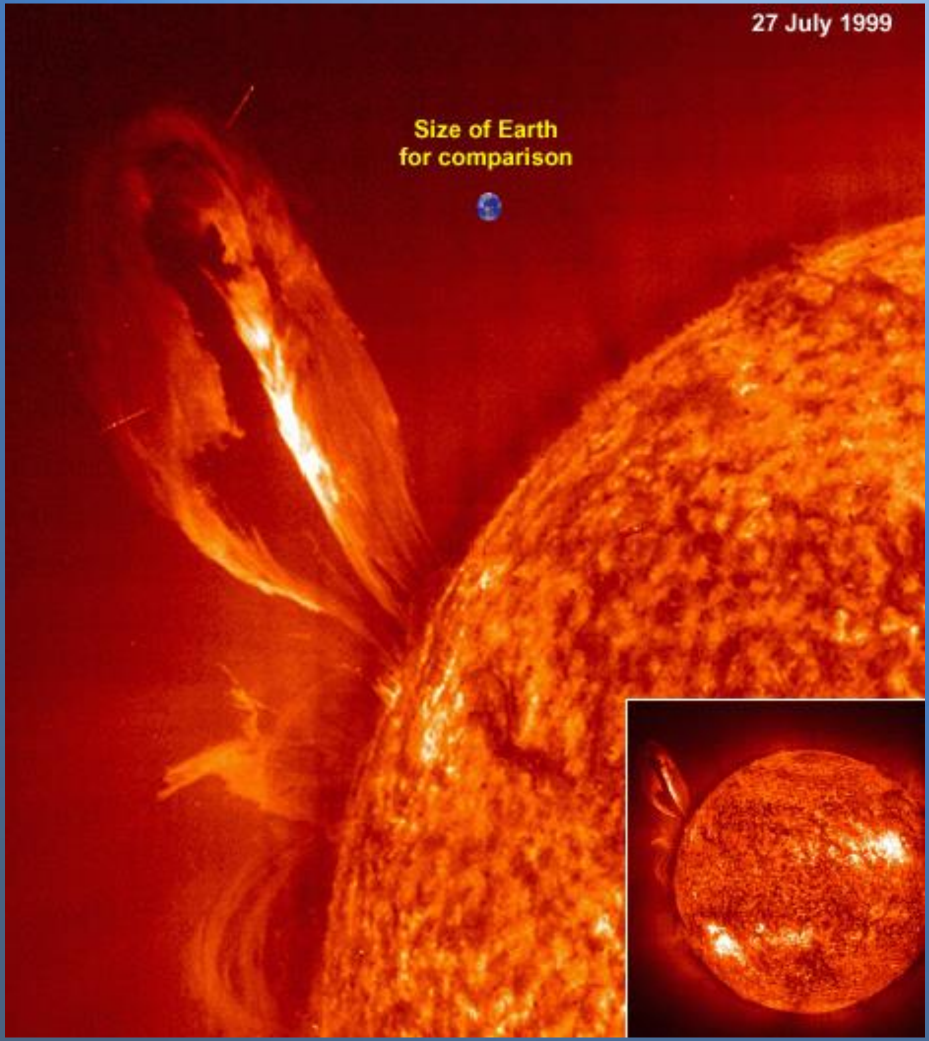
Solar wind
Coronal holes
Solar flares
Coronal mass ejections (CMEs)

The Quiet and Active Sun



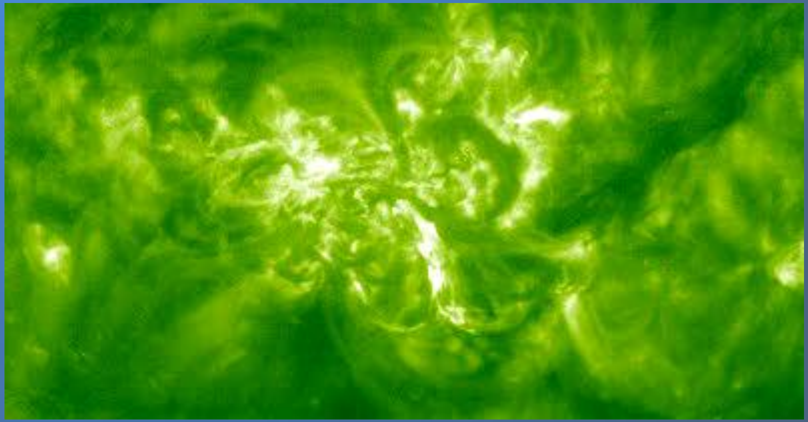
Major changes in solar activity over just a three year span

Solar Eruptions



Solar prominence dwarfs Earth in size

Eruptions are common during periods of high solar activity

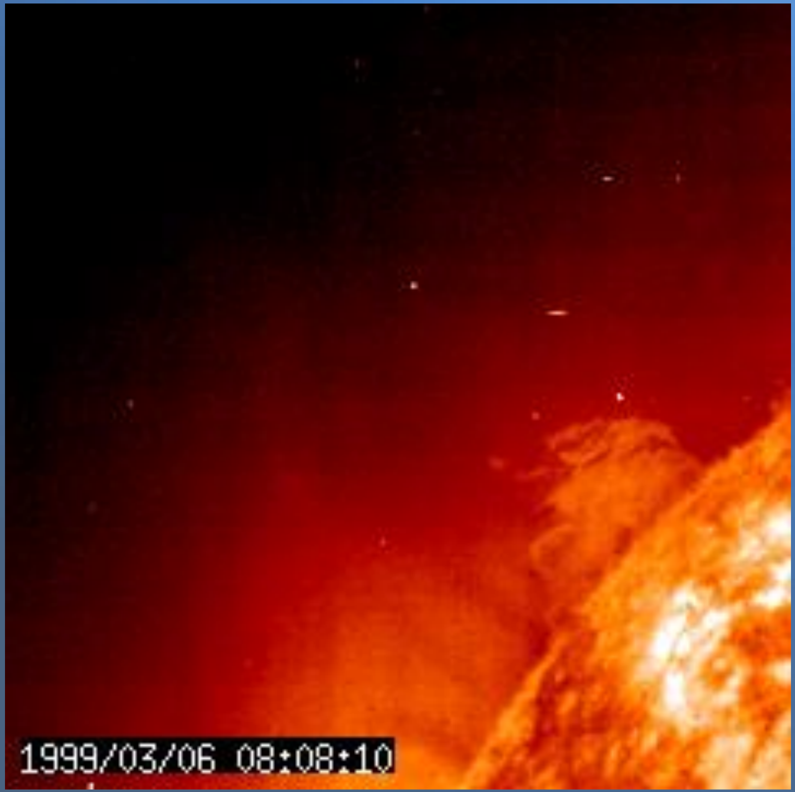


Huge flare of 28 October 2003

Solar Flares

massive explosions on the Sun's surface

In just a few minutes they heat solar gasses to millions of degrees Fahrenheit and release as much energy as billions of megatons of TNT

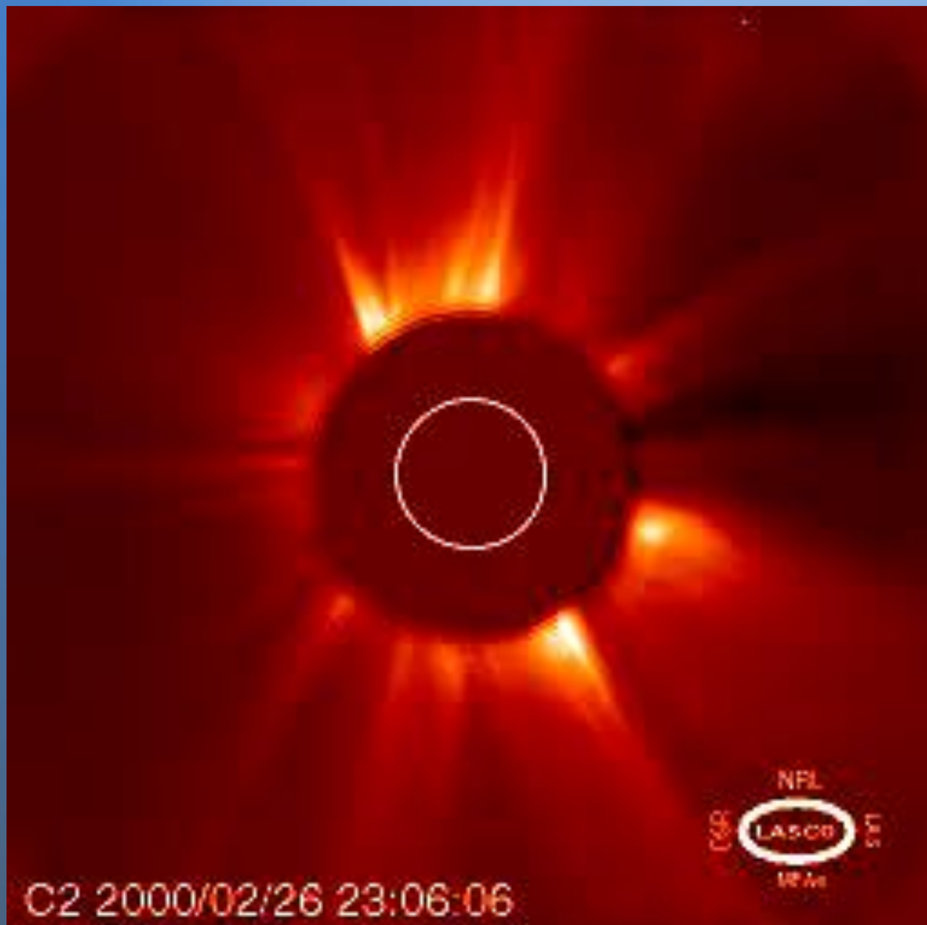


Images from NASA's SOHO Spacecraft

Solar Flares

- A plume of very hot gas ejected from the Sun's surface
- They rise through the chromosphere into the corona, disturbing both regions
- Emits very large quantities energetic protons
- Flares are so hot -- more than a million degrees Fahrenheit – that they also emit lots of x-ray radiation that travels to Earth in only 8 minutes
- Solar flares are very difficult to predict
- Solar flares occur during all phases of the solar cycle

Coronal Mass Ejections
Huge Explosions on the Sun

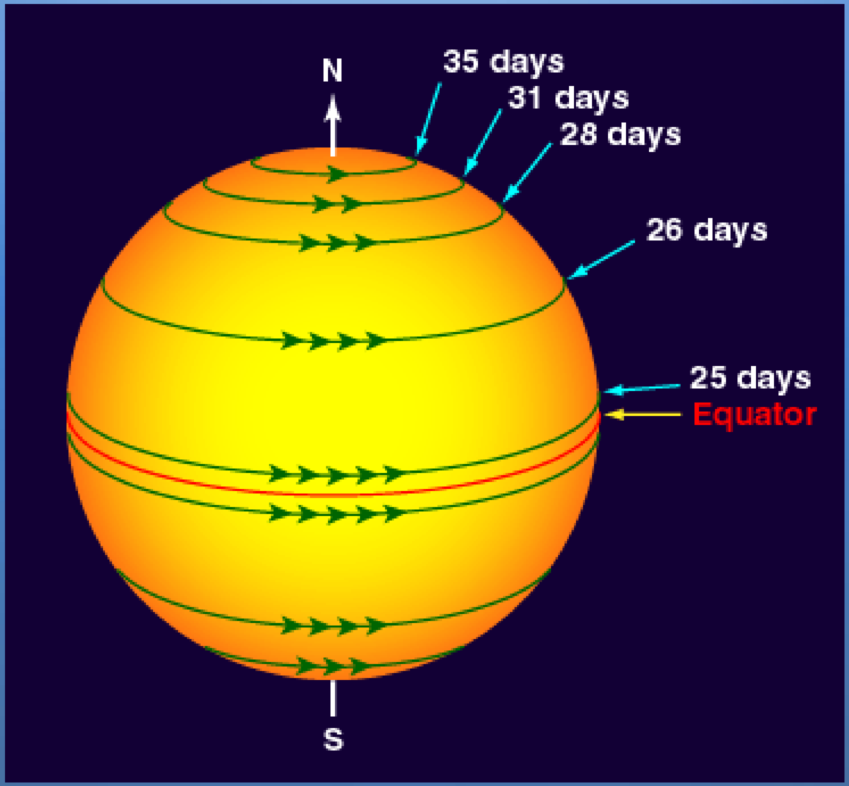


Billions of tons per second of energetic charged particles are launched from the Sun

How solar emissions affect the Earth

27 day Recurrence of Propagation Effects

caused by the Sun's 27 day solar rotation period

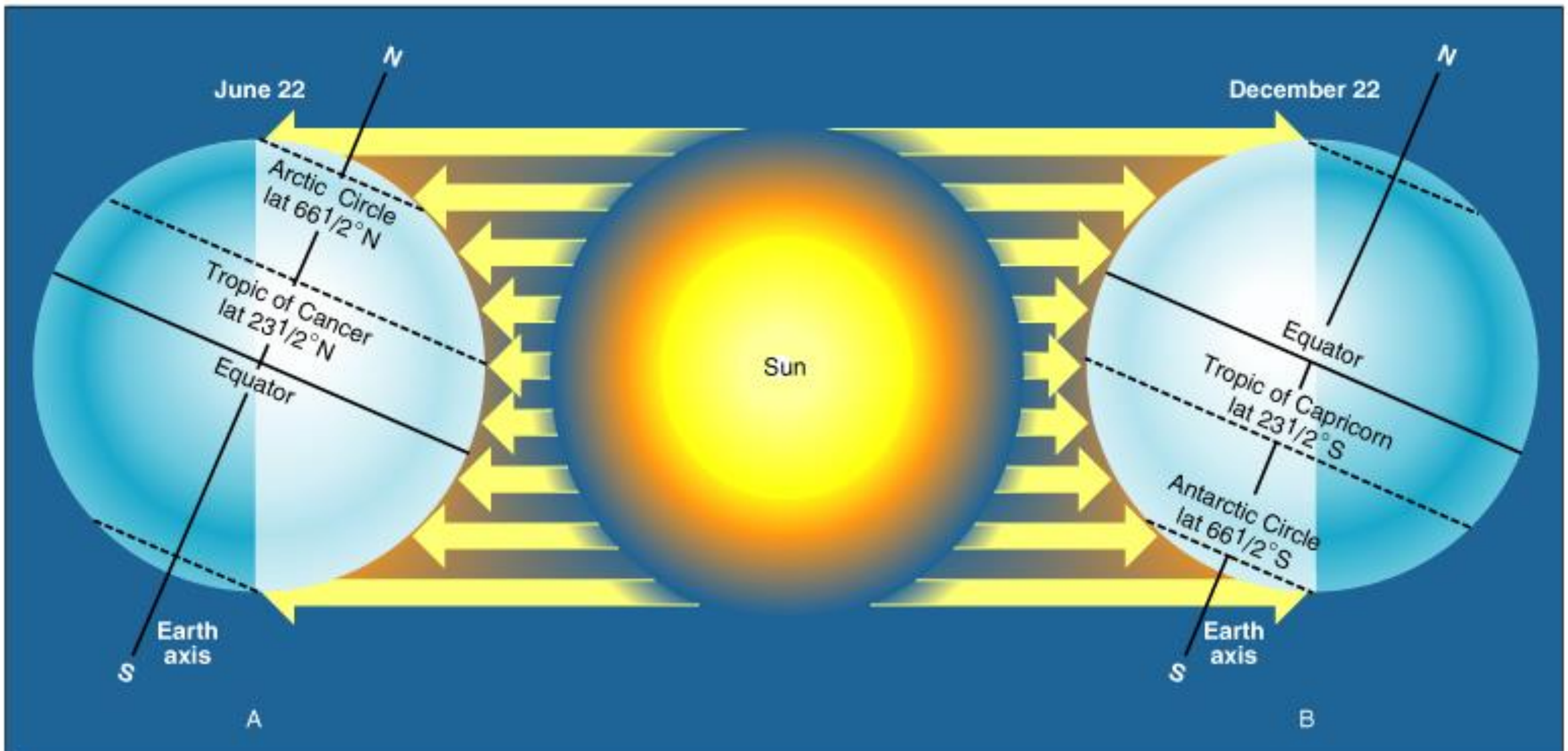


The actual solar rotation period varies significantly with solar latitude

The Sun does not rotate as a rigid sphere like the Earth
Its equator rotates much faster than its high latitude regions

Variability of Received Solar Energy Due to the Tilt of the Earth's Axis

Increased ionization during the Spring and Fall equinoxes
Less frequent and lower intensity geomagnetic storms during the Summer and Winter solstices



Sudden Ionospheric Disturbance (SID)

SIDs occur *only* during daylight hours

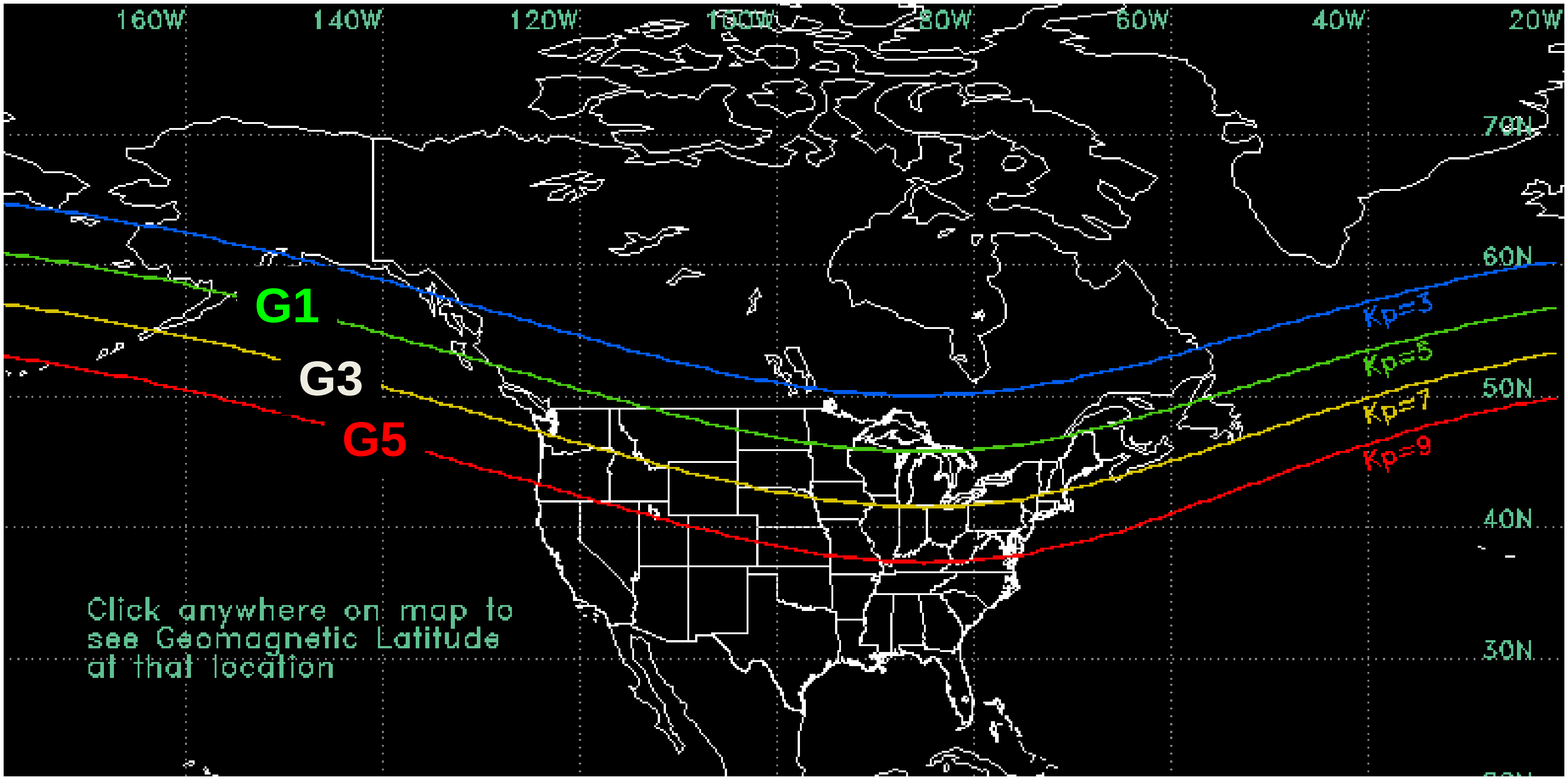
SIDs strongly ionize the D layer causing dramatically increased absorption of signals up to 30 MHz propagated via the ionosphere

Disrupts signals on lower frequencies for a longer duration than on higher frequencies but it can wipe out ionospheric communication on all of the HF bands

Propagation returns to pre-SID levels within about an hour

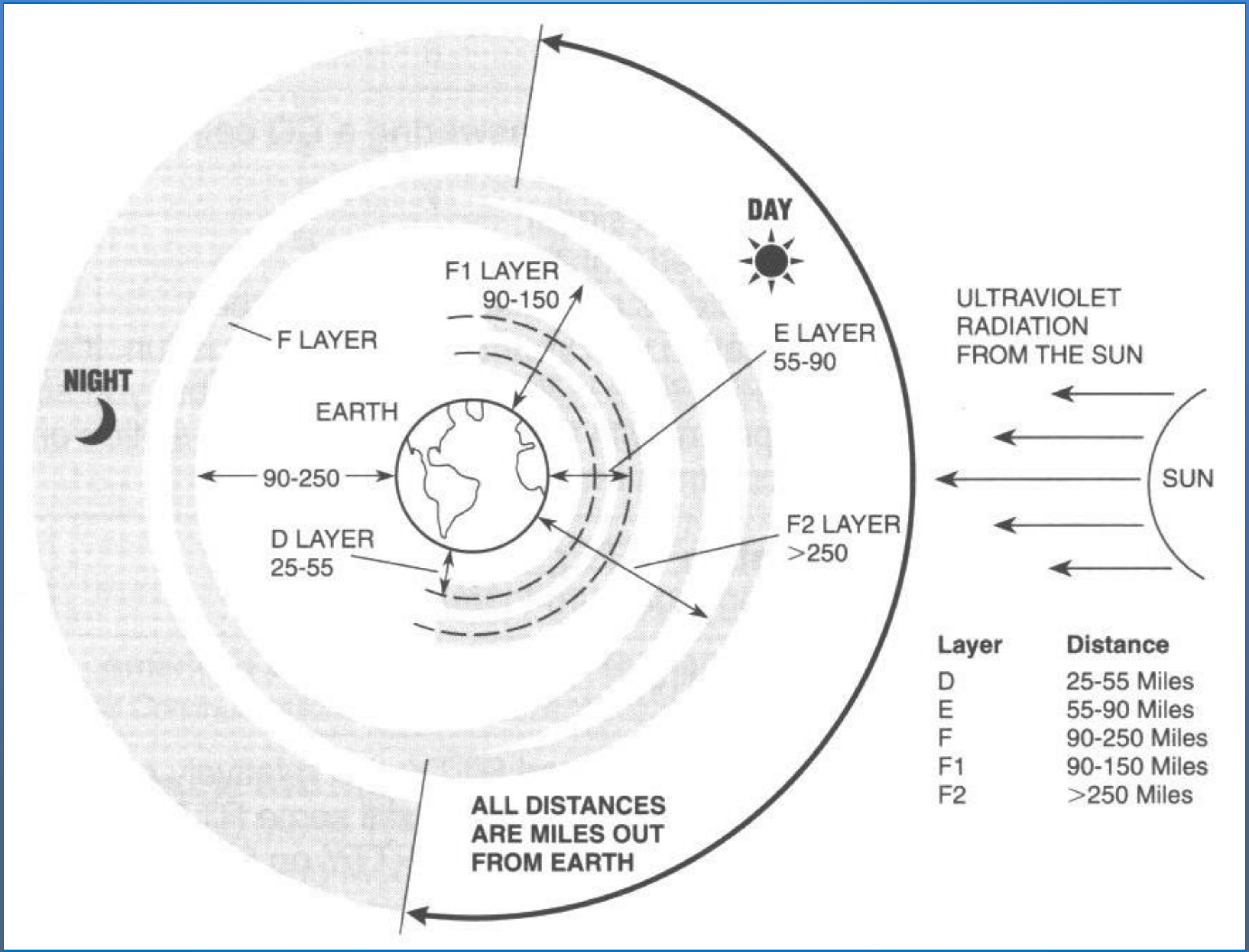
The Aurora

- Intensity and latitude of the aurora depend on the strength of the geomagnetic storm that caused it
- Best time to view the aurora is around midnight in a dark location
- The aurora is rarely visible at mid-Atlantic latitudes

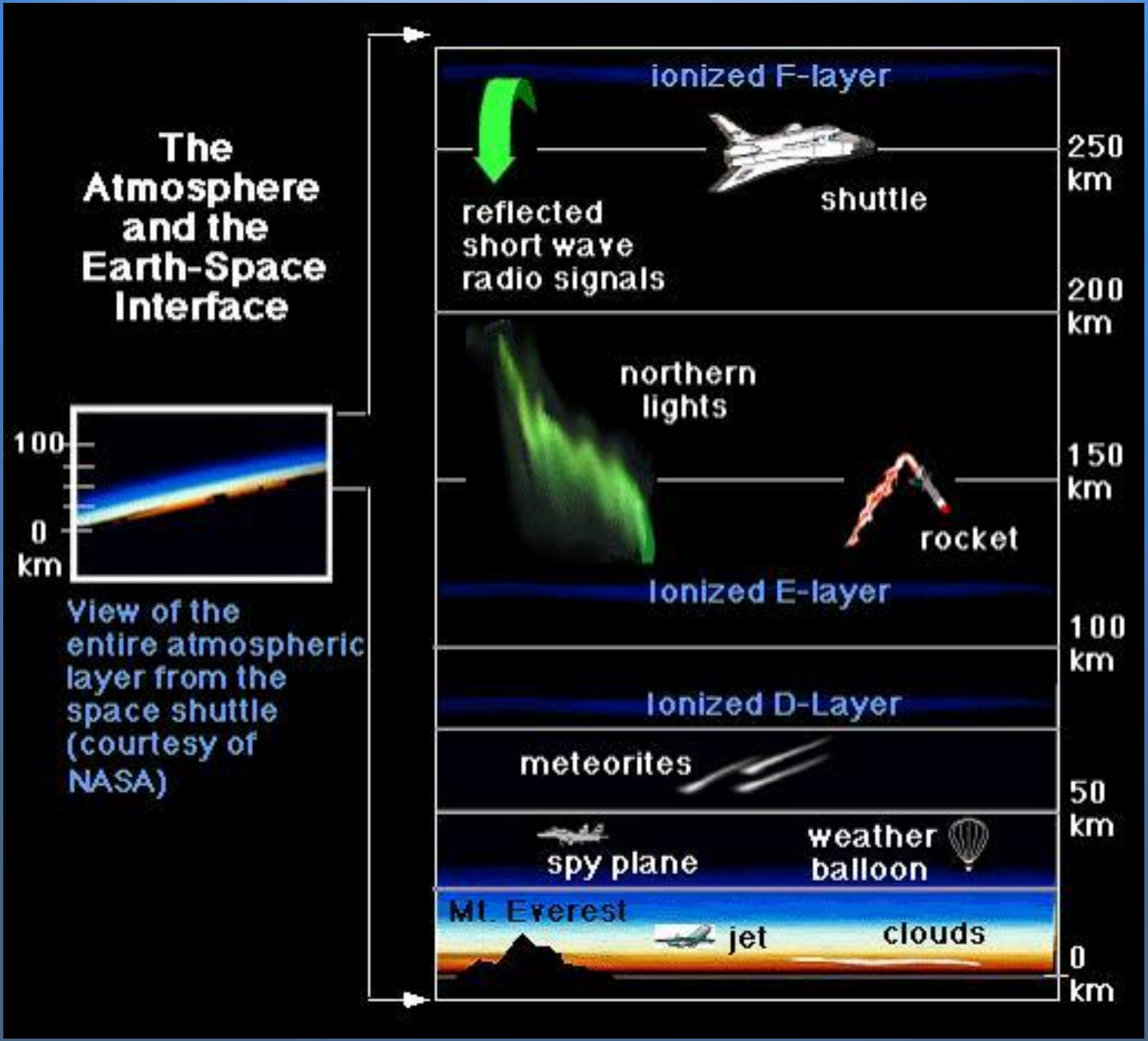


The Ionosphere

The Ionospheric Layers



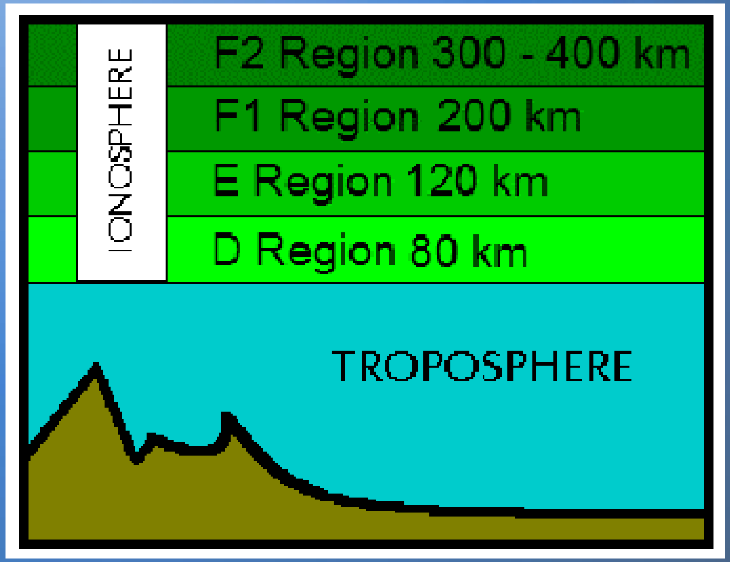
The Ionospheric Layers



D Layer of the Ionosphere

- Strongly absorbs lower HF frequencies during the day
- During daylight hours the D layer absorbs essentially all ionospheric propagation below 4 MHz
- Absorption extends up to 30 MHz during SIDs and intense geomagnetic storms
- The D layer totally disappears at sunset, making reliable worldwide 80 and 160 meter DX propagation possible

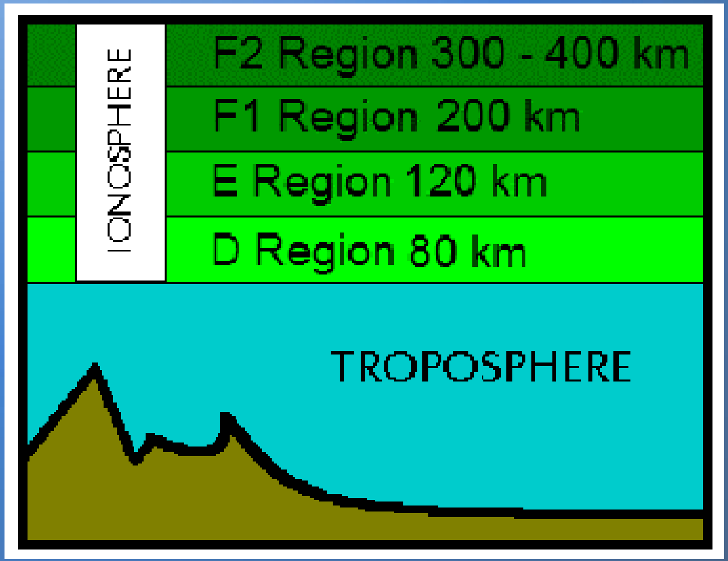
80 km height



E Layer of the Ionosphere

- Densely ionized during the day
- Reliably refracts 40 and 30 meter signals during daylight hours at distances less than 500 miles
- Blankets F layer propagation on 40 and 30 meters during the day
- E layer MUF rapidly drops rapidly after sunset

~ 120 km height

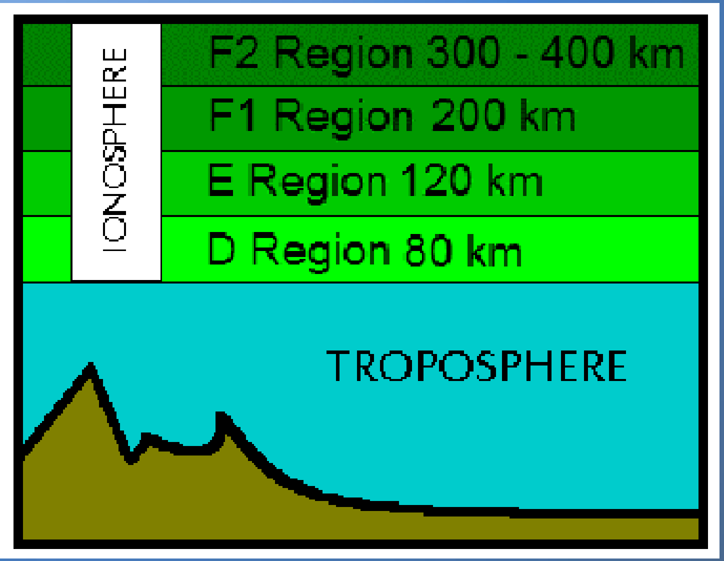


- **Sporadic-E Ionization**
- Thin patches of intense ionization
- Mainly useful for 10, 6 and 2 meter propagation
- Sporadic-E usually lasts a few hours or less
- Very difficult to forecast
- Occurs very frequently during June and July

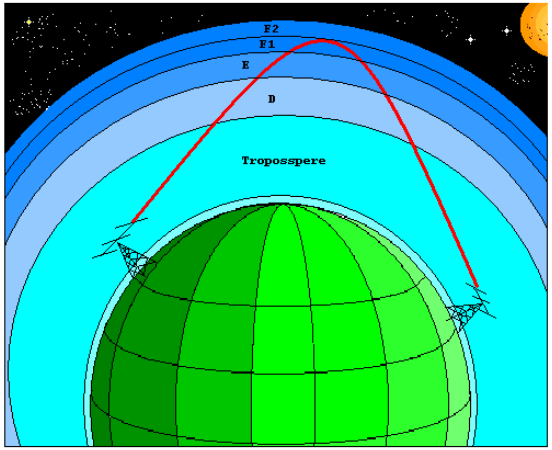
F Layers of the Ionosphere

- The F Layers are the highest layers and provide highly reliable DX propagation
- During the day the F layer ionizes into two distinct layers:
  - F1 layer at 200 km
  - F2 layer at 300 – 400 km
- At night the two layers combine into a single less intensely ionized F-layer
- Single-hop F2 provides propagation up to 2500 miles
- Multi-hop F2 provides world wide coverage
- Long path F2 propagation is common of 40 and 20 meters in the afternoon

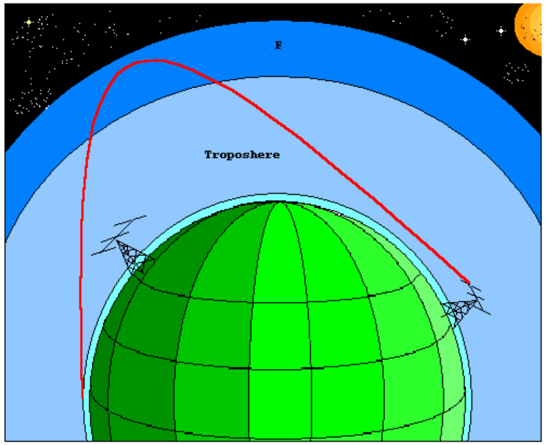
~200 – 400 km height



Day and Night Ionospheric Layers



< Daytime



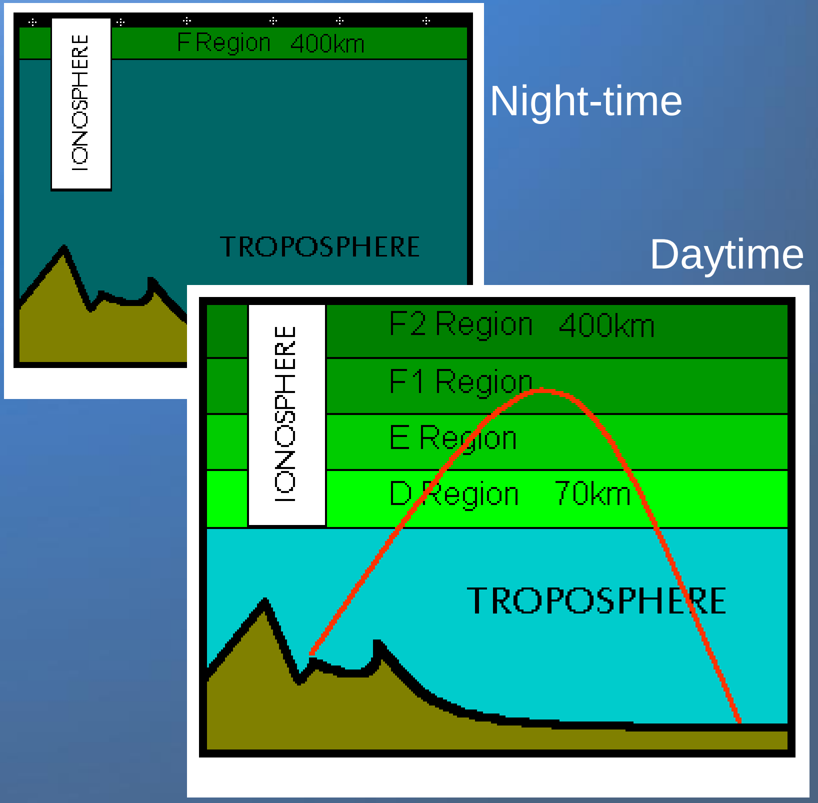
Night-time >

- The D, E, F1 and F2 layers are ionized during the day

- D layer vanishes at sunset
- E layer MUF drops rapidly after sunset
- F1 and F2 layers merge and remain ionized overnight but with much lower MUF especially during the winter

Day and Night Variation of the Ionosphere

- The F layer is the primary layer for reflecting DX signals
- Ionization varies with the time of day, season, geomagnetic storms and sunspot cycle
- Ionization is greatest during daylight hours
- Because it expands when heated, the F layer has significantly less ionization density during July and August
- The F1 and F2 layers merge at night, but the F-region is significantly weaker at night causing significantly reduced MUFs especially during winter



Ionospheric Propagation

- Ionospheric Layers
  - –The D layer absorbs frequencies below about 5 MHz during the day
  - – The E layer reflects radio waves below about 15 MHz during the day
  - – The F layers refracts radio waves below about 30 MHz
- Refraction via the ionosphere
  - – E layer propagation covers a ground range of 1200 miles
  - – Single hop F layer propagation covers a ground range of 2500 miles
  - – Multi-hop F layer propagation provides worldwide coverage including long paths of more than 12,000 miles
- Lowest Usable Frequency (LUF)
  - – D layer absorption primarily determines the LUF
- Maximum Usable Frequency (MUF)
  - – E and especially F layer refraction determines the MUF

Measures of the Daily Intensity of Solar Radiation affecting the Ionosphere

- **Solar Flux**
  - the sun’s radiation measured at 10.7cm wavelength
  - it is **not** a direct measure of ionizing UV radiation but its usually very well correlated to the intensity of UV radiation
- **K-index**
  - quantifies disturbances to the Earth's magnetic field caused by solar emissions during the prior 3 hour interval
  - an integer in the range from 0 to 9
  - 0-2 being quiet and 5 or more indicating geomagnetic storms of increasing intensity
- **A-index**
  - the 24 hour daily average level of geomagnetic activity for the previous day (2100Z-2100Z)

Propagation Indices – the K Index

- A localized index of geomagnetic activity computed every three hours at many points on Earth. The K scale is shown below

K Index	Geomagnetic Condition
0	Inactive
1	Very Quiet
2	Quiet
3	Unsettled
4	Active
5	Minor Storm
6	Major Storm
7	Severe Storm
8	Very Severe Storm
9	Extremely Severe Storm

- The most reliable HF propagation occurs when K is 3 or less. 160 and 80 meter propagation are often enhanced when the K is 2 or less

Propagation Indices – the Ap Index

A 24 hour average planetary geomagnetic activity index based on local K indices, updated daily at 2100Z The Ap Index scale is shown below:

Ap Index	Geomagnetic Condition
0-7	Quiet
8-15	Unsettled
16-29	Active
30-49	Minor Storm
50-99	Major Storm
100-400	Severe Storm

- Good HF propagation is likely when A is less than 15, particularly on the lower HF band

HF Propagation Modes

HF Propagation Modes

Three fundamental HF propagation modes:

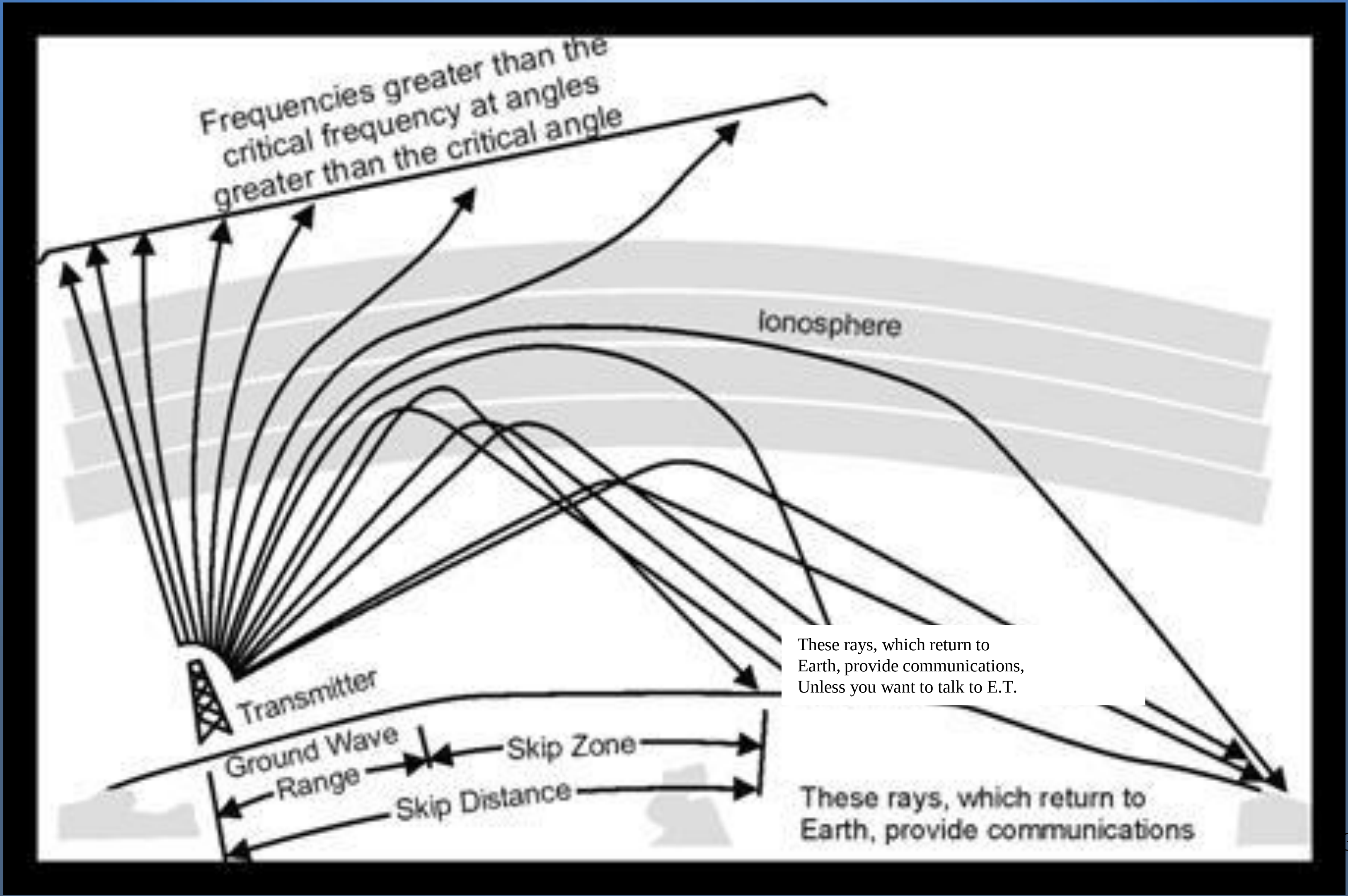
- Ground wave: vertically polarized local propagation on 160 and 80 meters only
- Surface or space wave: propagation extending somewhat beyond the line of sight
- Sky wave: all propagation via the ionosphere

Critical Frequency

- The highest frequency that returns to Earth via *directly overhead* propagation
- Dependent on the level of ionization directly overhead
- Usually measured by ionospheric sounders
- Typical critical frequencies are:
  - Summer day: 9 MHz Summer night: 4 MHz
  - Winter day: 14 MHz Winter night: 3 MHz
- Near Vertical Incidence Skywave (NVIS) uses frequencies below the critical frequency to provide reliable short distance communications with low power and simple antennas via high radiation angles
- Simple horizontally polarized antennas only 1/8 – ¼ wavelength high (20-30 feet high on 40 meters) provide extremely effective NVIS communications

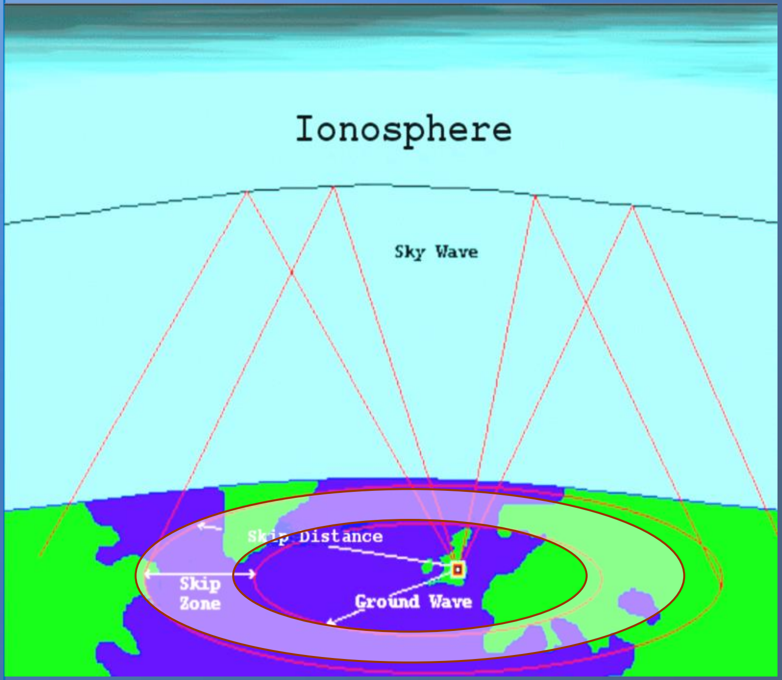
Critical Angle

The highest radiation angle that returns a radio wave to Earth on a specific ionospheric path under specified propagation conditions



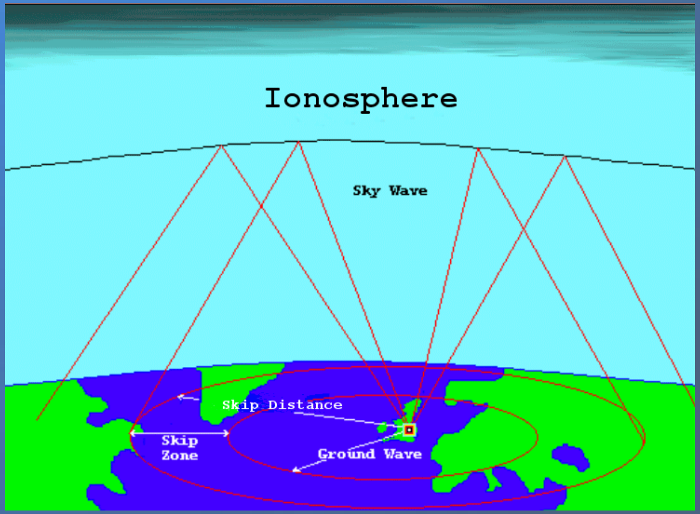
Skip Zone

- The zone between the skip distance and surface wave range that is not easily covered without changing to a lower frequency
- Tune to a DX station in QSO with a station a few hundred miles from you
- The DX station may have a strong signal, but often the nearby station is weak or totally inaudible despite being much nearer to your location
- You may hear the nearby station weakly via backscatter



Skip Distance and Skip Zone

- The surface wave propagates near the surface of the Earth but quickly weakens beyond line of sight
- Skip distance is measured from the transmitter to the closest point of sky wave return
- The skip zone is the annulus between the end of surface wave coverage and closest point of sky wave return
- No signal is received in the skip zone except via backscatter
- Only a tiny part of the signal energy is backscattered into the skip zone



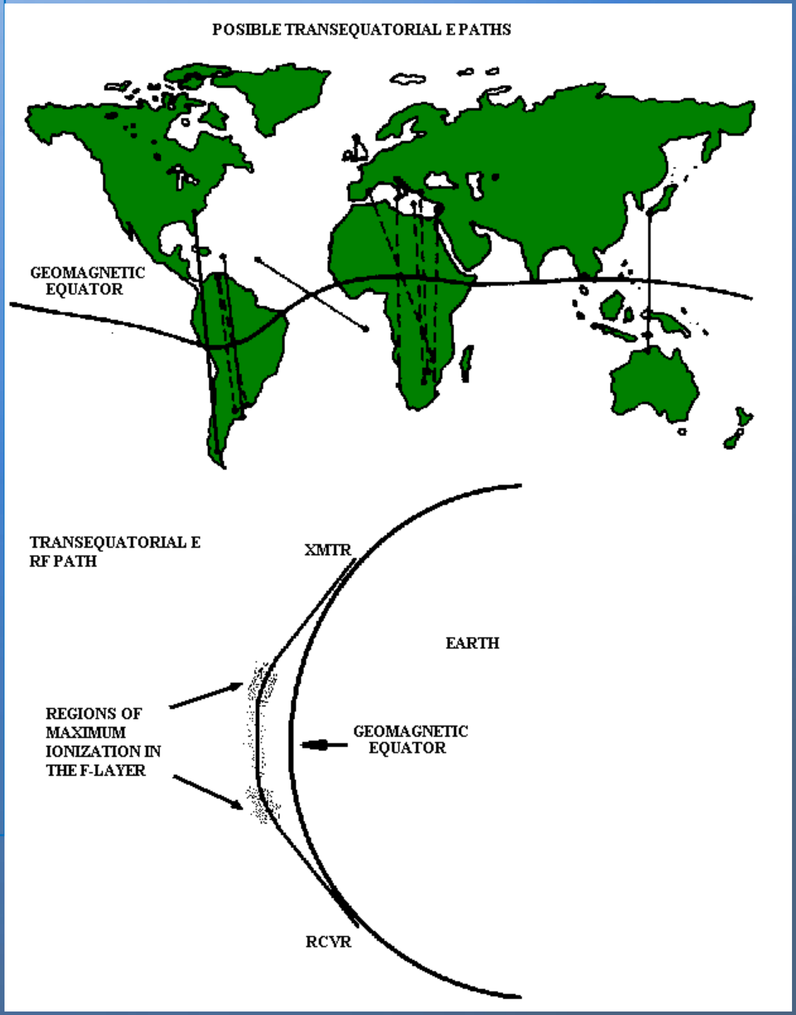
How the Sunspot Number affects High Frequency DX propagation

High sunspot numbers generally increase the probability of long distance propagation on 15, 12 and 10 meters especially from October through May

Unfortunately high sunspot activity most occurs during periods of generally high solar activity when severe geomagnetic storms are much more common and much more severe

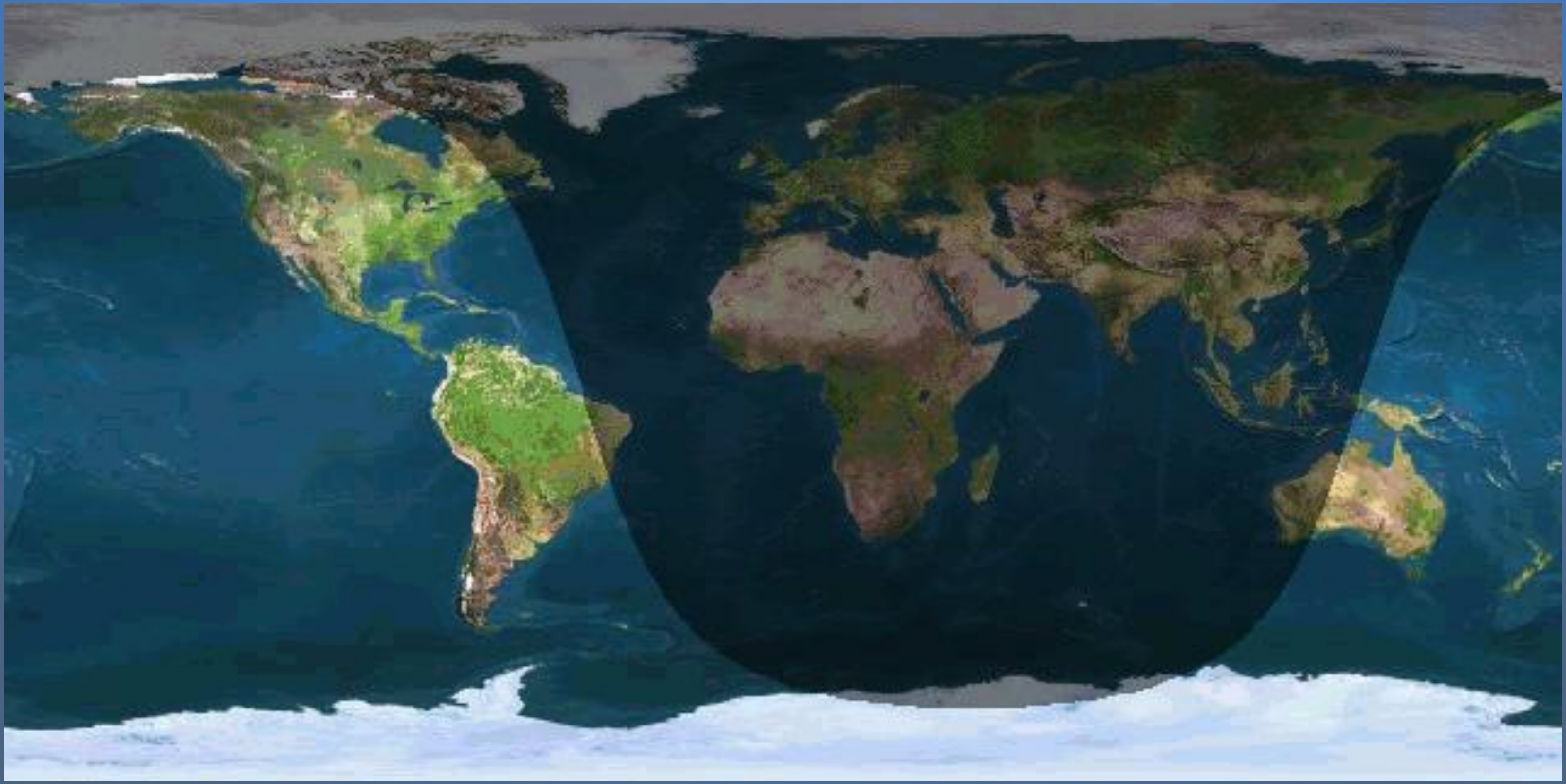
Trans-Equatorial Propagation - TEP

- The F layer is much more intensely ionized near the geomagnetic equator during local afternoon and early evening
- Stations within about 2500 miles of the geomagnetic equator can launch their signals directly into TEP propagation paths
- Stations outside the TEP zone can sometimes couple onto TEP propagation via an additional single sporadic-E or F layer hop
- TEP propagation refracts and travels across the equator and into the other hemisphere with no intermediary ground reflection
- Stations communicating via TEP must be at approximately equal distances from the *geomagnetic* equator



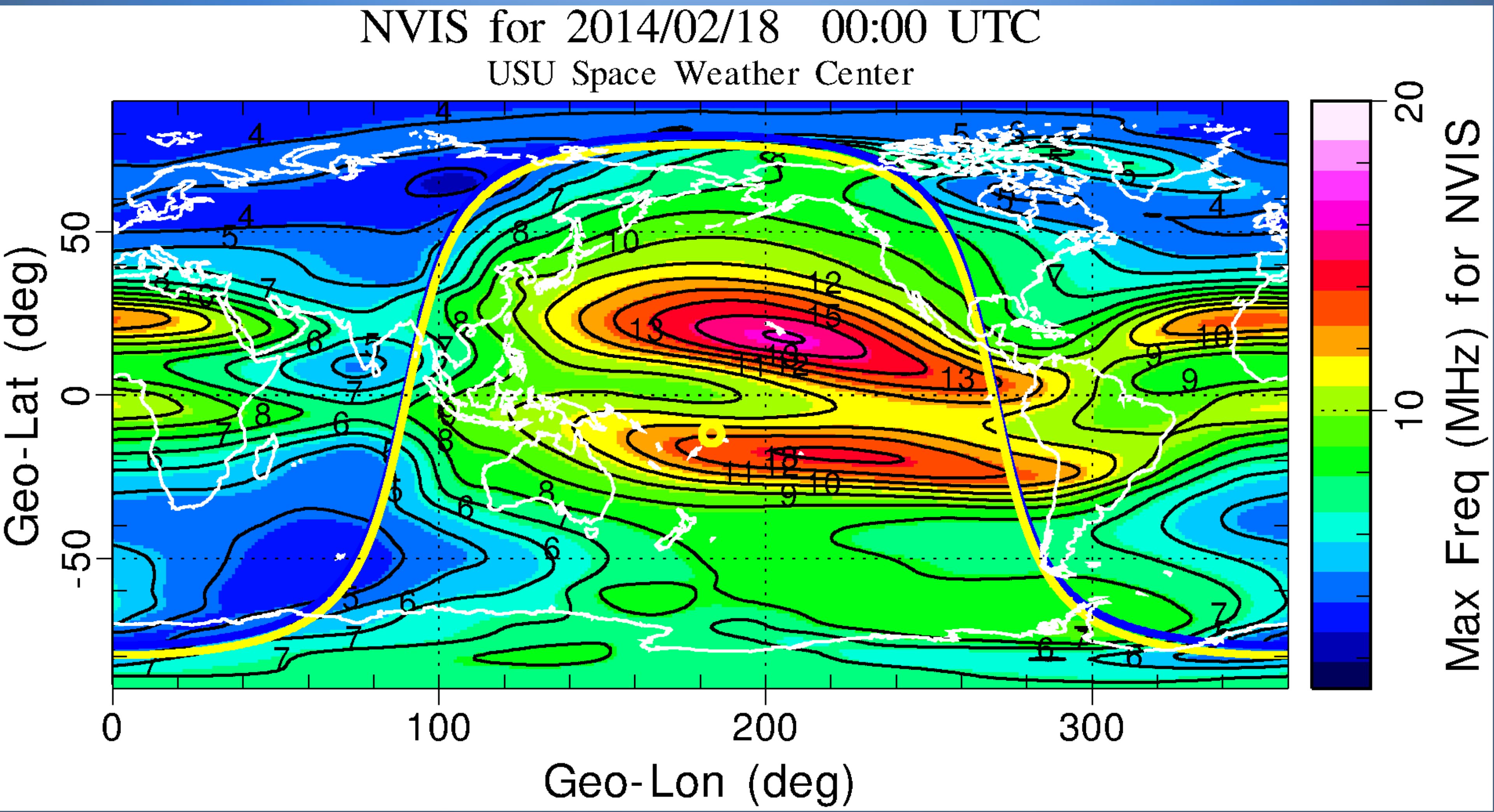
Gray Line Propagation

Long distance propagation between widely separated points near the daylight-darkness terminator especially on 160, 80, 40 and 30 meters



Near Vertical Incidence (NVIS) Propagation

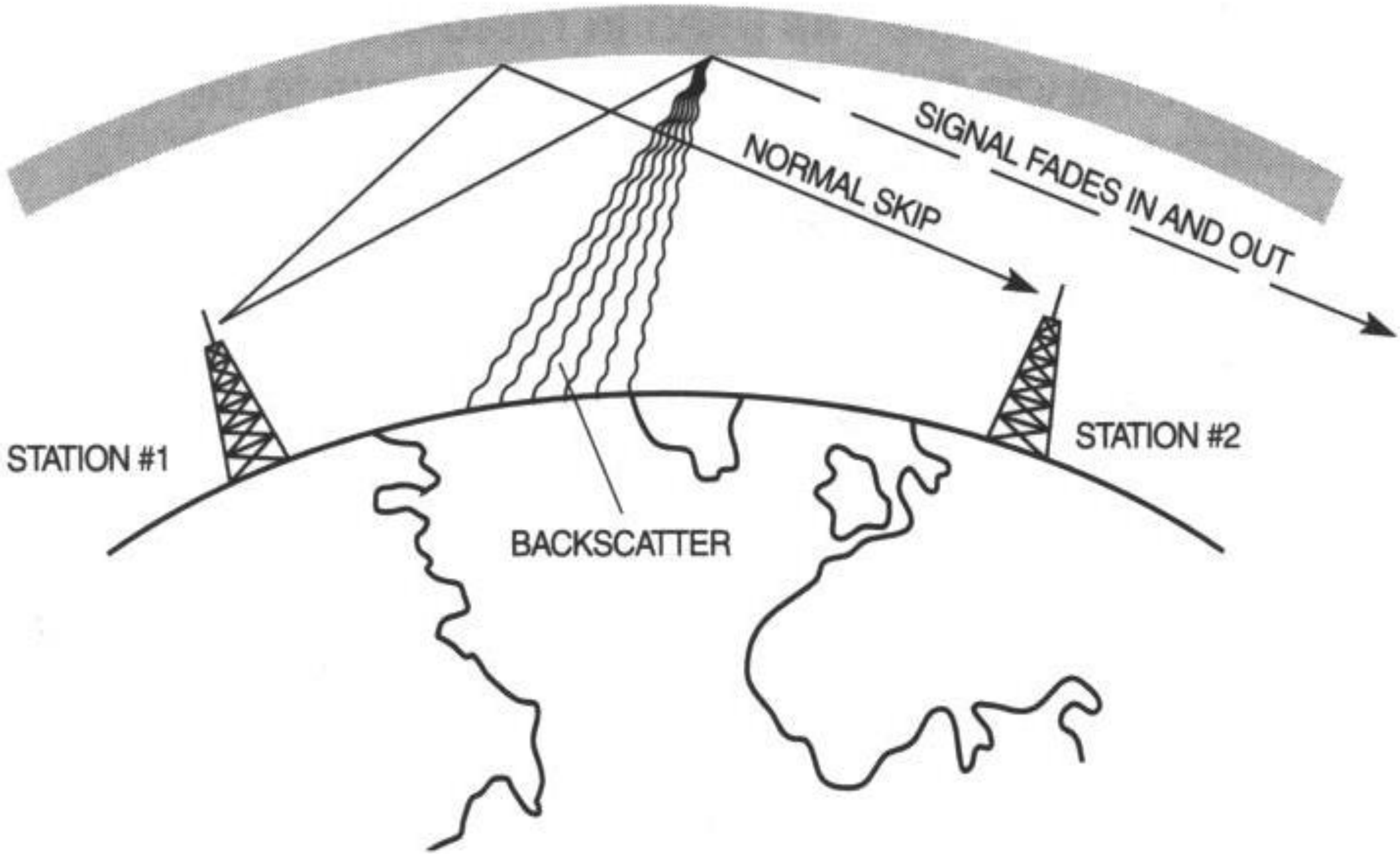
Typically uses low antennas only 1/8 - 1/4 wavelength high



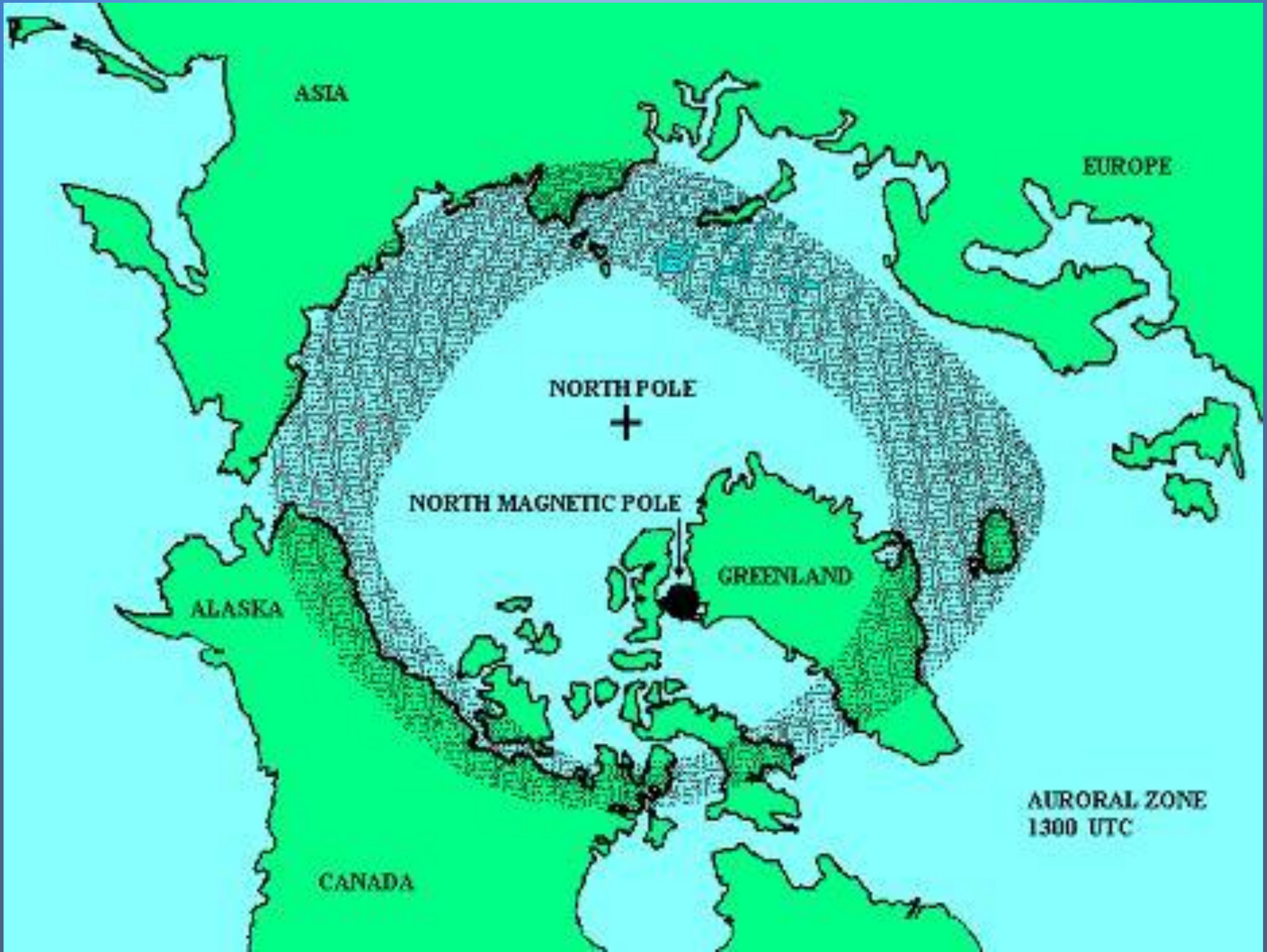
Auroral Flutter

- A common type of multipath fading that occurs almost exclusively on paths propagating via the auroral zone
- Caused by interaction of the signal with the auroral E and F layers
- Fades occur very rapidly (10 – 100 times per second) and make SSB signals sound “watery”

Backscatter Propagation



The Northern Auroral Zone during Quiet Geomagnetic Conditions

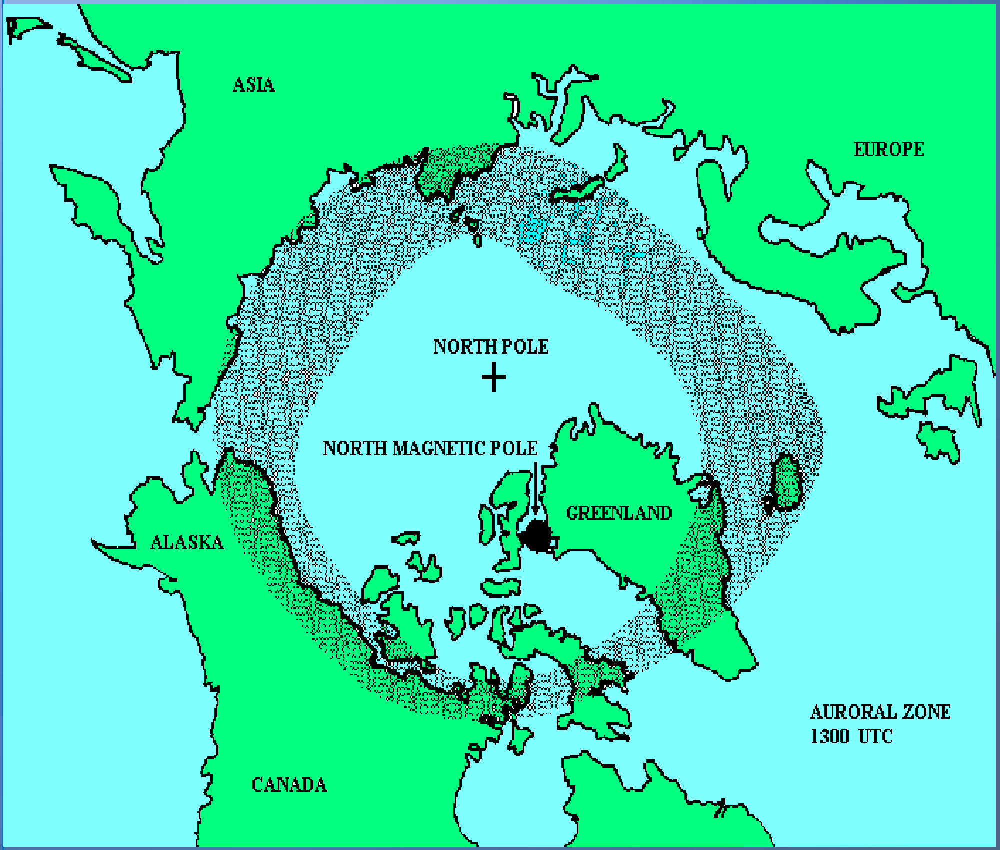


Auroral Backscatter

- When the sun is very active, its possible to have intense auroral backscatter propagation from both the auroral F layer and the auroral E layer
- The auroral-F layer MUF rarely exceeds 30 MHz
- The auroral-E layer MUF can exceed 450 MHz
- Backscatter communication is unique in that the stations in contact do not point their antennas at each other, but instead point at the region of intense ionization (typically +/- 45 degrees of due north for stations in the northern hemisphere)
- During periods of high solar activity, the auroral zone expands southward, approaching the US-Canadian border

Auroral-E Backscatter Communications

- During periods of intense auroral activity, the E-layer in the auroral zone can support intense backscatter of 10, 6 and 2 meter signals
- Multi-path propagation with the aurora zone contributes extreme noise modulation to the backscattered signal
- CW is normally used for Auroral-E backscatter communication
- To work via Auroral-E, the transmitter and receiver point their antennas at the auroral zone – typically +/- 45 degrees from North -- and never at each other



Long distance Propagation during Periods of Low Sunspot Activity

The 20 meter band almost always supports worldwide DX propagation during daylight hours at any point in the sunspot cycle

The 80 and 40 meter bands support worldwide DX propagation from October through April

15, meters becomes less reliable for daylight DX communications during the bottom of the solar cycle

12 and 10 meters become unreliable for daylight DX communications during the bottom of the solar cycle

Propagation Characteristics of the HF Amateur Bands

160 Meters

- Primarily a nighttime regional band from September through April
- Daytime operation is *very ineffective* compared to 80 and 40 meters
- Not a popular band during summer because of frequently intense QRN caused by lightning storms within 400 miles
- Night time range is reliable from NVIS ranges out to about 500 miles with a full size or loaded horizontal inverted-V dipole, about 50 feet high or more
- Worldwide DX is easily achieved with a 60 foot tall inverted-L vertical with a fairly efficient radial system
- Receiving antennas such as small loops, Beverages or phased arrays of short verticals are very effective and quite popular

80 Meters

- Primarily a nighttime regional band with reliable low power coverage out to about 1500 miles
- Reliable early morning and late afternoon low power NVIS operation out to about 200 miles
- Much less reliable than 40 meters from 9 a.m. to 3 p.m.
- Worldwide DX is easily achieved with low power and antennas such as
  – a full size or loaded inverted-V horizontal dipole, 50 feet high or more
  – or a 35 foot tall inverted-L vertical with a reasonably efficient radial system
- Not as badly impacted as 160 meters by summer lightning storm QRN

60 Meters

- Reliable daytime short range coverage to about 400 miles
- Because of the 50 watt ERP power limit, range is usually limited to about 750 miles even at night
- Transcontinental and intercontinental operation is possible from October through April
- Band is not available on many older rigs so activity is usually sparse

40 Meters

- Very reliable low power daytime regional operation from NVIS ranges out to about 400 miles
- The E layer blankets the F layer during daylight hours
- Worldwide DX is easily worked with low power from late afternoon through sunrise
- Lots of CW and digital activity between 7000-7100 kHz
- Can be difficult to find an empty spot for SSB operation between 7128- 7200 kHz when DX conditions are good in the evening
- The band above 7200 kHz is a short wave broadcast band in many parts of the world making night time operation difficult

30 Meters

- A good daytime band for low power communications out to about 500 miles
- A good late afternoon and night time band for worldwide DXing
- During low sunspot activity for the next five years, the best DXing opportunities are usually within a few hours of sunrise and sunset because the MUF drops below 10 MHz during the night in the winter months
- Unlike the other HF bands, low power and simple antennas are almost universally used

20 Meters

- The King of the DX Bands since the 1920s
- Almost always supports DX propagation during daylight hours at any point in the sunspot cycle
- Usually has a Skip Zone extending out to about 400 to 800 miles
- Stay open until very late at night during the spring and summer
- Low power with a simple dipole antenna only 30-50 feet high can easily work the world

17 Meters

- Low power and simple antennas are much more common than on 20 meters
- Opens somewhat later than 20 meters and closes earlier
- The skip zone typically extends out to about 800 miles
- No contesting on this band so its good for both DXing and rag-chewing during busy contest weekends

15 Meters

- A year round daytime worldwide DX band, but not as reliable as 20 or 17 meters for the next five years of low sunspot activity
- The skip zone is commonly about 800 to 1200 miles

12 Meters

- A combination of 15 and 10 meter characteristics
- Contesting is not allowed on this band so its clear for rag-chewing and DXing even on busy contest weekends
- DXing opportunities are less frequent with low sunspot activity for the next five years

10 Meters

- Sits on the threshold of VHF
- A daytime rag-chewing and DXing band
- Low power with modest antennas can easily make world wide DX contacts when the band is open
- The F layer skip zone often exceeds 1000 miles
- Sporadic-E propagation frequently allows closer contacts during June and July
- Short skip sporadic-E propagation in the 10 meter band during in June and July often indicates the possibility of 6 meter sky wave propagation

What bands should I use during the next five years of low solar activity?

- Each band has it unique advantages and disadvantages
- The most reliable worldwide daytime DX propagation will be on 20 and 17 meters and occasionally on 15 meters
- The most reliable worldwide night time DX propagation will be on 40 meters
- 80 meters will provide excellent worldwide DX propagation at night from October through April