Understanding HF/VHF/UHF/SHF Propagation relative to Guided Wave, Ground Wave, Direct Wave, Ionosphere, Troposphere, Aurora, Meteor Scatter, and Earth-Moon-Earth (EME or Moon Bounce)

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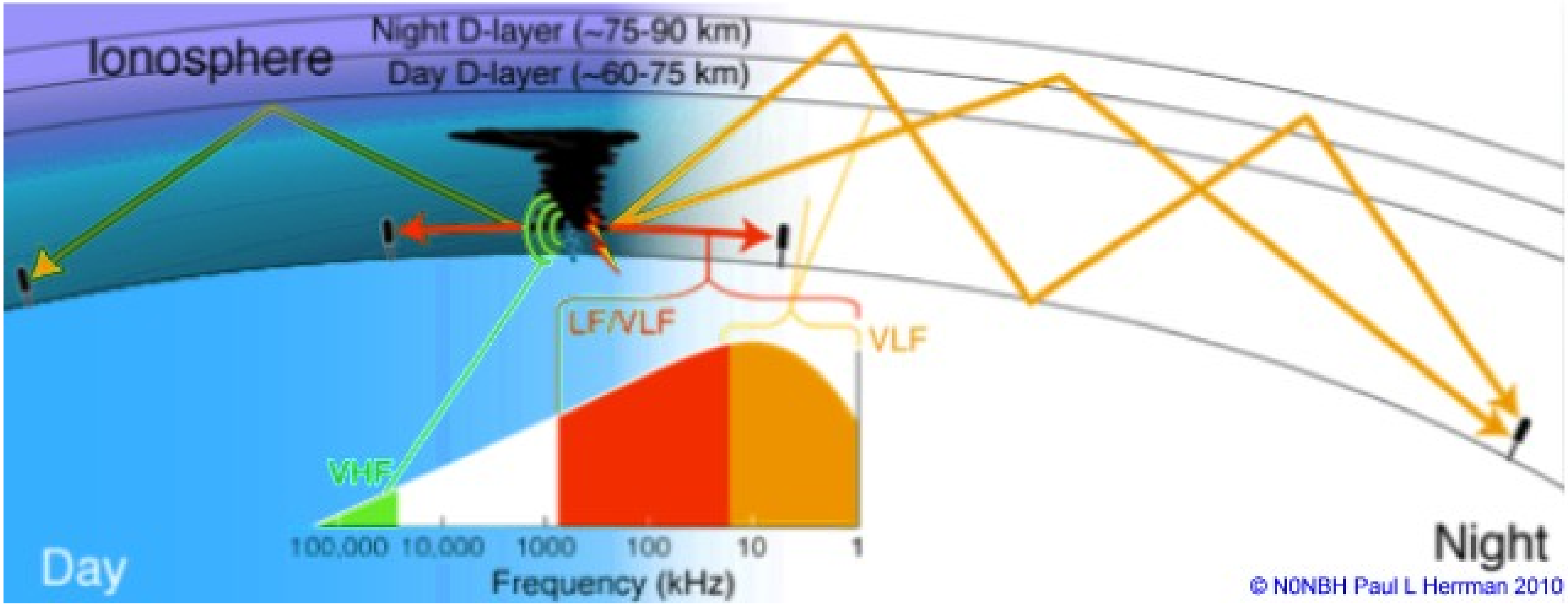
Propagation Modes

Band	Frequency	Primary Mode of Propagation
VLF	3-30kHz	Guided between the earth & ionosphere
LF	30-300kHz	Guided between the earth & D layer of ionosphere. Also surface waves
MF	300-3000kHz	Surface waves. E, F layer ionospheric refraction at night, when D layer absorption weakens
HF	3-30MHz	E layer ionospheric refraction. F1, F2 layer ionospheric refraction. Auroral reflection. Meteor scatter
VHF	30-300MHz	Infrequent E ionospheric refraction (Es). Extremely rare F1,F2 layer ionospheric refraction during high sunspot activity up to 80MHz. Direct wave. Auroral reflection. EME reflection. Meteor scatter. Sometimes tropospheric ducting
UHF	300–3000MHz	Direct wave. EME reflection. Tropospheric ducting. Meteor scatter
SHF	3–30GHz	Direct wave. EME reflection. Tropospheric ducting
EHF	30–300GHz	Direct wave limited by absorption. EME reflection

Image by soest



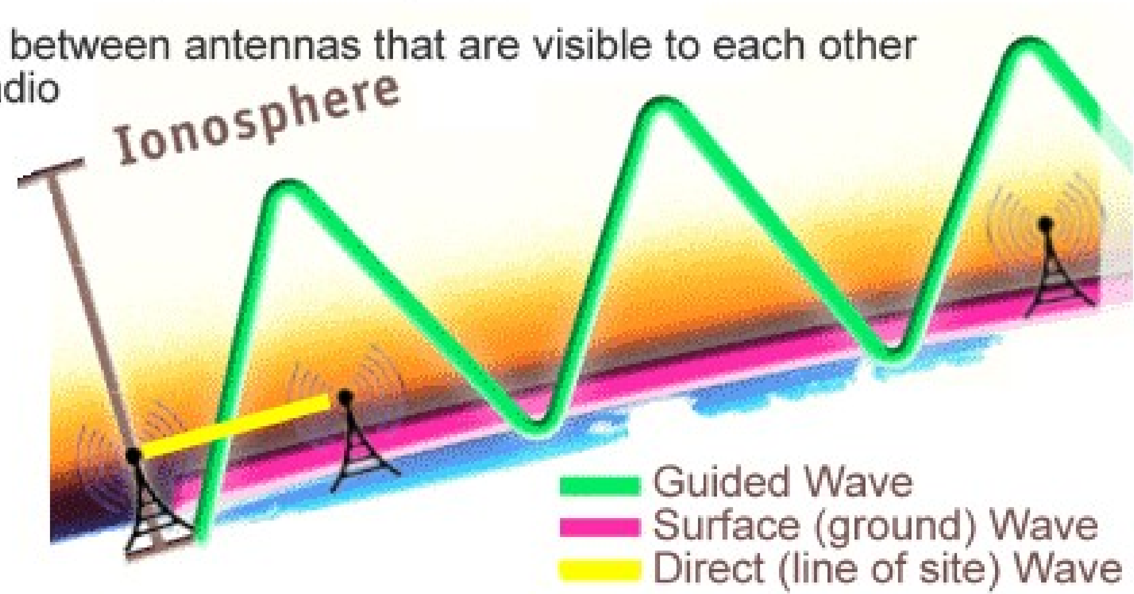
Guided/Ground/Direct Wave

Image by NIST

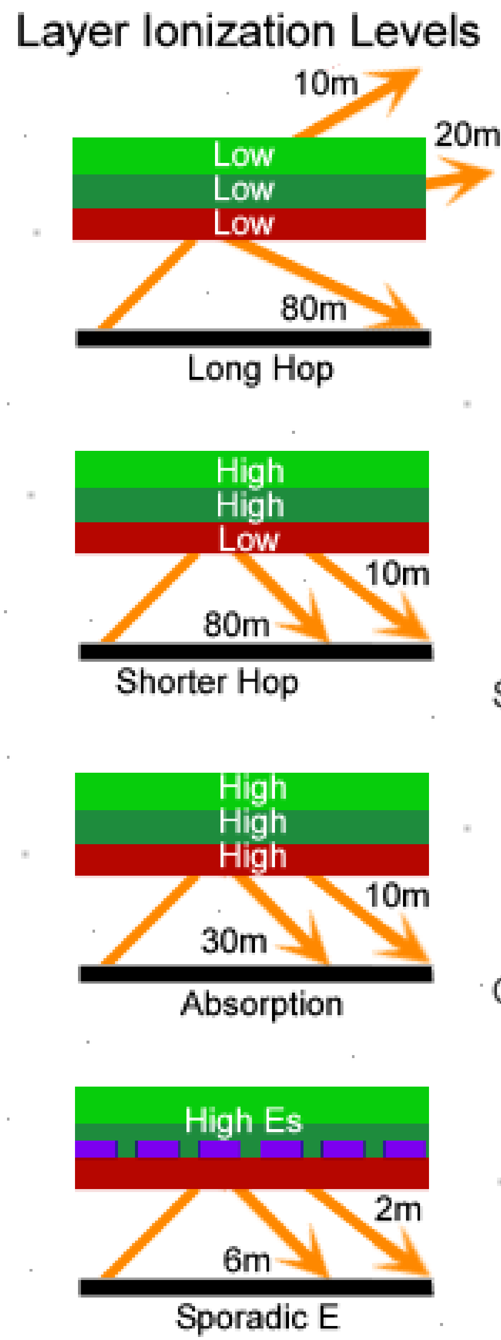
Guided Wave:
- Most VLF & LF propagation occurs via guided wave (due to long wavelength)
- Ground/water surface and ionosphere are highly conductive at these frequencies
- Form the "walls" of a spherical waveguide.
- Vertical Polorization always used:
  - Horizontal antennas not practical (due to extremely long wavelength)
  - Alleviates short circuiting the electric field through the conductivity of the ground

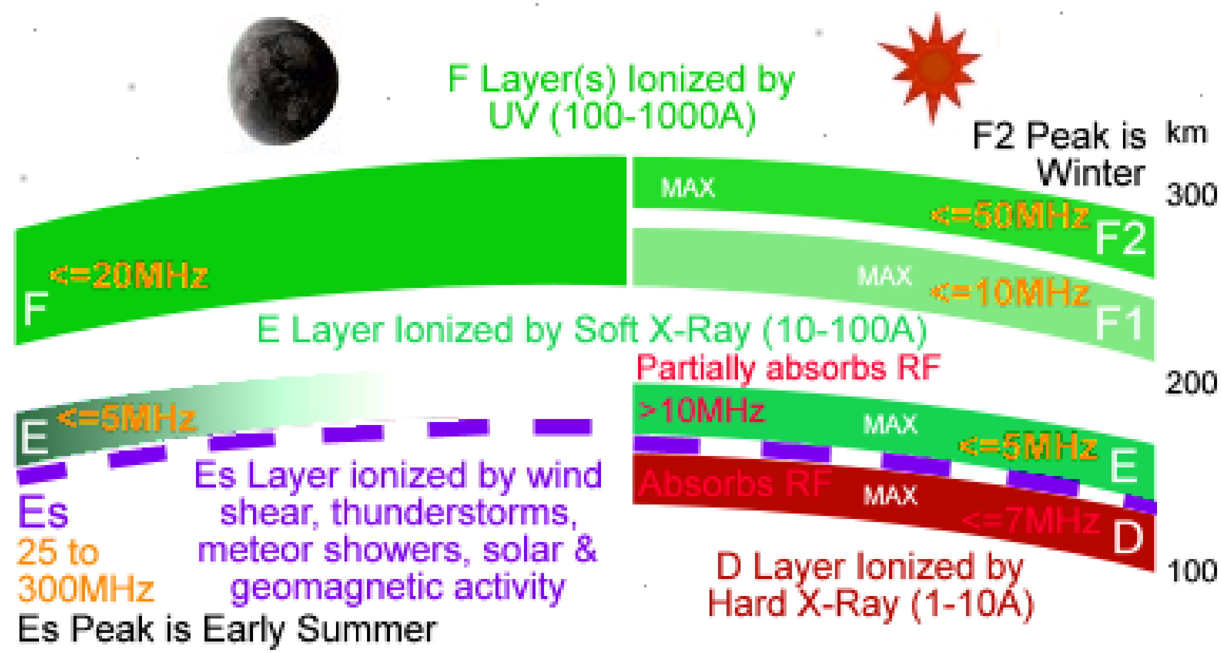
Surface (Ground) Wave:
- Low/medium frequencies travel efficiently as a surface waves
- Property of following the curvature of the earth
- Conductivity of the surface affects the propagation of ground waves (more conductive surfaces such as water providing better propagation and result in less dissipation)
- Since the ground is not a perfect electrical conductor, ground waves are attenuated as they follow the earth's surface
- Ground waves do not include ionospheric and tropospheric waves

Direct Wave (line-of-sight):
- Propagation of radio waves between antennas that are visible to each other
- The most common of the radio propagation modes at VHF and higher frequencies
- Includes radio signals that travel through non-metallic objects (like walls)
- Ground plane reflection effects are an important factor in line of sight propagation



Ionospheric Propagation

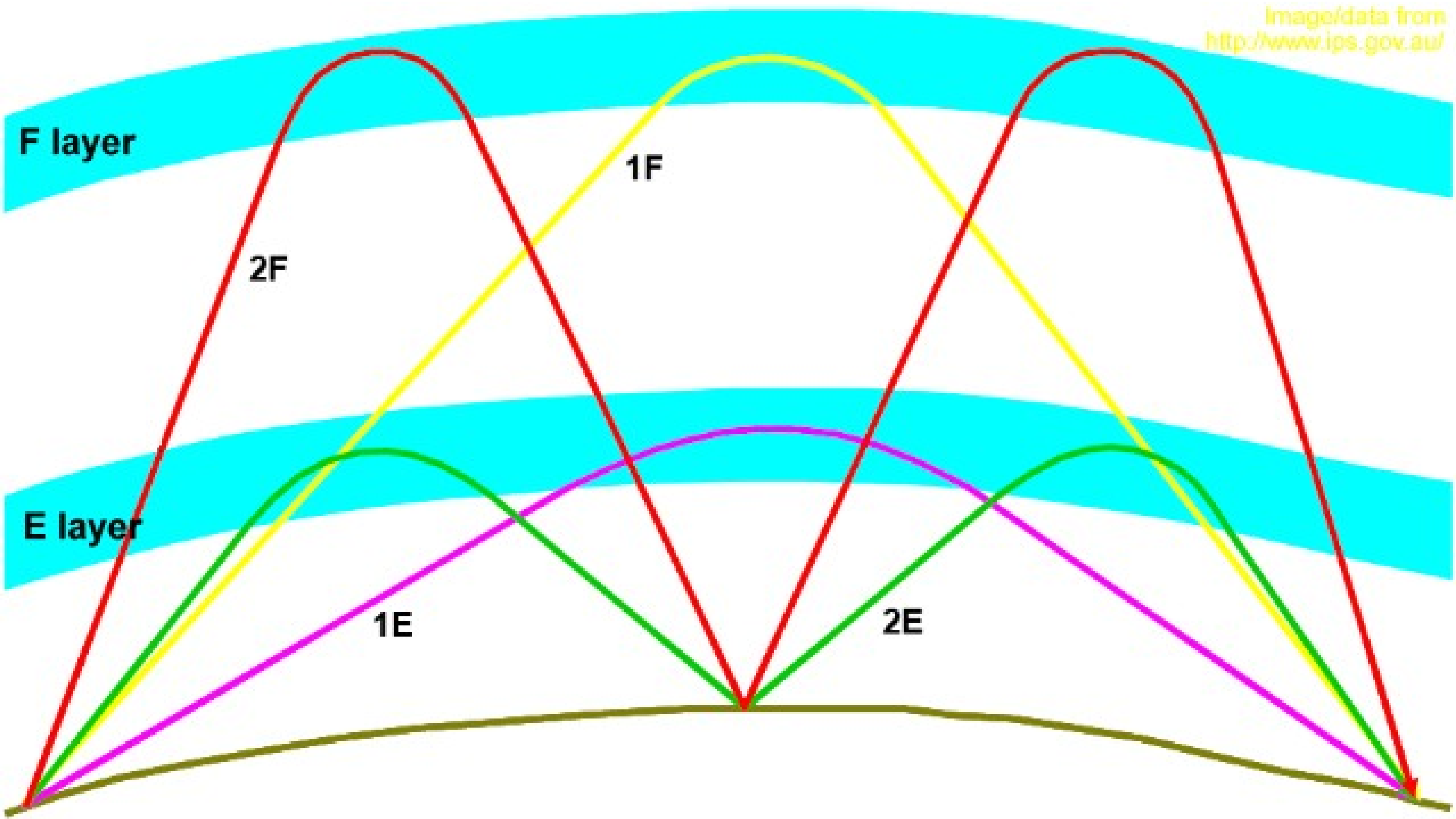




So what causes the layers in the ionosphere to reflect RF energy:
- When a radio wave reaches the ionosphere, the signal's electric field forces the ionosphere electrons into oscillation at the same frequency
- Some RF is given up to this resonant oscillation
- Oscillating electrons will then either be lost to recombination or re-radiate at the original signal energy
- If the transmitted frequency is higher than the layer's plasma frequency, then the electrons cannot respond fast enough, and do not re-radiate the signal

Other factors about the layers in the ionosphere:
- X-Rays and Gamma Rays ionize the layers in the Ionosphere
- 10cm Solar Flux provides a good indication of current F layer Ionization
- During geomagnetic storms the F2-layer becomes unstable, fragments, & may even disappear completely
- At night the E layer begins to disappear and solar wind drags it higher
- Flares can highly ionize D Layer to the point it absorbs everything to 30MHz
- Solar Wind can ionize high latitudes impacting Aurora
- Solar proton events can ionization the D-layer over high and polar latitudes creating Polar Cap Absorption (PCA)

Simple Propagation



Simple Propagation Mode:

- RF propagated by one layer
- Can be more than one single hop (reflection from Earth)
- Most (if not all) propagation predictions use simple mode
- Multiple paths by which RF travels
  * 1st order mode (1X) RF reflected by a layer requiring least number of hops
  * 2nd order mode (2X) requires one extra hop....(etc)

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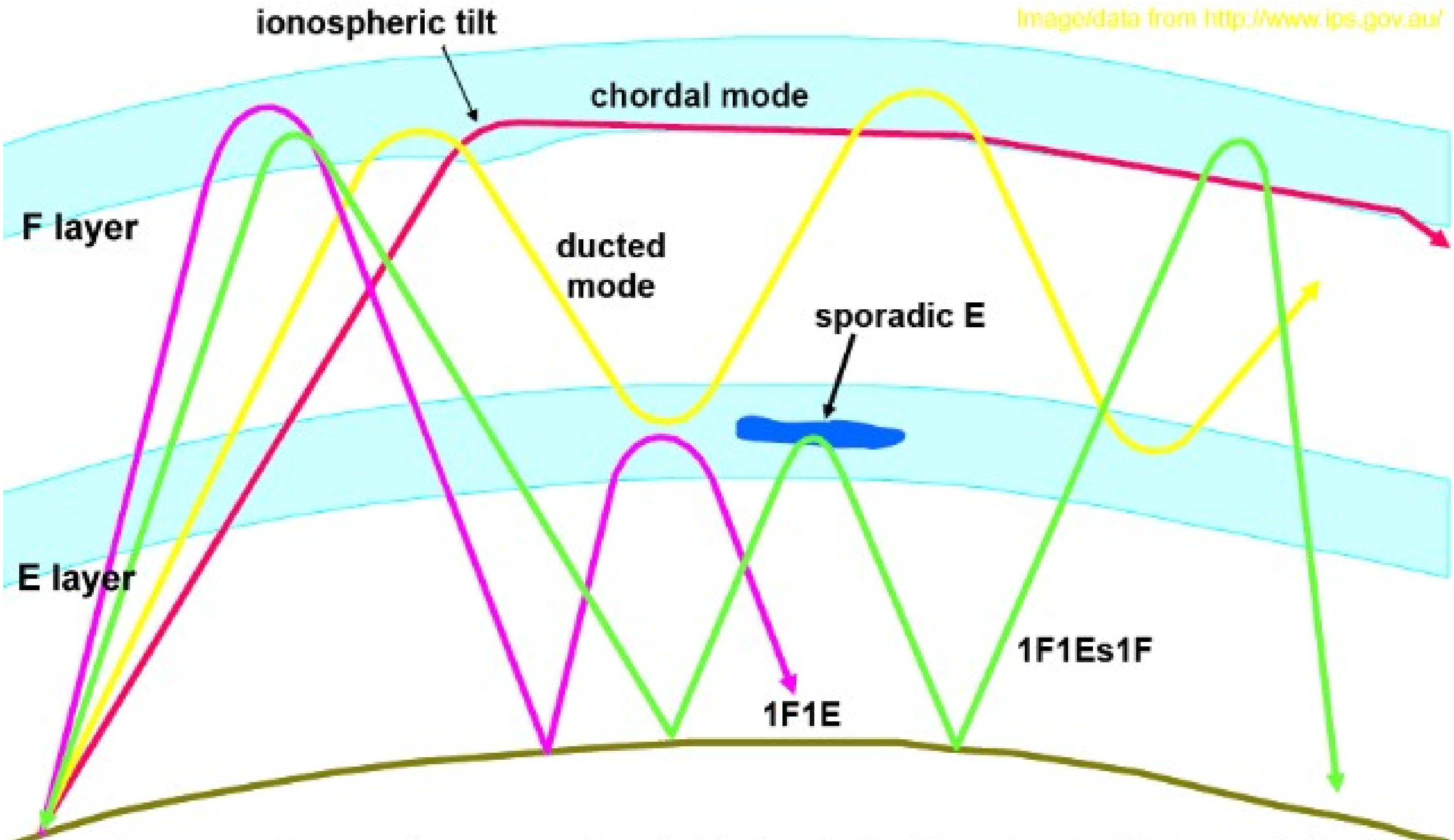
Complex Propagation



Complex propagation modes are combo of reflections/refractions from E & F layers & Earth
Layers of the ionosphere are not always smooth which affects the reflections/refractions of RF
- Most likely near equatorial anomaly, mid-latitude trough, and sunrise/sunset sectors of globe

When ionospheric layers tilt chordal and ducted modes may occur:
- Ducted mode is reflections/refractions between layers in the ionosphere
- Chordal mode is ducting within a single ionosphere layer
- Signals strong since RF not attenuated by D layer/ground

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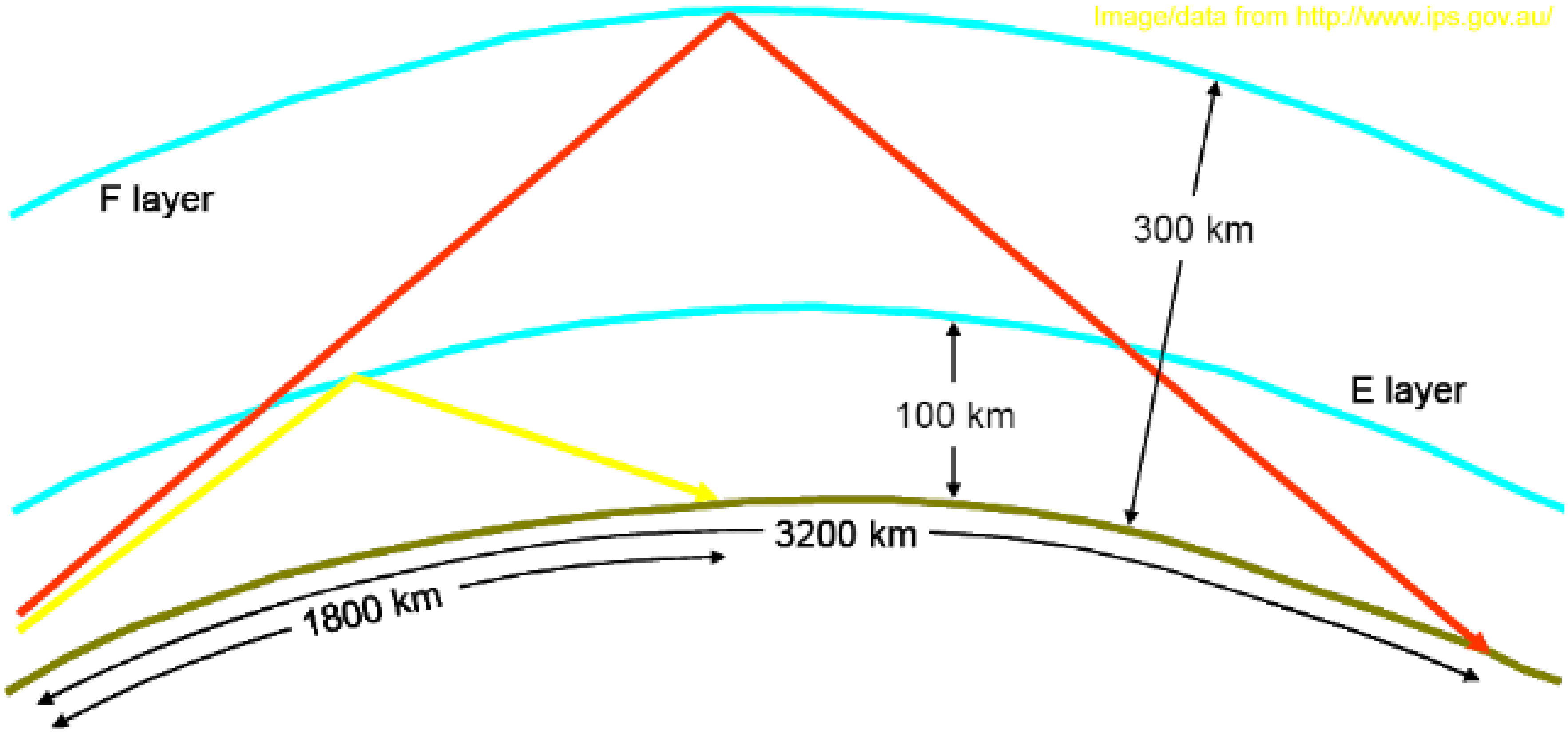
Propagation Distances



Hop length is the ground distance covered by RF after it has been reflected once from the ionosphere and returned to Earth

Maximum hop length is set by the height of the ionosphere and curvature of the Earth

The maximum hop lengths shown:

- Assumes antenna radiation angle of 4° (shorter with larger antenna elevation angles)
- Assumes E/F layer heights as specified

Distances greater than shown will require more than one hop

- Results in weaker RF signal at the receiver (RF is attenuated by multiple passes through D layer absorption and ground reflection)

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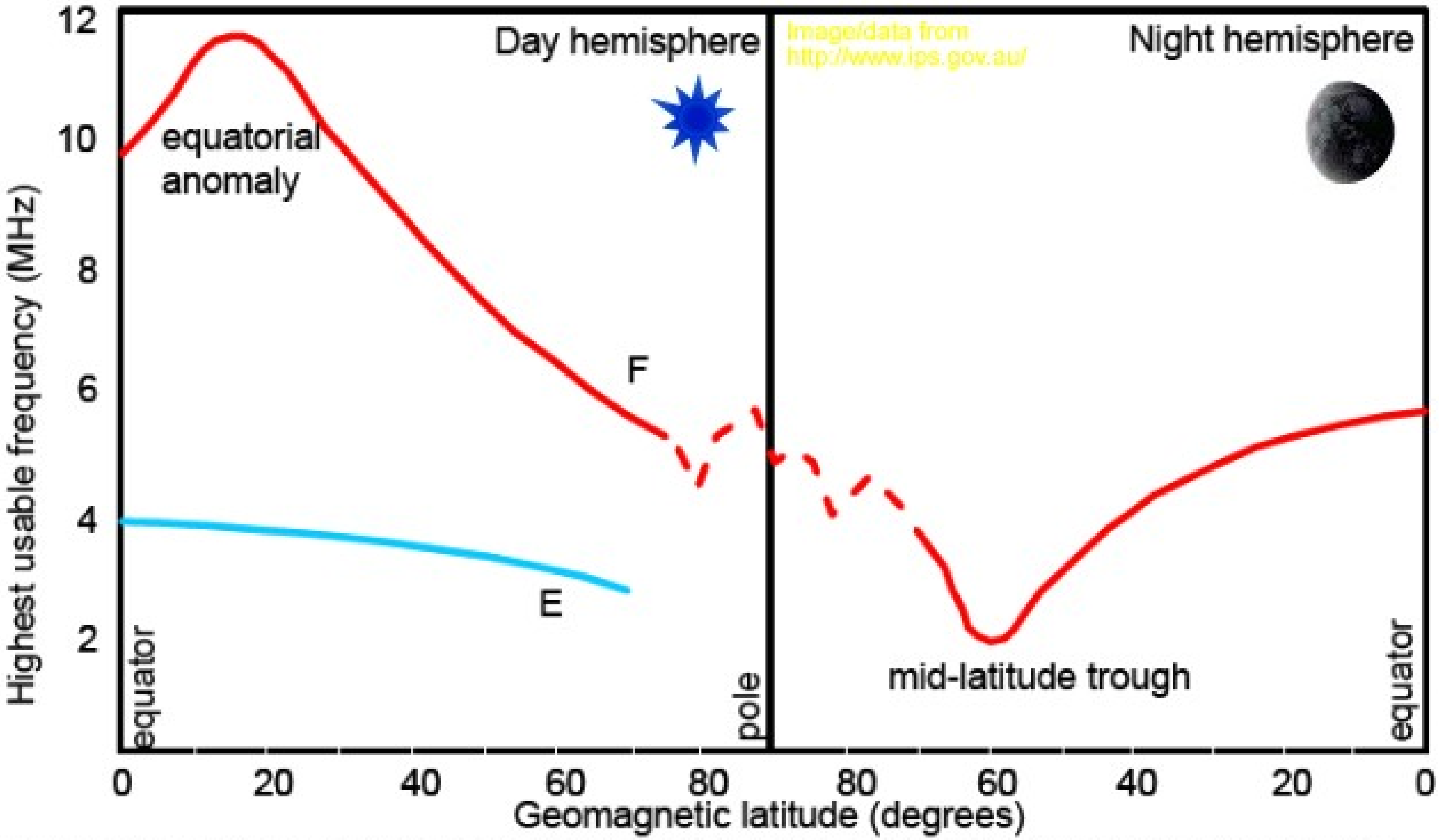
Latitude Variations



During the day solar radiation strikes the atmosphere more obliquely with increasing latitude
Intensity of radiation and daily production of free electrons decreases with increasing latitude
- F region latitude variation persists throughout the night due to the action of upper atmospheric wind currents from day-lit to night-side hemispheres

Deviations from the low to high latitude decrease are:
- Equatorial anomaly-daytime F layer peak 15 to 20° N/S latitude
- Mid-latitude trough-nightime minimum around 60° N/S latitude

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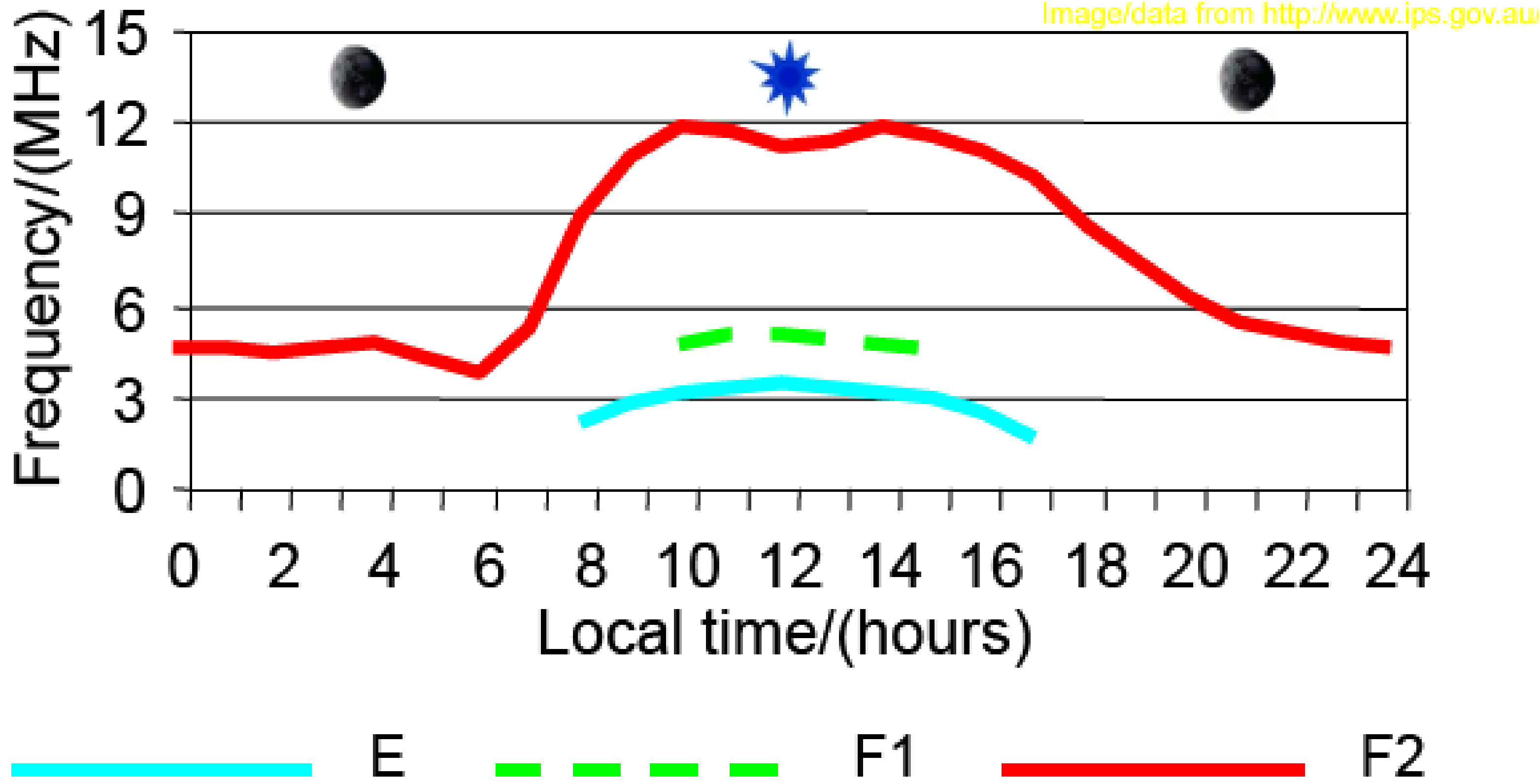
Time-of-Day Variations



Frequencies are normally higher during the day and lower at night
After dawn, solar radiation causes electrons to be produced in the ionosphere and frequencies increase rapidly to a maximum around noon
During the afternoon, frequencies begin falling due to electron loss and with darkness the D, E and F1 layers disappear
Communication during the night is by the F layer only and attenuation is very low
Through the night, maximum frequencies gradually decrease, reaching their minimum just before dawn

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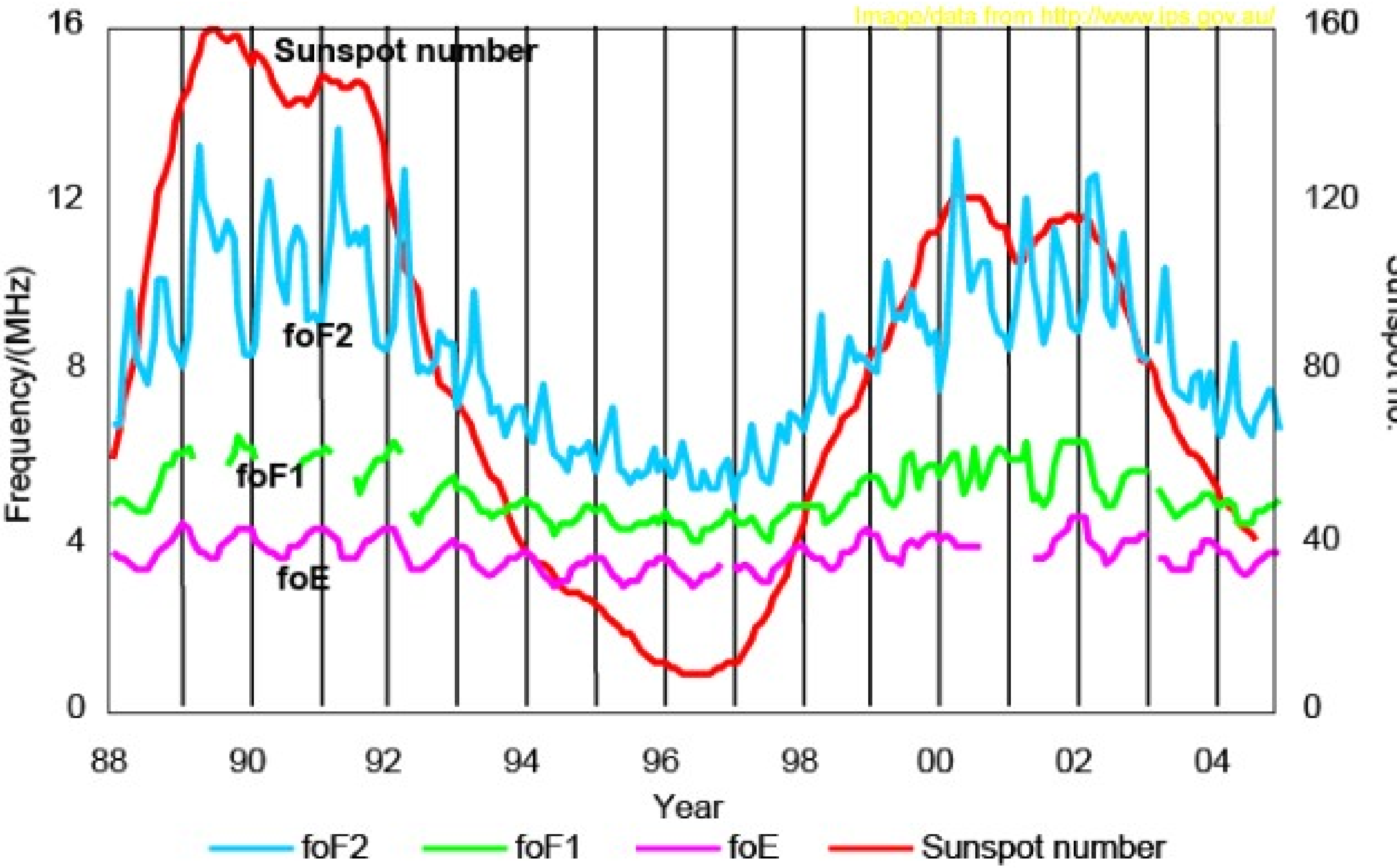
Sunspot Cycle Variations



Solar Cycle is periodic rise and fall in activity which affects HF communications (9-14 years)
The higher the activity, the more radiation being emitted from the Sun producing more electrons in the ionosphere which allows the use of higher frequencies.
At solar minimum, only the lower frequencies of the HF band will be reflected by ionosphere
At solar maximum the higher frequencies will successfully propagate

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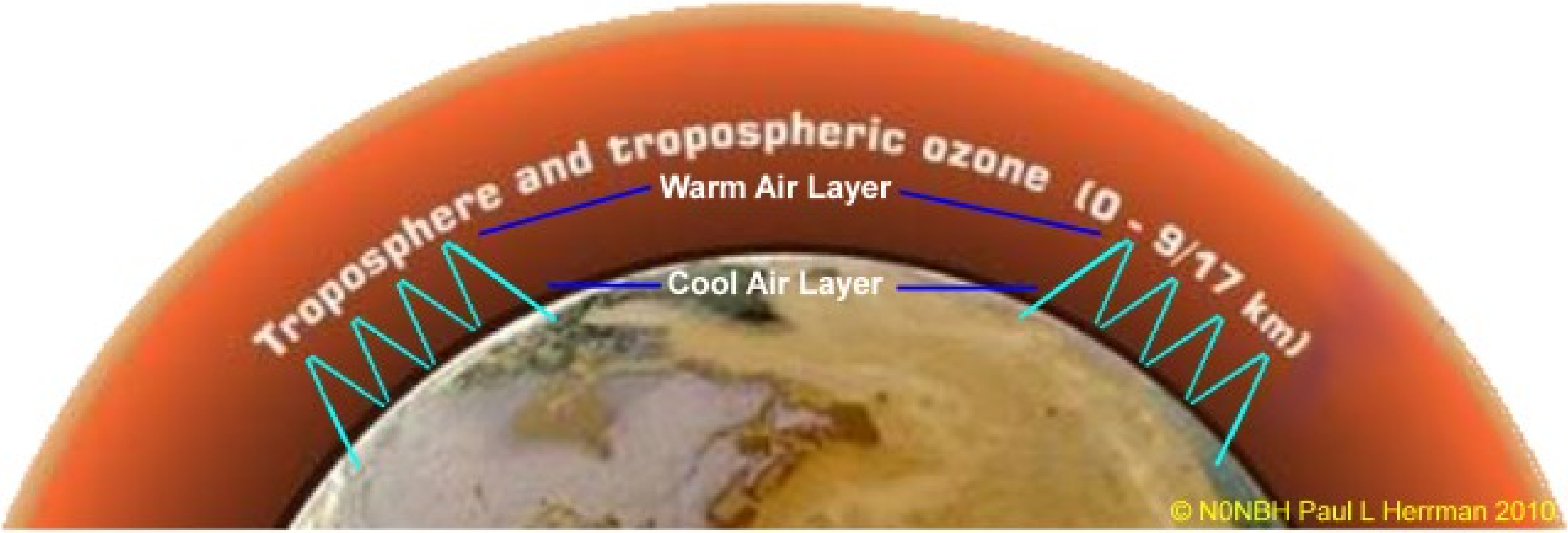
Tropospheric Propagation

What causes Tropospheric Propagation:

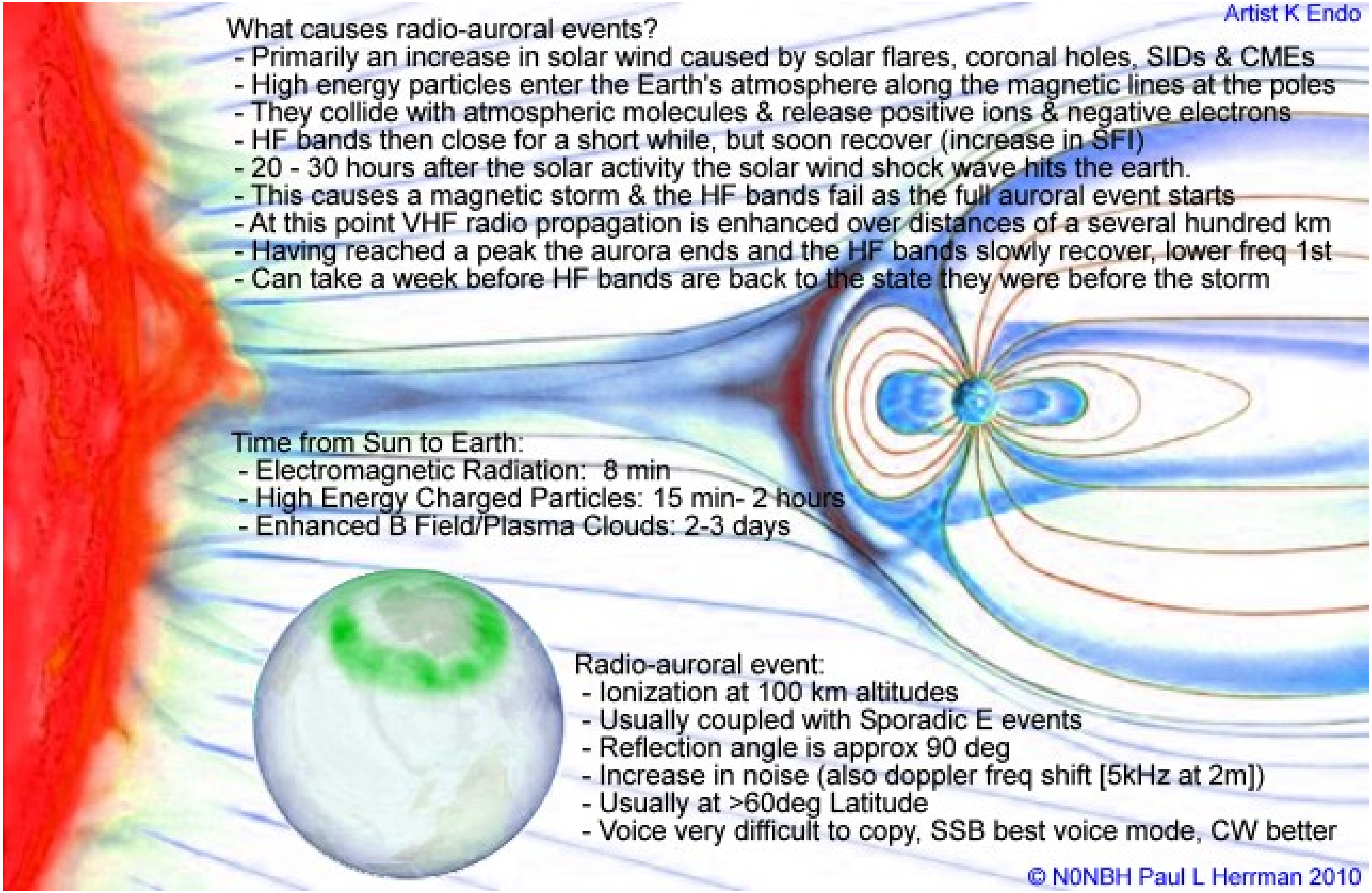
- Weather causes the condition
- When a large mass of cold air is overrun by warm air (temperature inversion)
- Typically found along a stationary weather front
- Most frequently along coastal areas bordering large bodies of water
- Also in the morning when the rising sun warms the upper layers

Additional Information on Tropospheric Ducting:

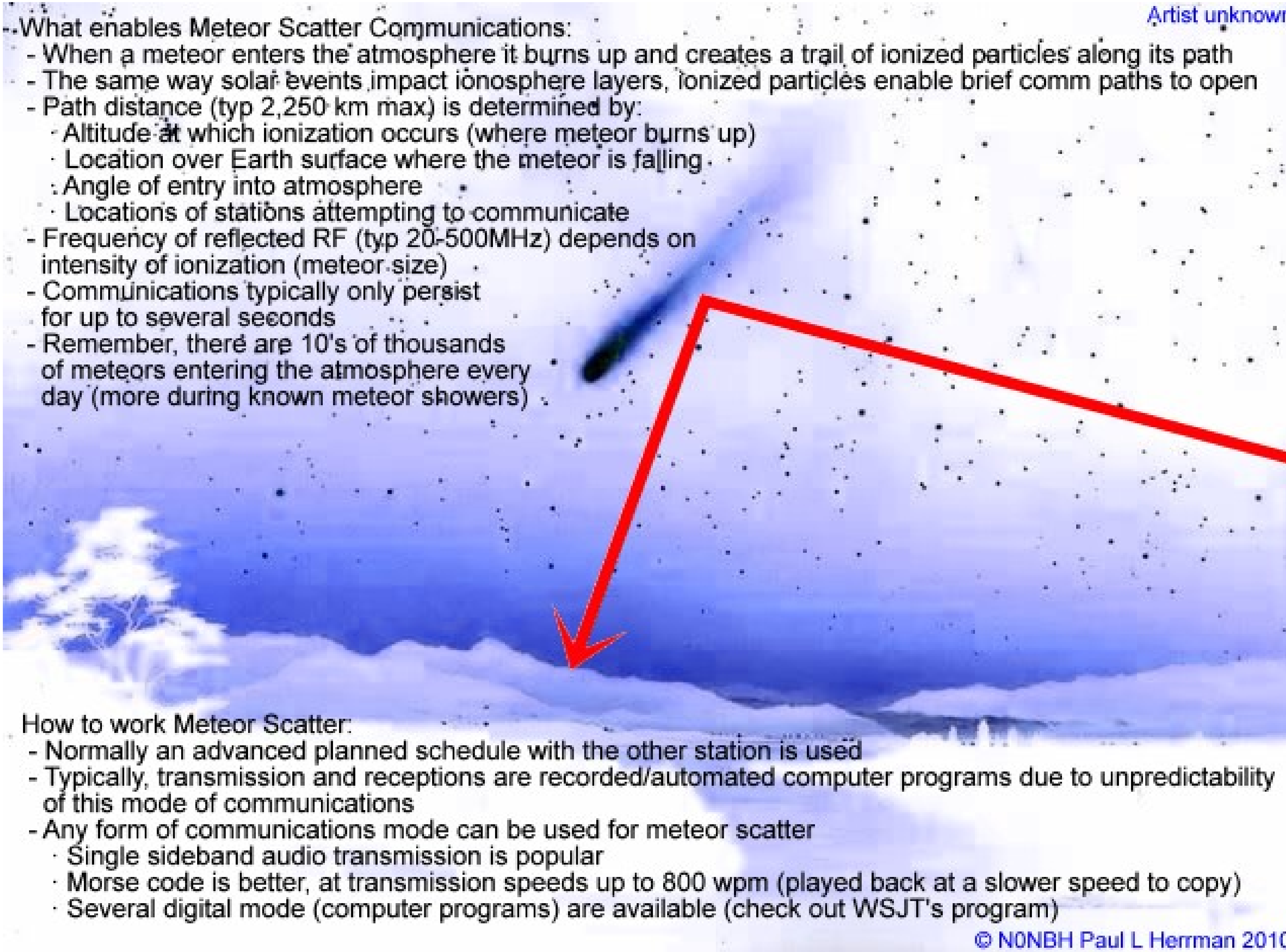
- The boundary between the two air masses may extend for 1,000 miles (1,600 km)
- Frequencies above 90MHz are more favourably propagated
- Signals exhibit a slow cycle of fading with occasional strong signal levels
- High mountainous areas and undulating terrain between the transmitter and receiver can block tropospheric signals
- A relatively flat land path between the transmitter and receiver is ideal for tropospheric ducting
- Sea paths also tend to produce superior results



Auroral Propagation

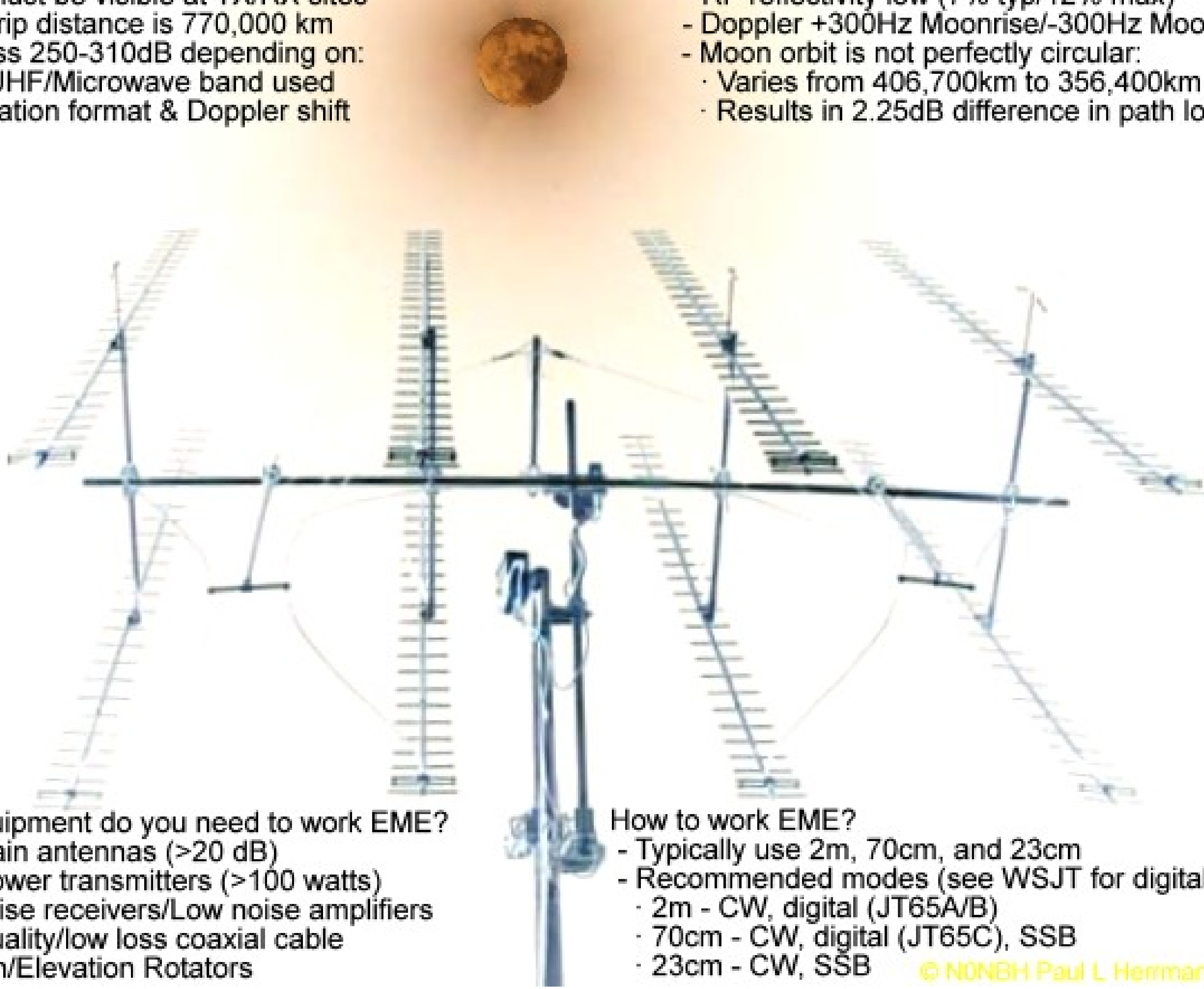


Meteor Scatter



EME/Moon Bounce

How do Earth-Moon-Earth (EME or moon bounce) communications work:
- RF propagation from an Earth-based transmitter to receiver via reflection from the moon surface
- Moon must be visible at TX/RX sites
- Roundtrip distance is 770,000 km
- Path loss 250-310dB depending on:
  - VHF/UHF/Microwave band used
  - Modulation format & Doppler shift
- RF reflectivity low (7% typ/12% max)
- Doppler +300Hz Moonrise/-300Hz Moonset
- Moon orbit is not perfectly circular:
  - Varies from 406,700km to 356,400km
  - Results in 2.25dB difference in path loss

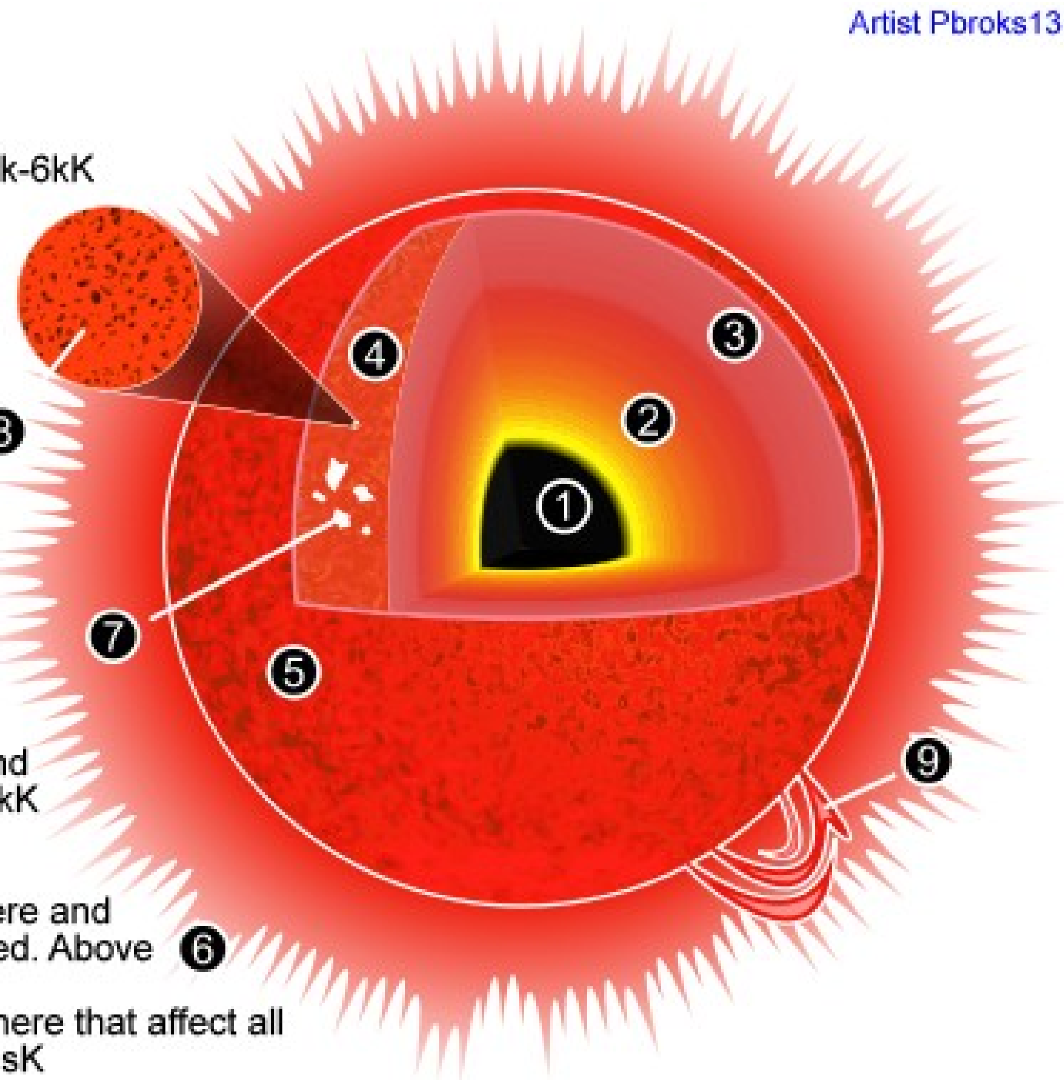


What equipment do you need to work EME?
- High-gain antennas (>20 dB)
- High power transmitters (>100 watts)
- Low noise receivers/Low noise amplifiers
- High quality/low loss coaxial cable
- Azimuth/Elevation Rotators

How to work EME?
- Typically use 2m, 70cm, and 23cm
- Recommended modes (see WSJT for digital):
  - 2m - CW, digital (JT65A/B)
  - 70cm - CW, digital (JT65C), SSB
  - 23cm - CW, SSB

Parts of the Sun (for next slide)

Parts of the Sun:
1-Core. Temp ~15MK
2-Radiative zone. Temp ~7MK
3-Convective zone. Temp ~2MK
4-Photosphere. Sun's visual surface. Temp 4k-6kK
5-Chromosphere. ~2,000km deep. Primarily hydrogen. Temp 4k-20kK
6-Corona. Plasma "atmosphere" of Sun. Spectral features traced to highly ionized Iron. Temp in excess of 1MK
7-Sunspots. Concentrations of magnetic flux (0.4 to >1.0 tesla) in photosphere, typically 2,500-50,000 km across. Appear dark because 1.5k-2.5kK cooler than surrounding area. ~5,000km deep
8-Granules. On photosphere. Caused by convection currents of plasma within Sun's convective zone. 1,000-30,000 km dia. Life 8 minutes to 24 hours
9-Prominence. Large, bright loop, spray, or surge. Anchored to photosphere, and extend into corona, but much cooler plasma by 10kK



Not shown:
Solar transition region. Between chromosphere and corona. Below region, helium not fully ionized. Above region it is fully ionized. Temp 60k- 80kK
Solar flare. Large explosion in Sun's atmosphere that affect all solar layers. Heats plasma to tens of millionsK

Definitions for the images:
EIT = Extreme Ultraviolet (EUV) Imaging Telescope. Provides images of transition region and inner corona
MDI = Michelson Doppler Imager measures underlying magnetic fields & gas flow patterns on solar surface
VSM = Vector Spectromagnetograph provides magnetic field observations in photosphere & chromosphere
SH = Spectroheliograph provides photographic image of Sun's visible surface in light of a single wavelength
LASCO=Large Angle and Spectrometric Coronagraph

Putting the Solar Data to Use

Current Solar-Terrestrial Data

Solar-Terrestrial Data
2010 Jul 11 1206 UTC
SFI: 80 SN: 18
A-Index: 2
K-Index: 1 / 8 nT
X-Ray: B2.8
304A: 121.8 @ SEM
Ptn Flx: 1.54e-01
Elc Flx: 1.06e+03
Aurora: 3 /n=0.93
Mag (Bz): 2.8
Solar Wind: 266.4

HF Conditions

Band	Day	Night
80m-40m	Fair	Good
30m-20m	Fair	Fair
17m-15m	Poor	Poor
12m-10m	Poor	Poor

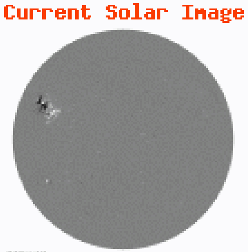
VHF Conditions

Aur Lat	65.6°	
Aurora	Band	Closed
6m EsEU	Band	Closed
4m EsEU	Band	Closed
2m EsEU	Band	Closed
2m EsNA	Band	Closed

MUF
MS
0 6 12 18 UTC
MIN MAX

Geomag Field VR QUIET
Sig Noise Lvl S0-S1

Current Solar Image



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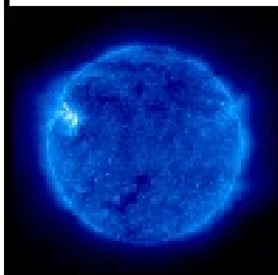
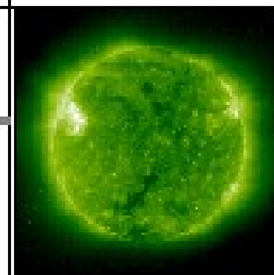
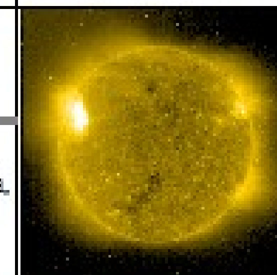
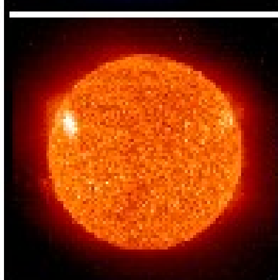
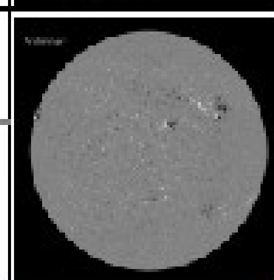
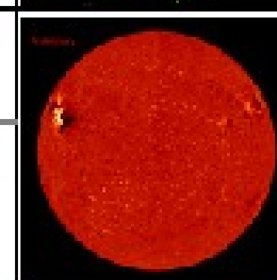
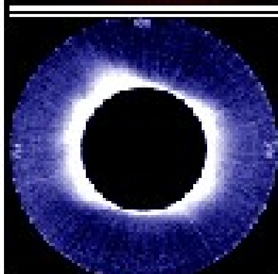
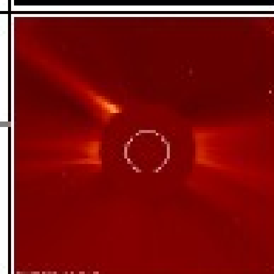
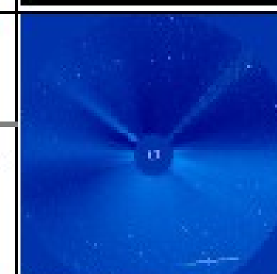
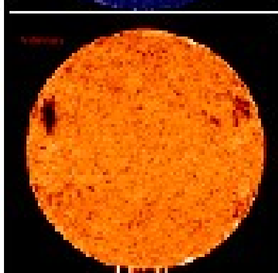
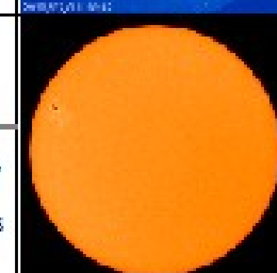
Category	Radio Blackouts Use X-Ray	Solar Radiation Storms Use Proton Flux	Geomagnetic Storms Use K-Index/K-nT/ Aurora/Solar Wind/Bz	Band Openings Use Solar Flux (SN)	Electron Alert Use Electron Flux
Extreme	X20 (1 per cycle) Complete HF blackout on entire sunlit side lasting hours	1.0e+06 (1 per cycle) Complete HF blackout in polar regions	K=9 (nT=>500) [Aur=10++] (SW=>800) [Bz=-40 -50] (4 per cycle) HF impossible. Aurora to 40°. Noise S30+.	200-300 (SN=160-250) Reliable communications all bands up through 6m	>1.0e+03 Alert Partial to complete HF blackout in polar regions
Severe	X10 (8 per cycle) HF blackout on most of sunlit side for 1 to 2 hours	1.0e+05 (3 per cycle) Partial HF blackout in polar regions	K=8 (nT=330-500) [Aur=10+] (SW=700-800) [Bz=-30 -40] (100 per cycle) HF sporadic. Aurora to 45°. Noise S20-S30.		
Strong	X1 (175 per cycle) Wide area HF blackout for about an hour on sunlit side	1.0e+04 (10 per cycle) Degraded HF propagation in polar regions	K=7 (nT=200-330) [Aur=10] (SW=600-700) [Bz=-20 -30] (200 per cycle) HF intermittent. Aurora to 50°. Noise S9-S20.	150-200 (SN=105-160) Excellent conditions all bands up through 10m w/6m openings	
Moderate	M5 (350 per cycle) Limited HF blackout on sunlit side for tens of minutes	1.0e+03 (25 per cycle) Small effects on HF in polar regions	K=6 (nT=120-200) [Aur=9] (SW=500-600) [Bz=-10 -20] (600 per cycle) HF fade higher lats. Aurora to 55°. Noise S6-S9.	120-150 (SN=70-105) Fair to good conditions all bands up through 10m	<1.0e+03 Active Degraded HF propagation in polar regions
Minor	M1 (2000 per cycle) Occasional loss of radio contact on sunlit side	1.0e+02 (50 per cycle) Minor impacts on HF in polar regions	K=5 (nT=70-120) [Aur=8] (SW=400-500) [Bz=0 -10] (1700 per cycle) HF fade higher lats. Aurora to 56°. Noise S4-S6.	90-120 (SN=35-70) Fair conditions all bands up through 15m	<1.0e+02 Active Minor impacts on HF in polar regions
Active	C1 Moderate Flare Low absorption of HF signals	1.0e+01 Active Very minor impacts on HF in polar regions	K=3-4 (nT=20-70) [Aur=6-7] (SW=200-400) [Bz=0-+50] Unsettled/Active Minor HF fade higher lats. Aurora 60-58°. Noise S2-S3.	70-90 (SN=10-35) Poor to fair conditions all bands up through 20m	<1.0e+01 Normal No impacts on HF
Normal	A1-B9 No/Small Flare No or very minor impact to HF signals	1.0e+00 Normal No impacts on HF	K=0-2 (nT=0-20) [Aur=<5] (SW=200-400) [Bz=0-+50] Inactive/Quiet No impacts on HF. Aurora 67-62°. Noise S0-S2.	64-70 (SN=0-10) Bands above 40m unusable	<1.0e+00 Normal No impacts on HF

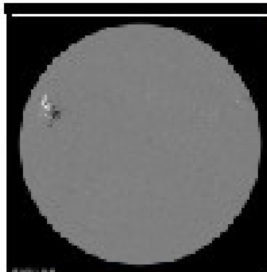
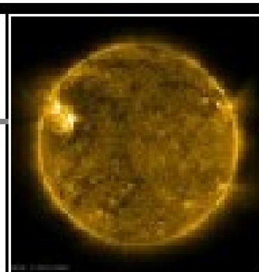
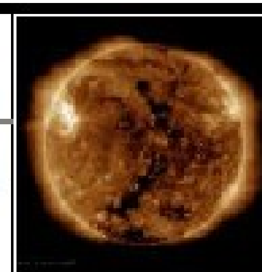
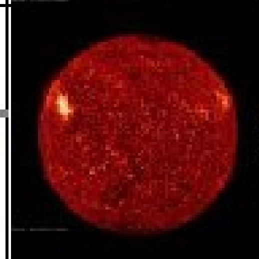
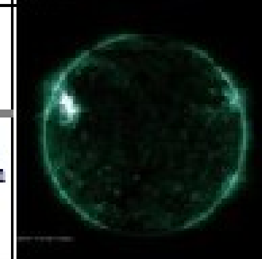
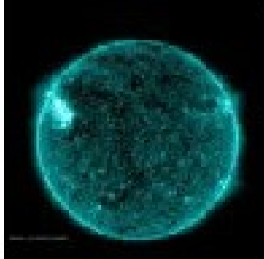
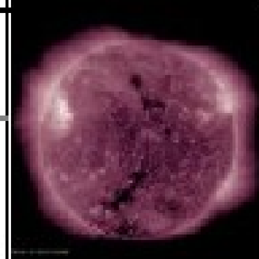
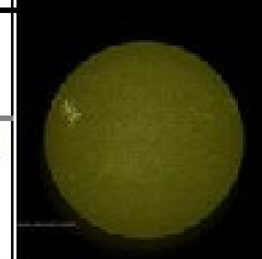
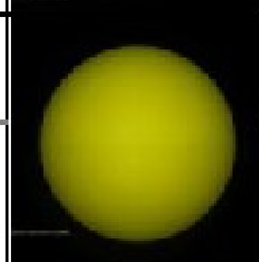
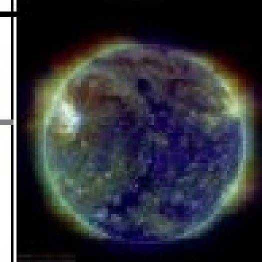
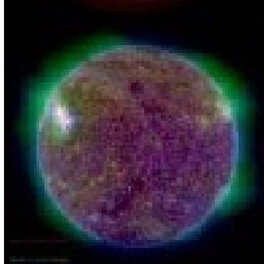
VHF Conditions

Aur Lat (Auroral Latitude): Indicates lowest latitude from the current Aurora Activity measurement. Text color coded for low activity, hi-latitude, & mid-latitude.
Aurora (Northern Auroral Activity): Band Closed = No/Low Auroral activity. High LAT AUR = Auroral activity >60°N. MID LAT AUR = Auroral activity 60° to 30°N.
EsEU (Sporadic E - Europe): Band Closed = No Sporadic E (ES) activity. High MUF (2M only) = Cond support 2M ES 50/70/144MHz ES = Respective band open
EsNA (Sporadic E - North America): Band Closed = No Sporadic E (ES) activity. High MUF = Cond support 2M ES 144MHz ES = ES reported @ 2M
MUF (Max Usable Frequency Bar Color): No Sporadic E (ES) activity / ES reported @ 6M / ES reported @ 4M / Cond support 2M ES / ES reported @ 2M
MS (Meteor Scatter Bar): Use color code below bar to determine relative activity.

Putting the Solar Images to Use (1)

SoHo/SDO/Other Image	Å nm ?image=	Temp K Temp °C Temp °F	SoHo/SDO/Other Image	Å nm ?image=	Temp K Temp °C Temp °F	SoHo/SDO/Other Image	Å nm ?image=	Temp K Temp °C Temp °F
	Spectral Line & Ionization	Best used to see		Spectral Line & Ionization	Best used to see		Spectral Line & Ionization	Best used to see
	171 Å 17.1 nm eit171	1,000,000K 999,727°C 1,799,540°F		195 Å 19.5 nm eit195	1,500,000K 1,499,727°C 2,699,540°F		284 Å 28.4 nm eit284	2,000,000K 1,999,727°C 3,599,540°F
	Iron (Fe) 8-9 times ionized	Tran-reg, sunspots, low temp loops		Iron (Fe) 11 times ionized	Tran-reg, sunspots, corona, flares		Iron (Fe) 14 times ionized	Tran-reg, sunspots, corona, high temp loops
	304 Å 30.4 nm eit304	80,000K 79,727°C 143,540°F		6302 Å 630.2 nm vsm 1	5,800K 5,527°C 9,980°F		8542 Å 854.2 nm vsm 2	10,000K 9,727°C 17,540°F
	Helium (He) 1 times ionized	Chromosphere, Tran-reg, Prominence, sunspots, Granules		Iron (Fe) 0 times ionized	Photosphere, sunspots		Calcium (Ca) 1 times ionized	Photosphere, Chromosphere, sunspots
	9500 Å 950 nm corona	2,000,000K 1,999,727°C 3,599,540°F		NA NA c2	2,000,000K 1,999,727°C 3,599,540°F		NA NA c3	2,000,000K 1,999,727°C 3,599,540°F
	White Light	Corona		White Light	Corona, CME, Flare		White Light	Corona, CME, Flare
	10830 Å 1083 nm sh	20,000K 19,727°C 35,540°F		6562.8 Å 656.28nm ha	20,000K 19,727°C 35,540°F		6767 Å 676.7 nm mdi	6,000K 5727°C 10,340°F
	Helium (He) 0 times ionized	Chromosphere, Tran-reg, sunspots, Granules		Hydrogen (H) Hα-Line	Chromosphere, Tran-reg, sunspots, flares		Nickel (Ni) 0 times ionized	Photosphere, sunspots

Putting the Solar Images to Use (2)

	Magnetogram N/A mag	N/A N/A N/A	N/A N/A	Sunspots
	171 Å 17.1 nm sdo_171	1,000,000K 999,727°C 1,799,540°F	Iron (Fe) 8 times ionized	Quiet corona, upper transition region
	193 Å 19.3 nm sdo_193	1,500,000K 1,499,727°C 2,699,540°F	Iron (Fe) 11/23 times ionized	Corona and hot flare plasma
	335 Å 33.5 nm sdo_335	5,000,000K 5,000,000°C 9,000,000°F	Iron (Fe) 15 times ionized	Active-region corona
	304 Å 30.4 nm sdo_304	80,000K 79,727°C 143,540°F	Helium (He) 1 times ionized	Chromosphere, transition region
	94 Å 9.4 nm sdo_094	9,000,000K 9,000,000°C 16,000,000°F	Iron (Fe) 17 times ionized	Flaring regions
	131 Å 13.1 nm sdo_131	1,000,000K 999,727°C 1,799,540°F	Iron (Fe) 7/19/22 times ionized	Flaring regions
	211 Å 22.1 nm sdo_211	2,000,000K 1,999,727°C 3,599,540°F	Iron (Fe) 13 times ionized	Active-region corona
	1600 Å 160.0 nm sdo_1600	Unknown	Carbon (C) 3 times ionized	Transition region, upper photosphere
	1700 Å 170.0 nm sdo_1700	Unknown	Continuum	Temperature minimum, photosphere
	4500 Å 450.0 nm sdo_4500	2,000,000K 1,999,727°C 3,599,540°F	White Light	Photosphere
	211/193/ 171 Å sdo_comp1	Unknown	Composite Image	See above
	304/211/ 171 Å sdo_comp2	Unknown	Composite Image	See above
	94/193/ 335 Å sdo_comp3	Unknown	Composite Image	See above

N0NBH Solar Web Pages

- I hope the information in this presentation helps you with Ham Radio DX on all the bands
- Additional data, tools, and even Solar banners/widgets for your webpages and computer devices are available at http://www.hamqsl.com/solar.html
- Please feel free to contact me with any questions, comments, or additional ideas at n0nbh@cox.net
- 73 all and good DX de Paul N0NBH