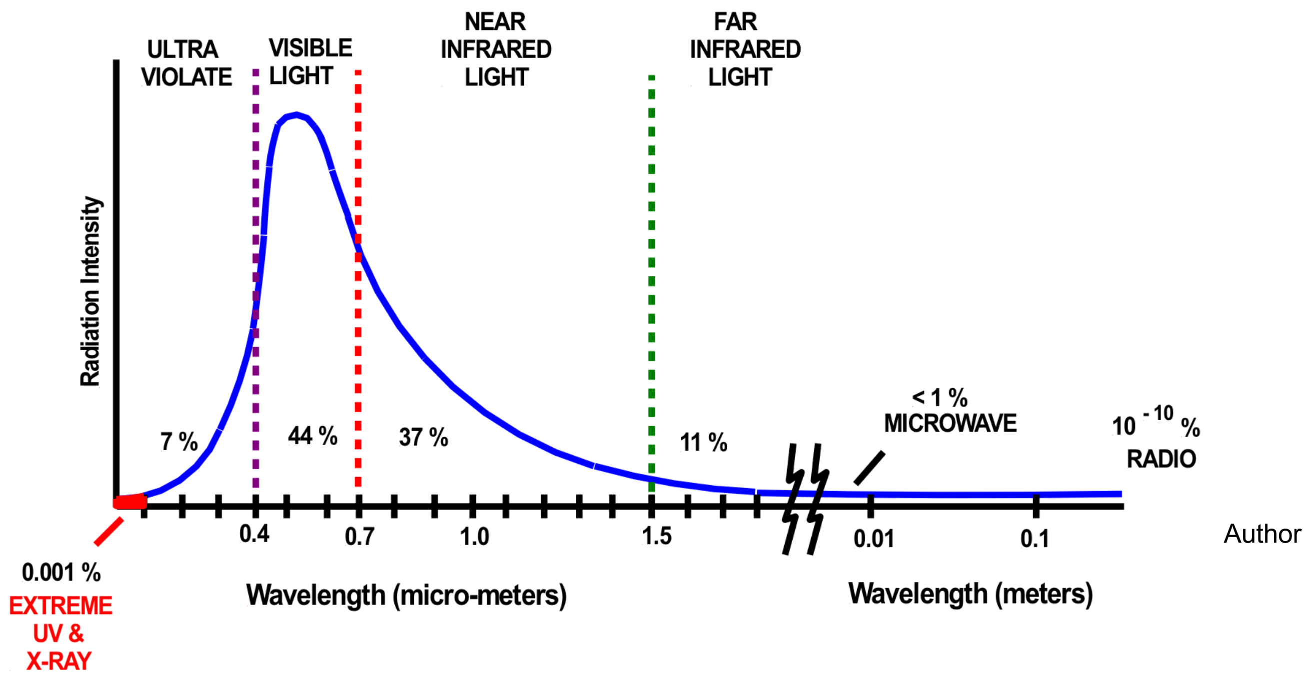
HF Radio Communications Overview

Ken Larson KJ6RZ
April 2024

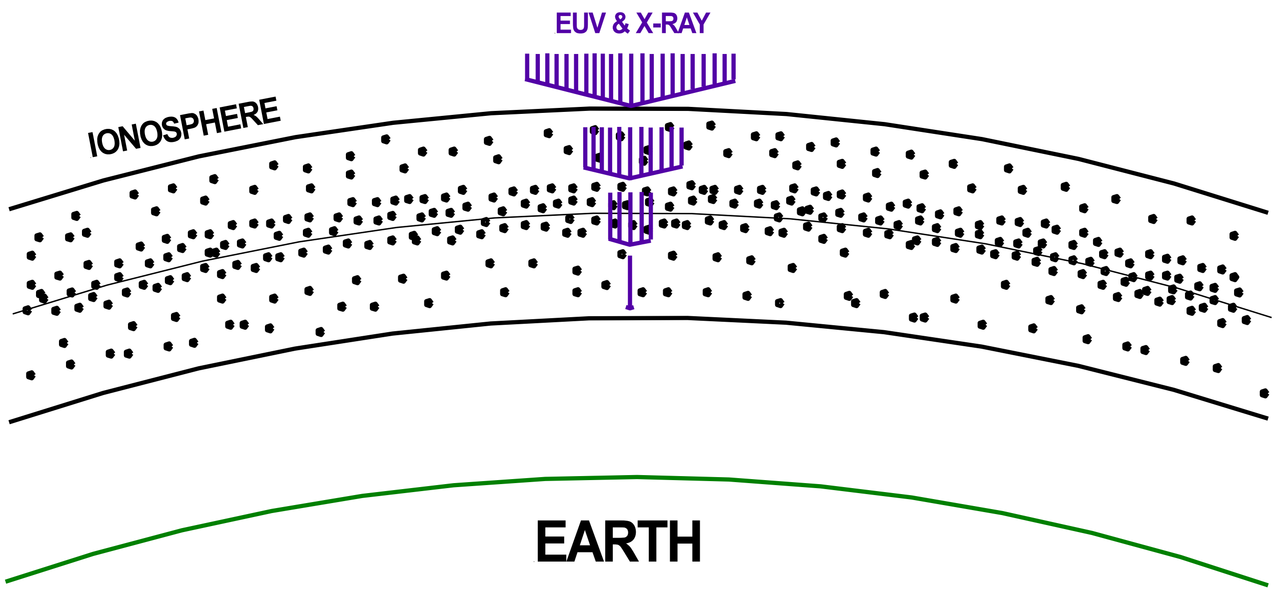
www.skywave-radio.org

Solar Spectrum



- The Extreme Ultra-violate (EUV) and X-Ray radiation that we depend upon to create the ionosphere accounts for only 0.001% of solar energy output
- EUV & X-Ray radiation is VERY deadly
- The ionosphere shields us from EUV & X-Ray radiation making live on Earth possible

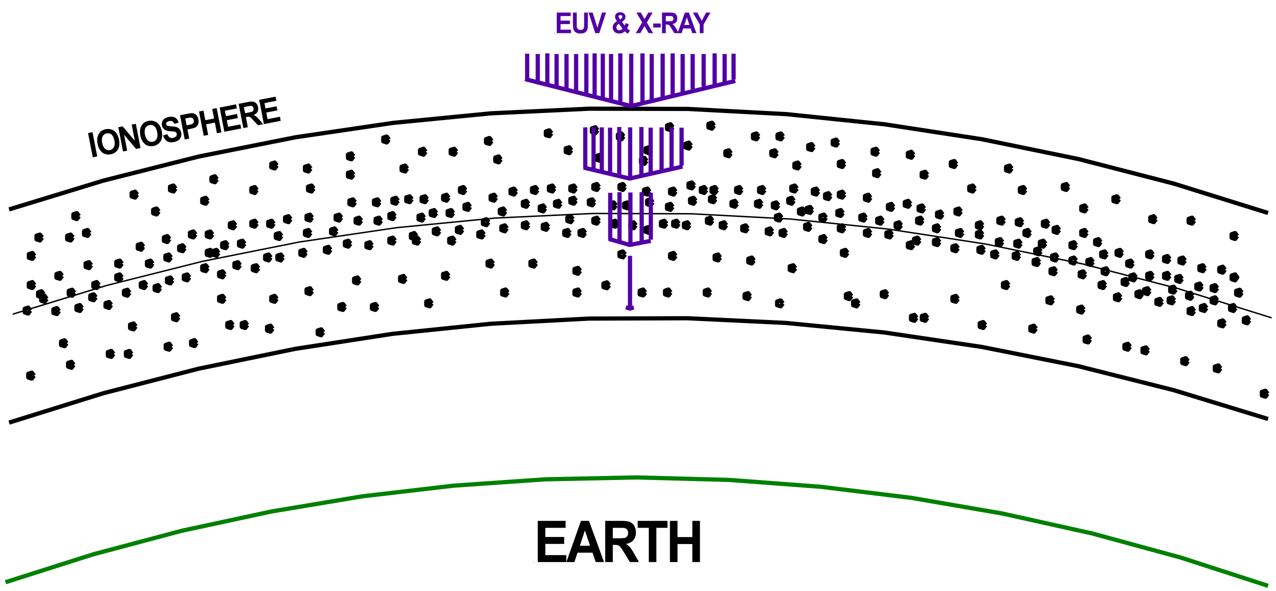
Formation of the Ionosphere



Author

- EUV & X-ray radiation from the Sun ionizes atoms in the upper atmosphere
- This radiation is intense at the top of atmosphere but few atoms to ionize
- As the radiation penetrates deeper into the atmosphere, the atmosphere's density increases (more atoms) resulting in higher levels of ionization

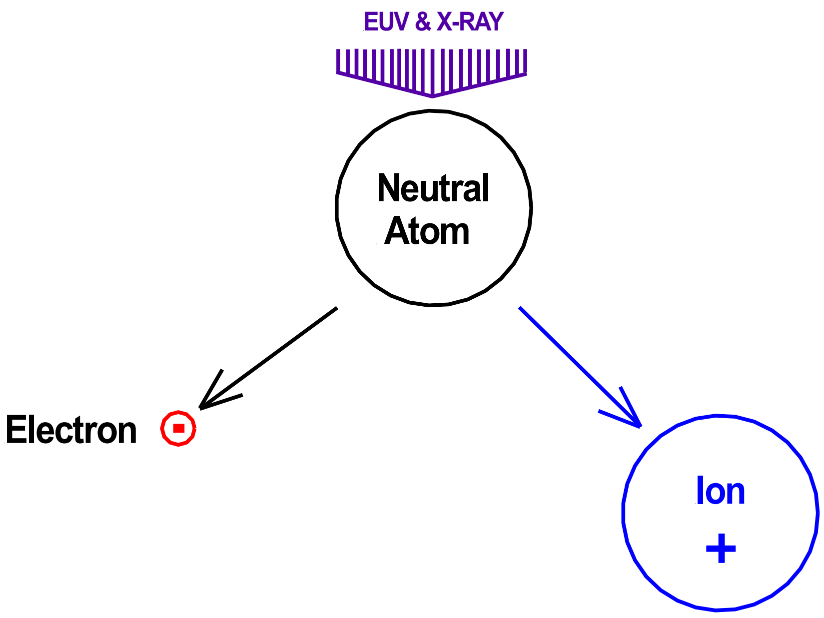
Formation of the Ionosphere continued



- The ionization process continuously weakens EUV & X-ray radiation
- Consequently, the number of atoms ionized decreases as the radiation penetrates further into the atmosphere, even though the density of atoms continues to increases
- **The greatest level of ionization occurs roughly in the middle of the ionosphere**
- From that point downward toward the Earth ionization levels drop and eventually disappear

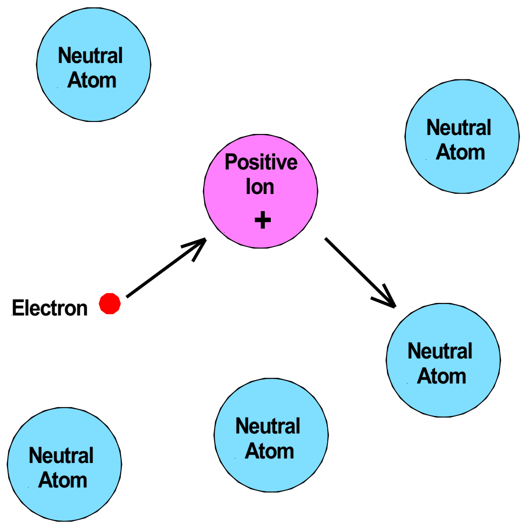
Upper Atmosphere Ionization

- Solar EUV & X-ray radiation bombards the upper atmosphere
- Some of the EUV (or X-ray) radiation may be absorbed by a neutral atom
- The absorbed energy excites electrons in the atom
- If an electron is excited enough, it will break free from the atom
- Resulting in a free electron and a positively charged ion
- Neutral atoms and ions are massive compared to free electrons
- Ions are typically 20,000 times more massive than electrons

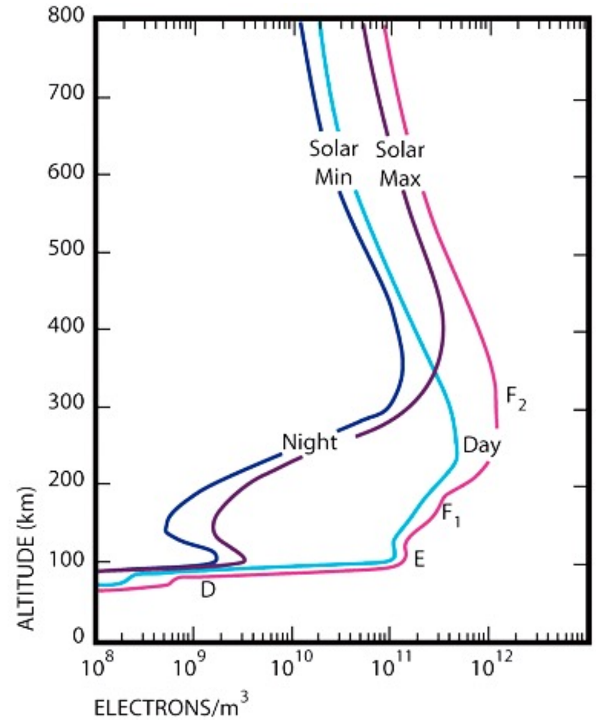


author

Monatomic Recombination



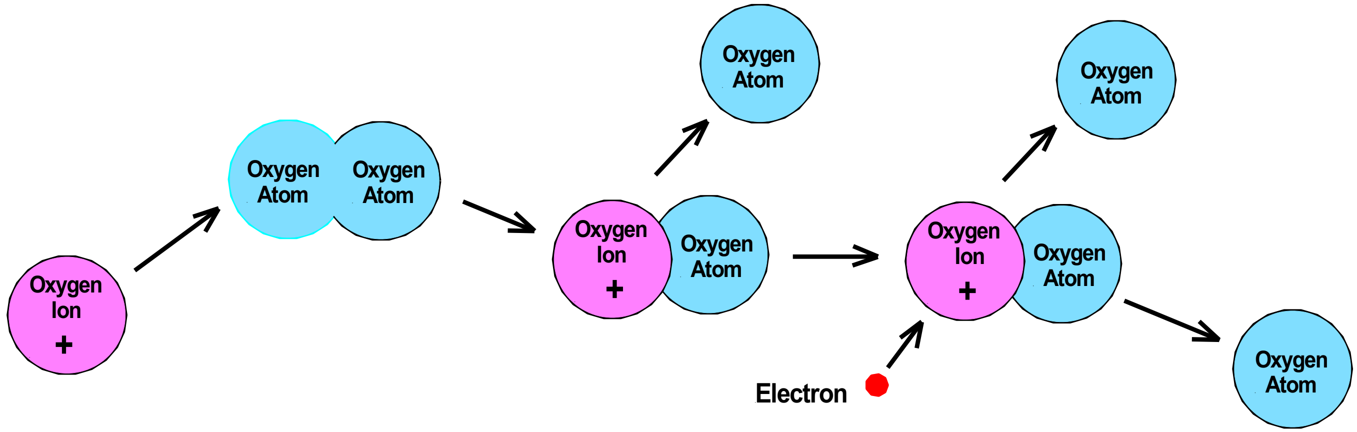
Author



QSL.net

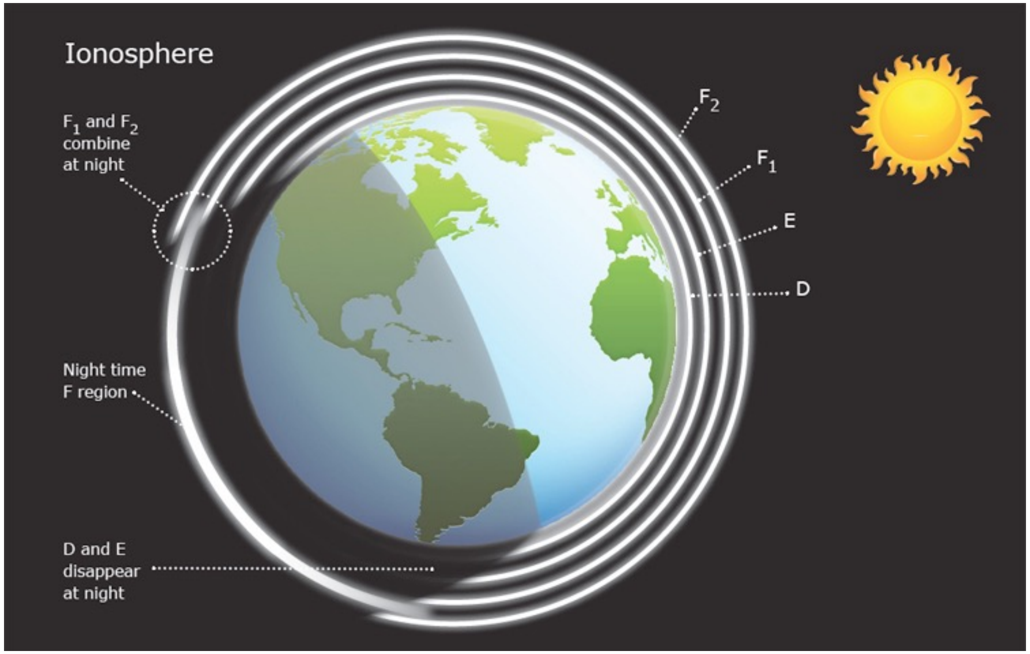
- The ionosphere looses free electrons through the process of recombination
- In its simplest form a positive ion captures a free electron converting the ion back into a neutral atom
- Recombination occurs all the time, both day and night
- However, ionization occurs only during the day when EUV & X-ray radiation from the Sun are present
- Consequently, electron concentrations are much greater during the day than at night

Molecular Recombination



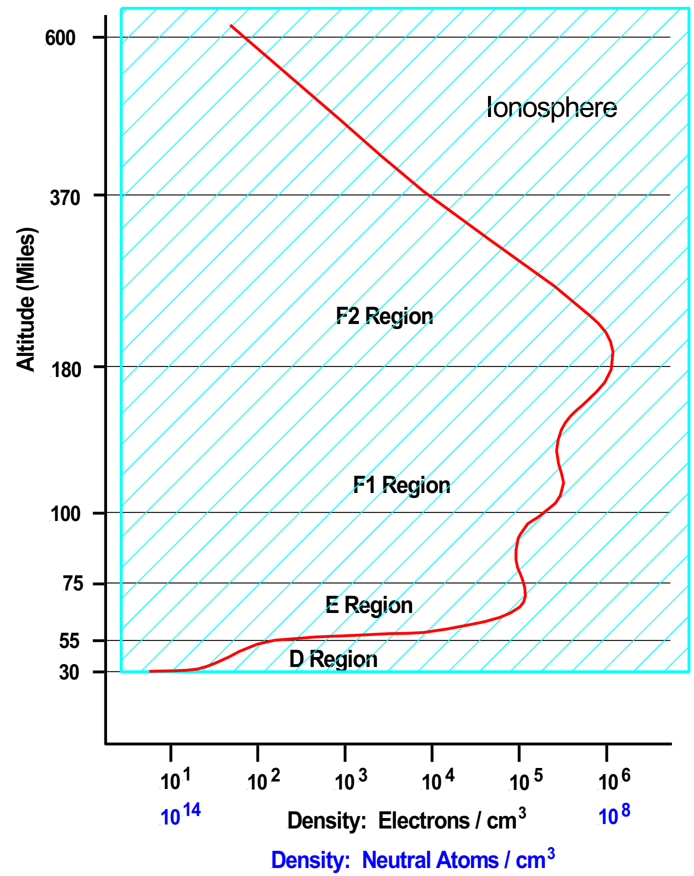
author

- Recombination also occurs at the molecular level through a process know as Dissociative Recombination
- In the example above, an oxygen ion collides with a neutral oxygen molecule replacing one of the molecule's neutral atoms
- The molecule becomes a positive molecular ion
- Eventually a free electron is captured by the molecular ion causing the molecule to split (dissociate) into two neutral oxygen atoms
- The rate of Dissociative Recombination is about 100,000 greater than monatomic recombination



Science Learning Hub

Ionospheric Regions of the Ionization

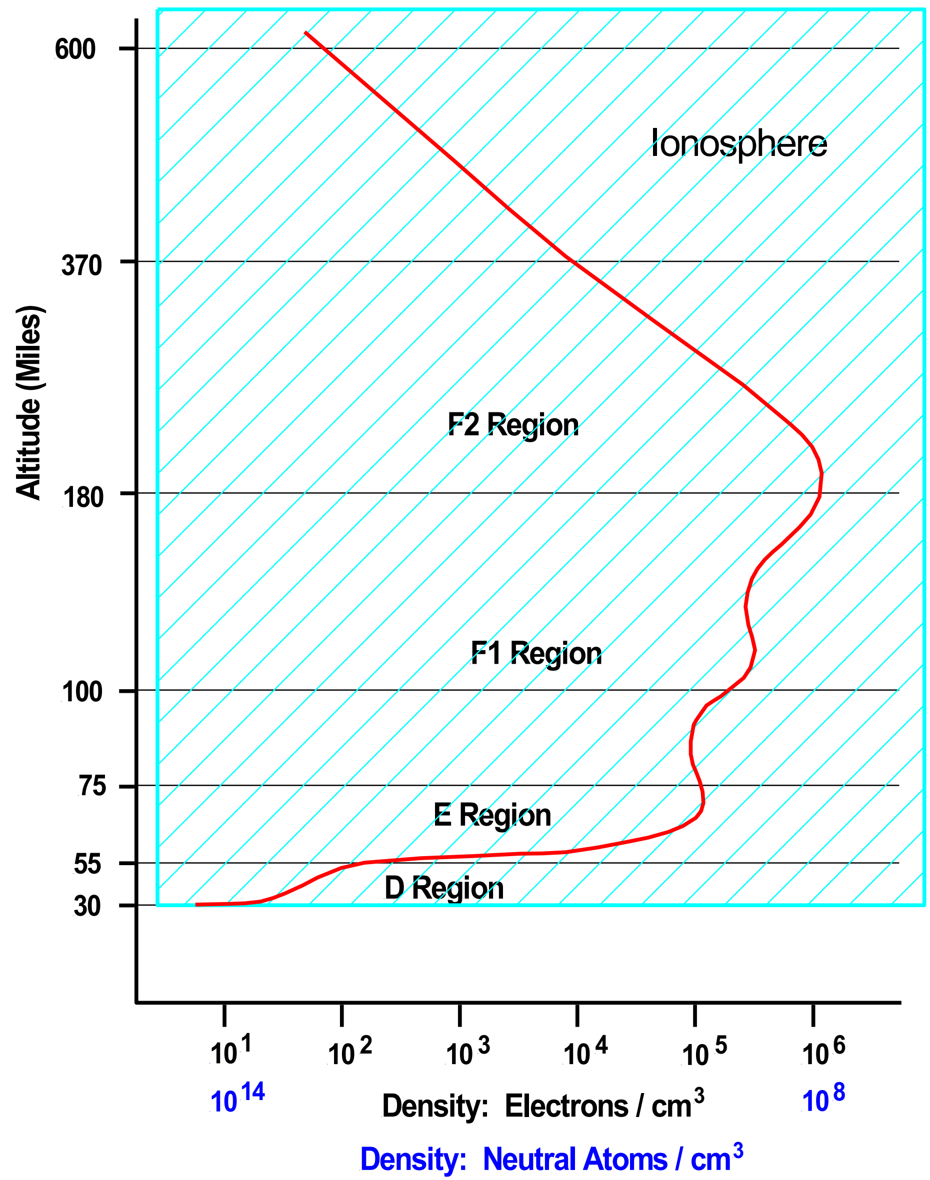


Author

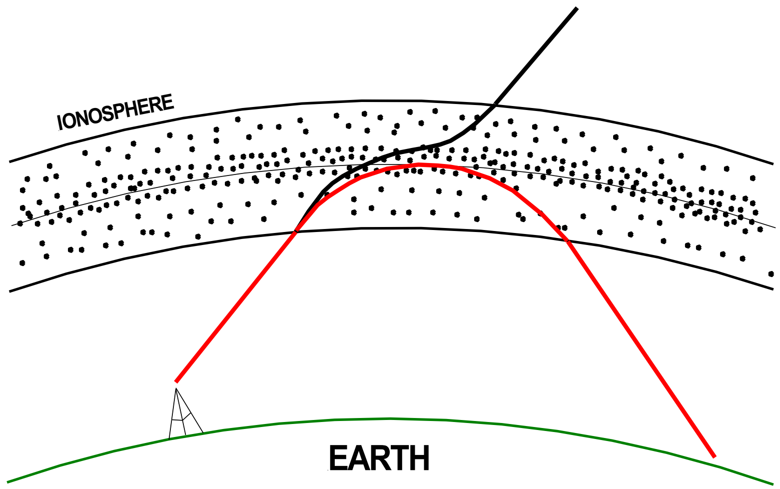
- The ionosphere consists of the D, E, F1, and F2 regions, one region flowing into the next
- All four develop during the day with the
- D region disappearing at night
- E region mostly disappearing, and
- The F1 level merging into a weakening F2 region at night
- The F2 region is the most heavily ionized region

The Ionosphere is Very Thin and Wispy

- The neutral atmosphere is **hundreds** to **billions** of times more dense than the ionosphere
- The ionosphere is very thin and wispy. Easily blow around by high altitude winds
- The 10.7 cm Solar Flux Index (SFI) provides a good measure of solar activity and level of ionization
- The SFI is available on the website www.skywave-radio.org
- 50 < SFI < 300
- SFI = 60 very poor radio conditions
- SFI = 200 very good conditions



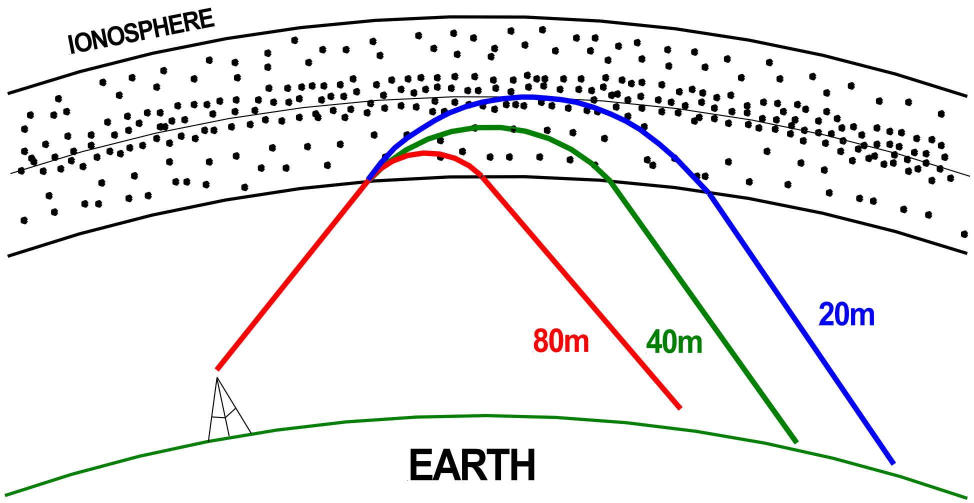
Ionosphere Refraction



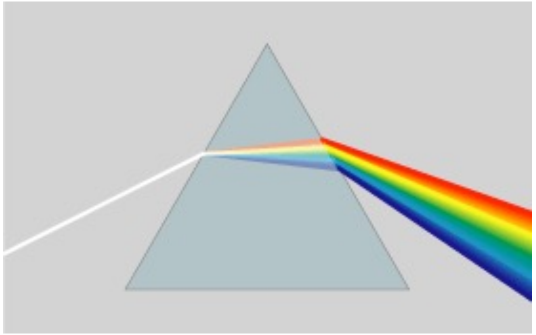
author

- Radio waves bends back toward Earth as they travel through increasing levels of ionization from the bottom to the middle of the ionosphere
- When the radio waves travel back down toward the Earth, they bend in the opposite direction (straighten out) as the levels of ionization decreases
- Similarly, radio waves that pass through the most dense part of the ionosphere bend away from the Earth, as they travel through decreasing levels of ionization, and are lost to outer space

Wavelength Dependency of Refraction



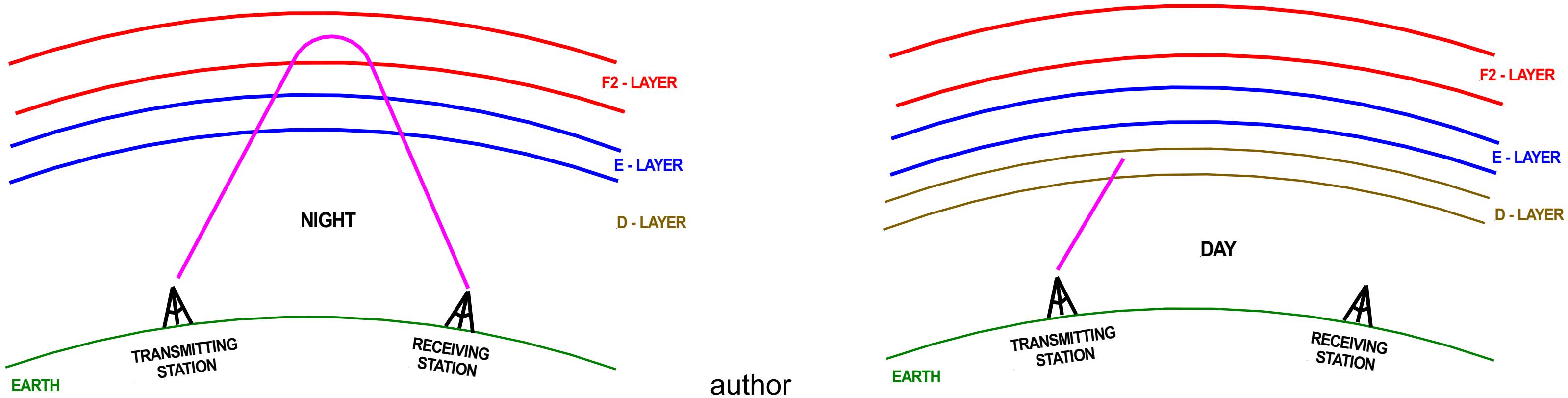
Author



Wikipedia

- The ionosphere's index of refraction is wavelength dependent
- Long wavelength 80 meter (3.8 MHz) signals refract quickly in the lower part of the ionosphere
- Shorter wavelength 20 meter (14.2 MHz) signals travel further into the ionosphere before refracting back to Earth
- This same wavelength dispersion phenomena causes sunlight to be split into its rainbow of colors when refracting through a glass prism

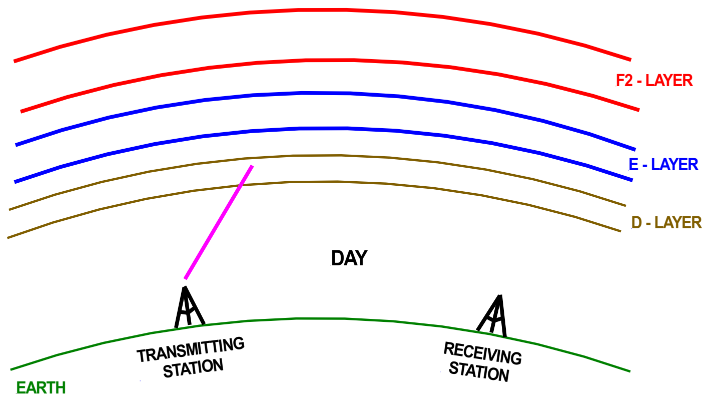
Anatomy of Absorption



- Radio waves are partially absorbed as they pass through the ionosphere
- Free electrons absorb energy from the passing radio waves causing the
- Electrons to vibrate at the radio wave frequency
- In the process the vibrating electrons reradiating their absorbed radio energy
- Little radio wave energy is lost in passing thru the upper ionosphere
- **D Layer is different**
- During the day electrons recombine with ions so fast in the D Layer they do not have time to reradiate their absorbed radio wave energy
- Instead, absorbed radio wave energy is dissipated as heat in D Layer

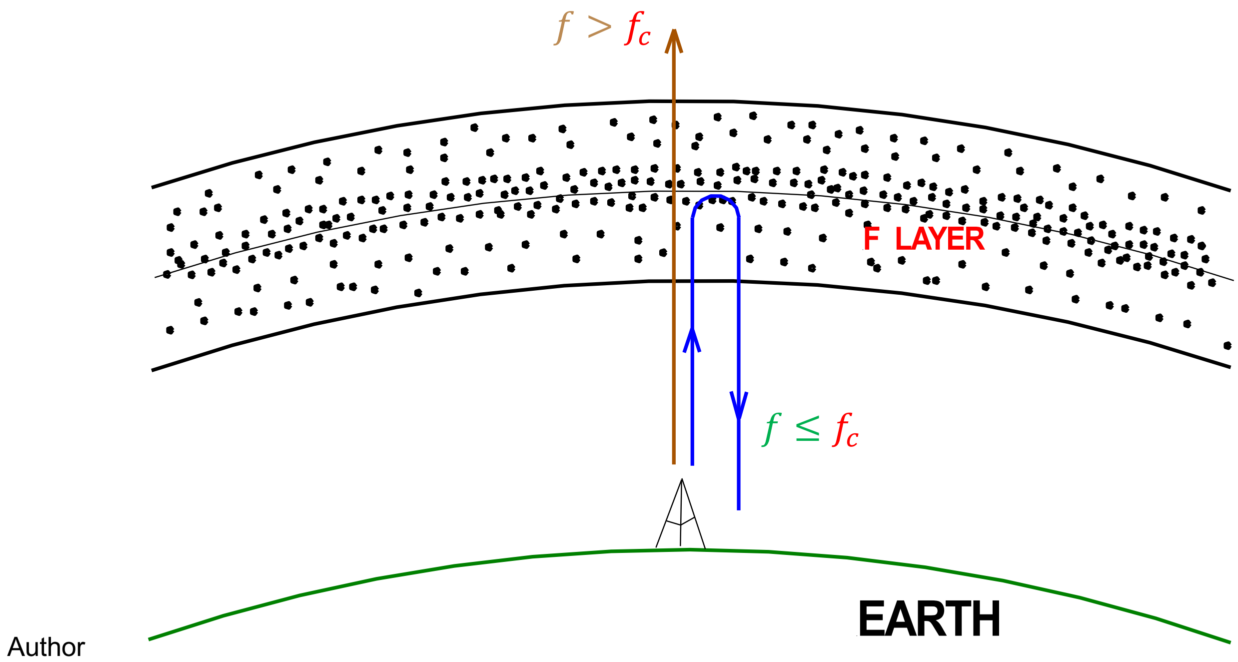
Absorption vs Frequency

$$\text{Absorption} \propto \frac{1}{f^2}$$



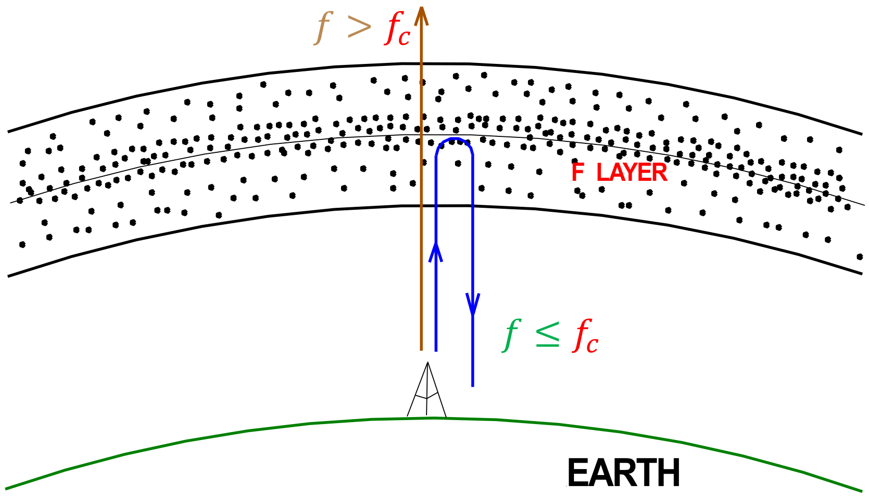
- Absorption is inversely proportional to frequency squared
- The absorption on 40 meters is only 1/4 that on 80 meters
- The absorption on 20 meters is only 1/16 that on 80 meters
- To minimize D-layer absorption, we want to operate at the highest frequency possible

Critical Frequency



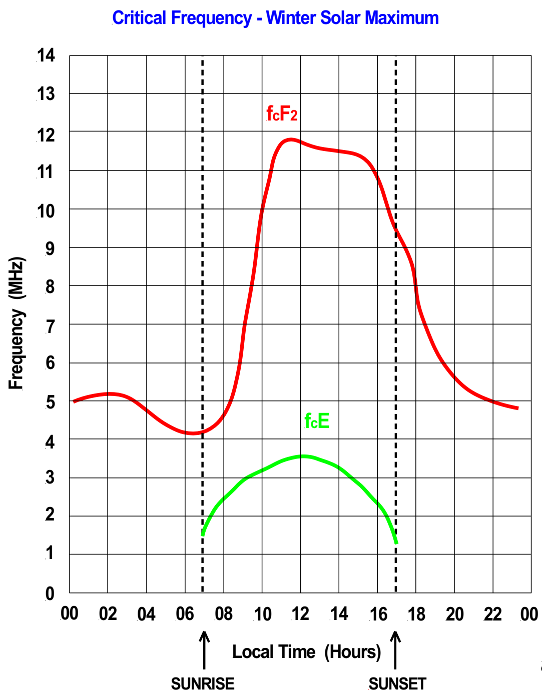
- Critical Frequency **f_c** is the **highest** frequency signal that can be transmitted straight up and reflected back down to Earth
- All signals **lower in frequency** than **f_c** will also be reflected back to Earth
- But, signals **higher in frequency** transmitted straight up will penetrate the ionosphere and be lost to outer space

Critical Frequency Is Important

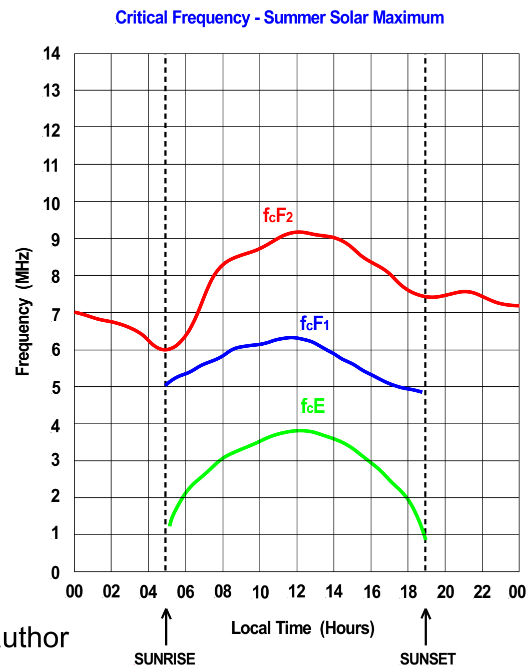


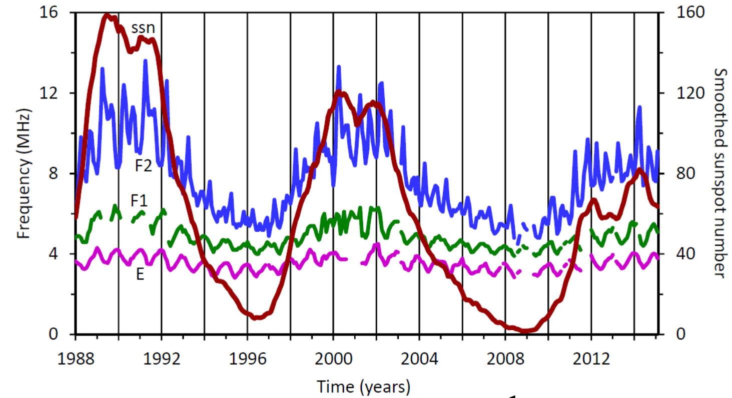
- Critical frequency in part determines what frequency bands are open
- Critical frequency determines the maximum usable frequency (MUF) that can be used to communicate with an other radio station
- Critical frequency determines if there is a skip zone or not, and if so how large the skip zone is [information needed for Winlink emergency communications]
- Critical frequency determines if Near Vertical Incident Skywave propagation (NVIS) is possible or not [information needed for local & regional HF nets]
- And more

Critical Frequency Varies



author

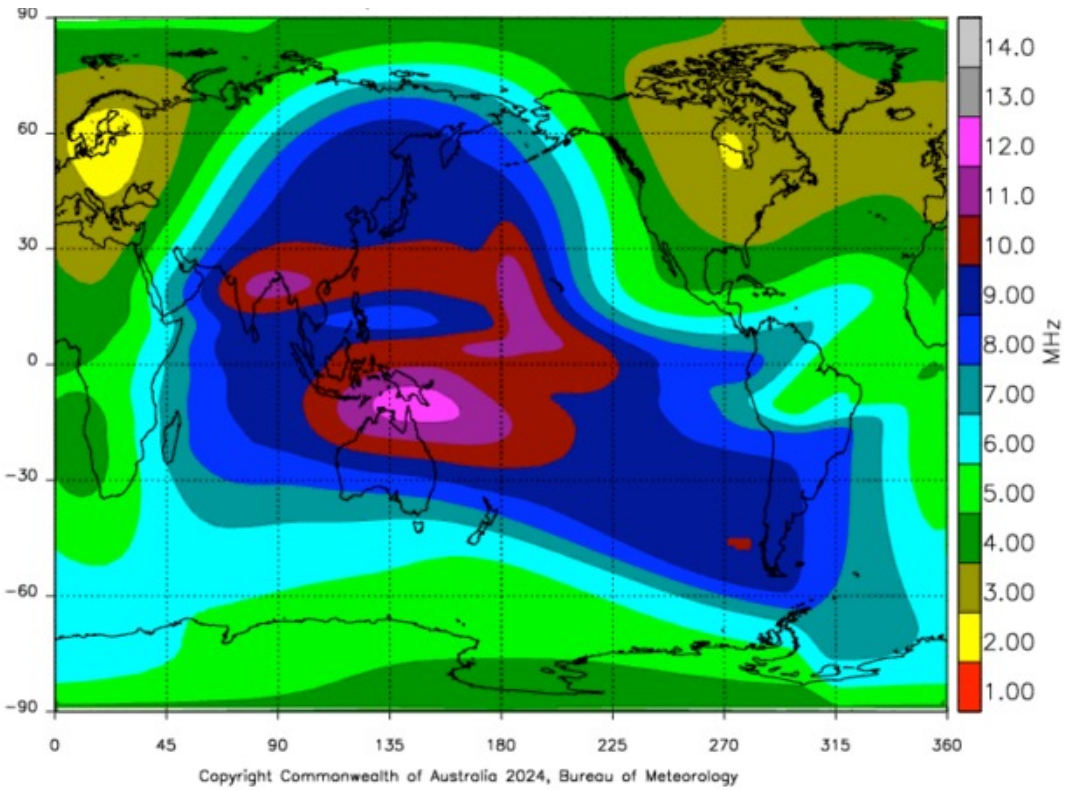




sws.bom.gov.au

- Critical Frequency varies:
  - Throughout the day as the Earth rotates,
  - Seasonally as the Earth's upper atmosphere changes, and
  - With the 11 year solar cycle as Extreme Ultra-Violate (EUV) & X-ray radiation from the Sun changes

Determining Current F2 Critical Frequency



This chart shows the Critical Frequency for January 31, 2024 at 03:00 UT (7 PM local time)

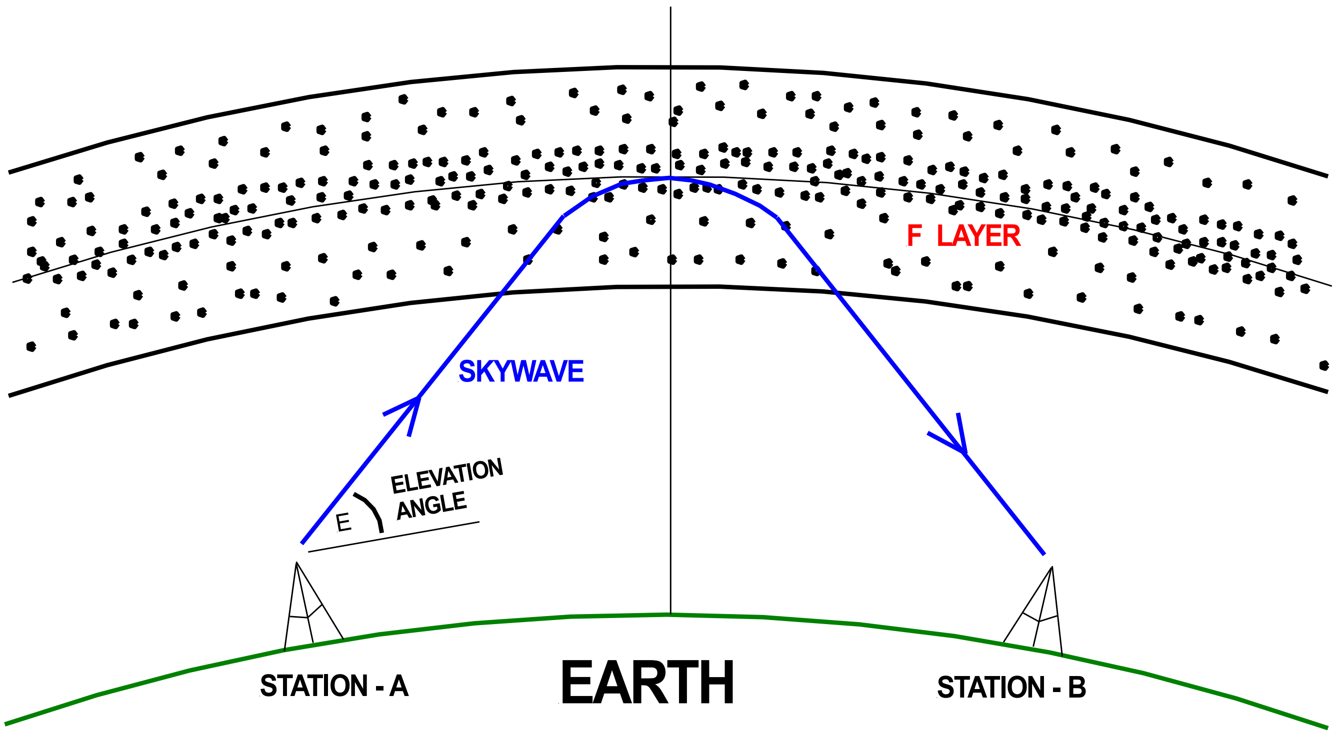
Over California the Critical Frequency was between 4 to 5 MHz

Critical frequency in Northern Europe was 2 MHz

- The Australian Government produces a global F2 critical frequency map that is available on the www.skywave-radio.org website
- The critical frequency map is updated every 15 minutes
- The map is created automatically from reports received from ionosonde monitoring stations around the world
- **Seasonal Variation**: The shape of fc profiles are different in N. Hemisphere (winter) than in S. Hemisphere (summer)

Maximum Usable Frequency (MUF) is:

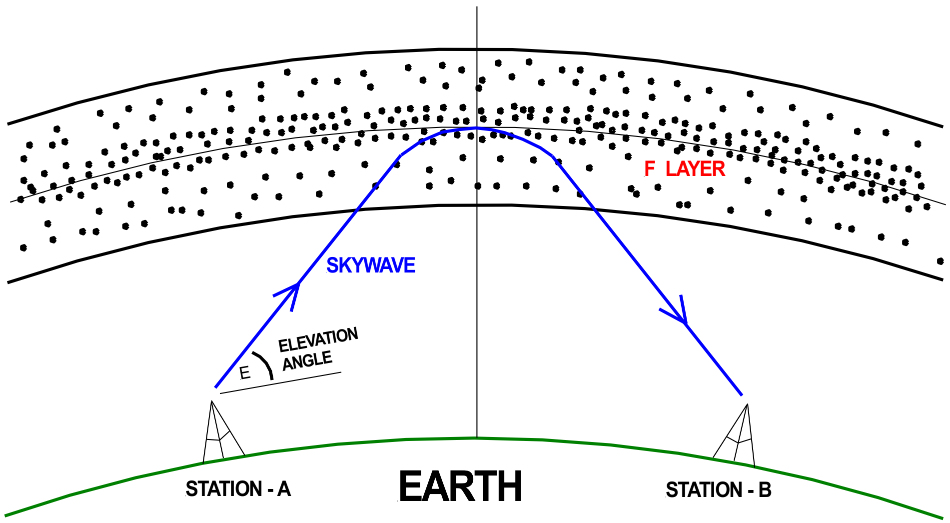
- The highest frequency radio signal that is
- Capable of propagating through the ionosphere
- From one specific radio station to an other



Author

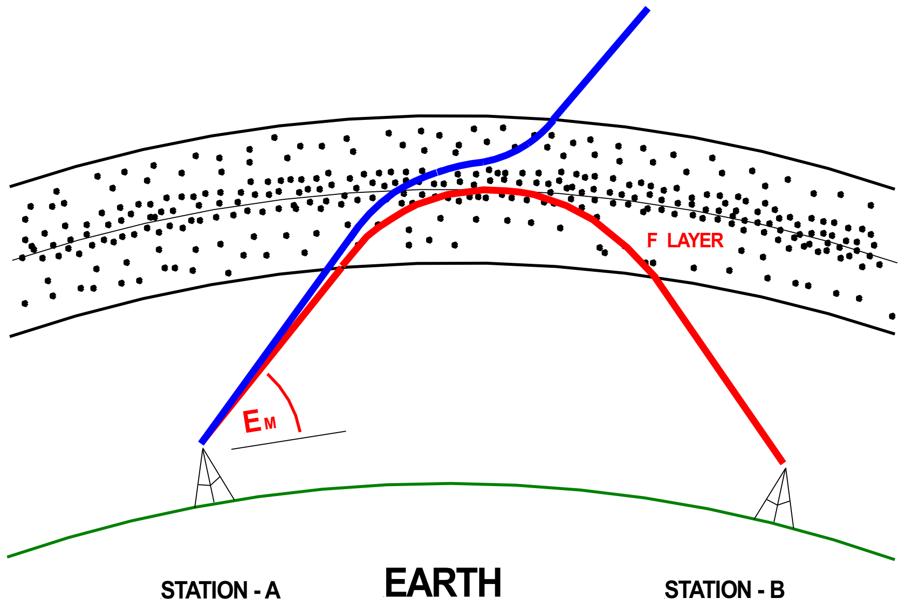
MUF Equation

$$MUF = \frac{f_c}{\sin E}$$



- MUF = Maximum Usable Frequency
- f_c = Critical Frequency of the ionosphere at the refraction point
- E = The elevation angle of the signal radiating from your antenna

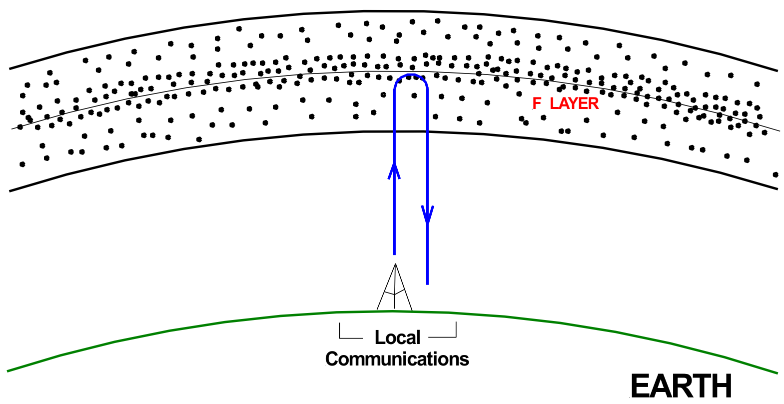
Elevation Angle E

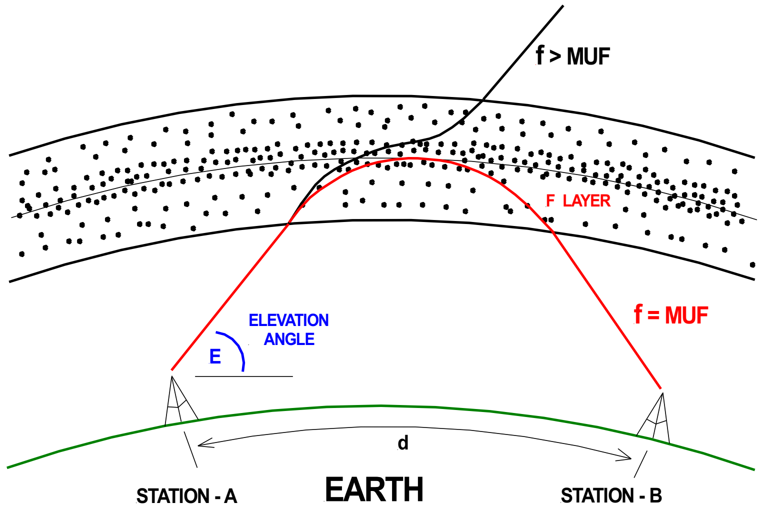


$$MUF = \frac{f_c}{\sin E}$$

- Elevation angle E is the angle with respect to the Earth's surface at which a signal is transmitted
- Maximum Usable Angle (MUA) is the highest angle signal (E_M) that can be transmitted and still be refracted back to Earth
- Signals transmitted at higher elevation angles (blue signals) penetrate the ionosphere and a lost to outer space

MUF is Greater Than or Equal To f_c



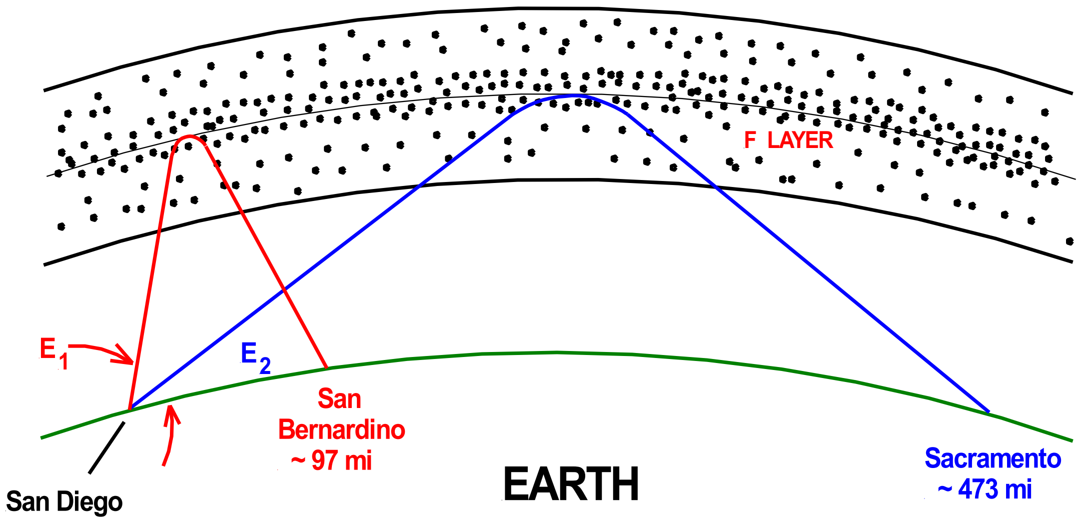


- At an elevation angle of 90 degrees, straight up, MUF = f_c
- MUF increases, becomes greater than f_c , as the elevation angle E decreases

$$\text{MUF} = \frac{f_c}{\sin E} = \frac{f_c}{\sin 90^\circ} = \frac{f_c}{1} = f_c$$

$$\text{MUF} = \frac{f_c}{\sin E} = \frac{f_c}{\sin 45^\circ} = \frac{f_c}{0.707} = 1.41\, f_c$$

MUF Depends on the Path



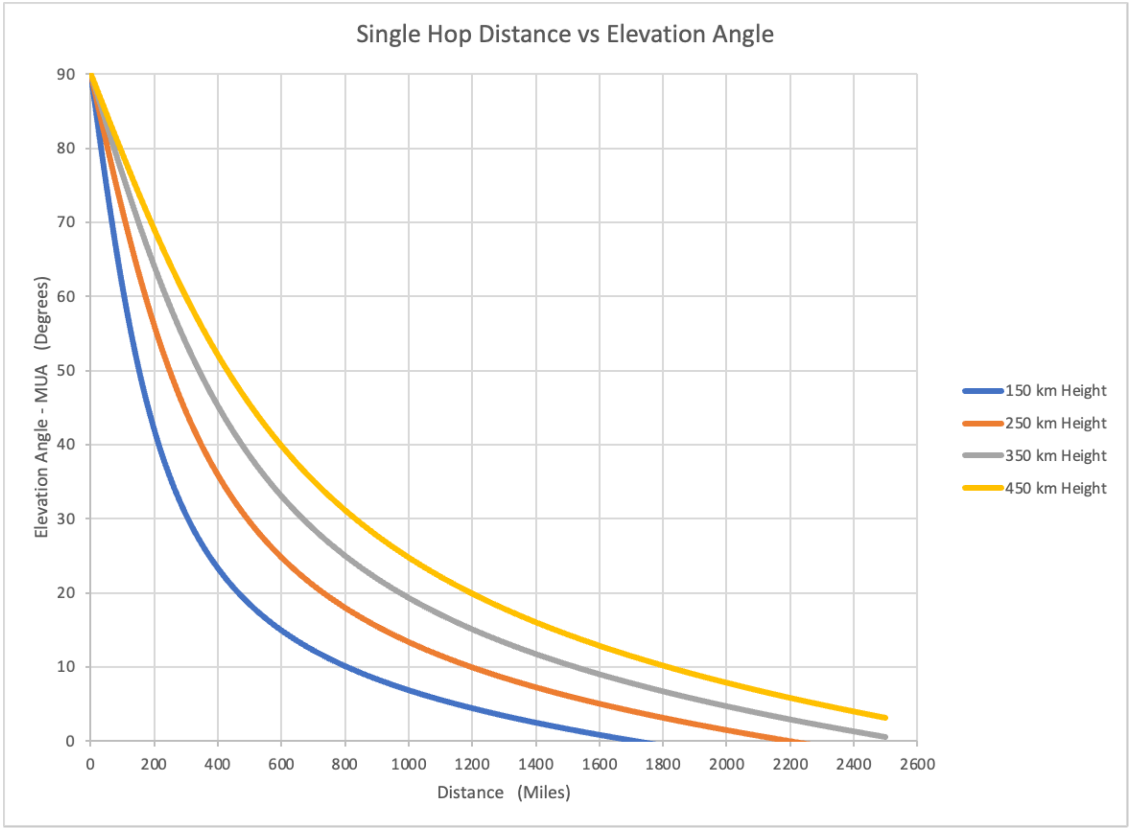
author

$$\text{MUF} = \frac{f_c}{\sin E}$$

- MUF increases as the angle E gets smaller
- Example:
- MUF2 for San Diego, CA to Sacramento is greater than
- MUF1 San Diego to San Bernardino

Distance vs Elevation Angle

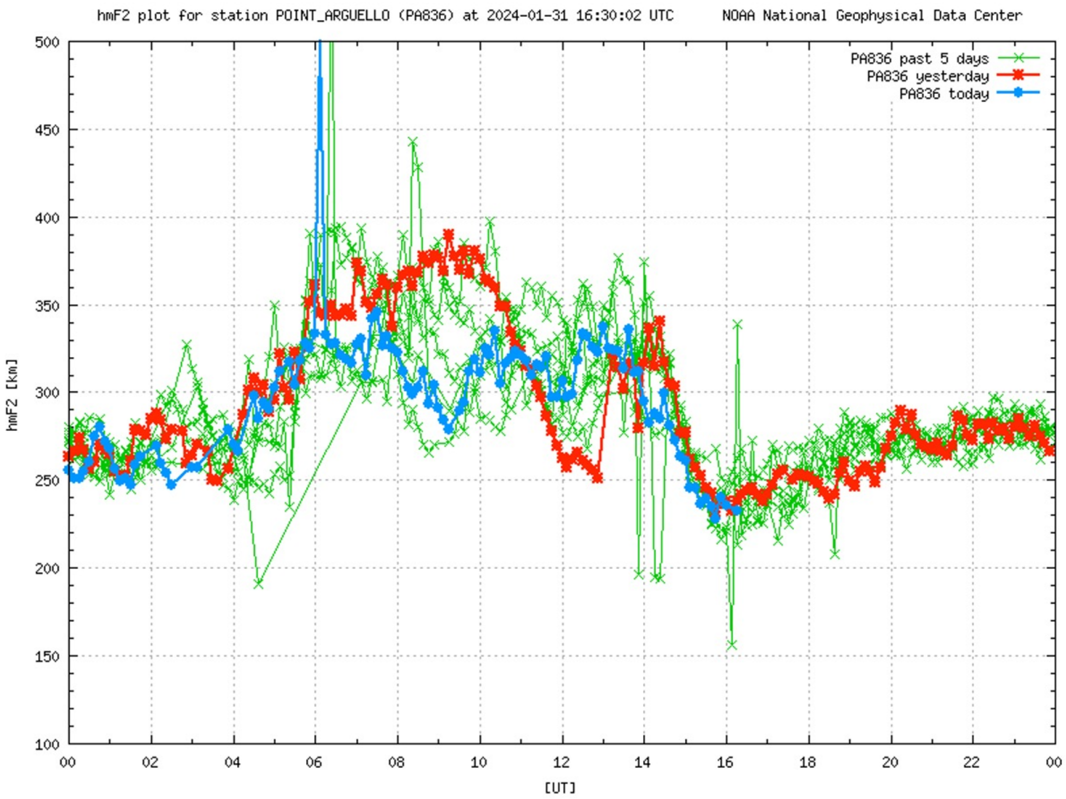
- The single hop distance traveled by a radio signal transmitted at a particular elevation angle depends on the current height of the ionosphere's F2 layer
- For example, at a height of 250 km (red trace) a signal transmitted at an elevation angle E = 20° will travel a little over 700 miles



Author

$$\text{MUF} = \frac{f_c}{\sin E}$$

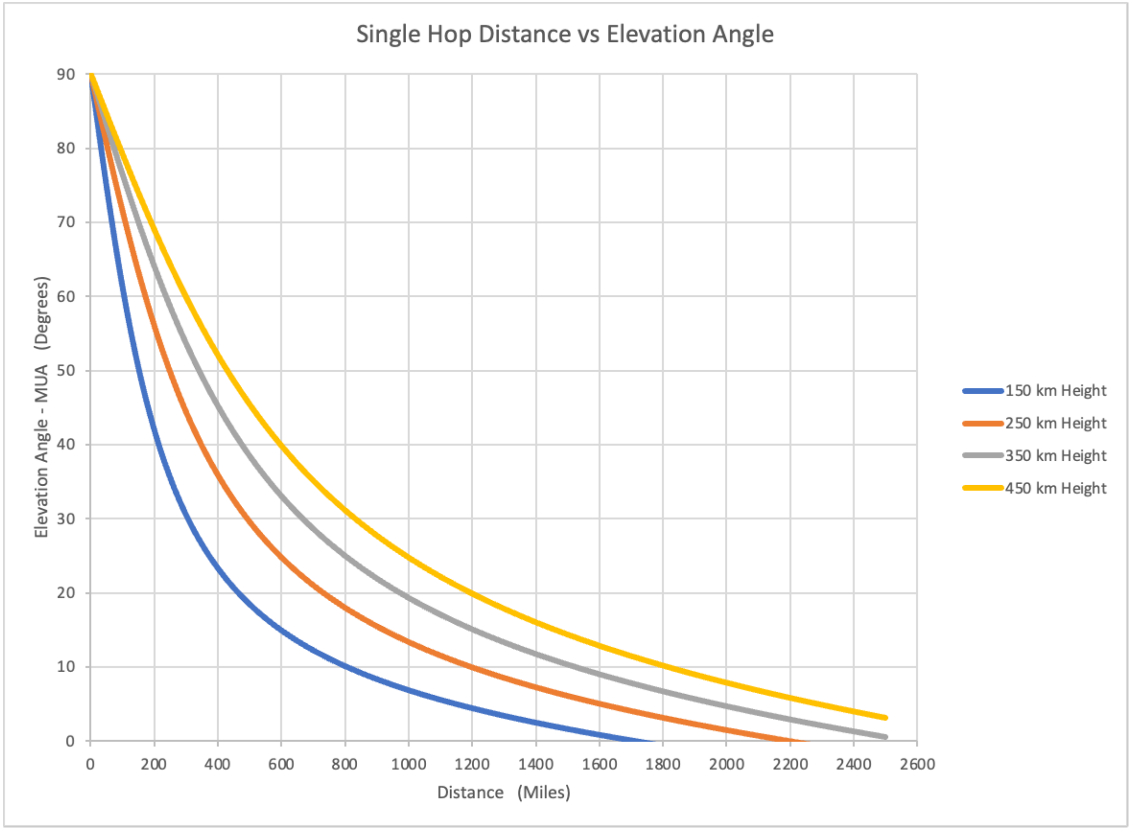
Height of Ionosphere's F2 Layer



- The current height of the F2 layer is available on the www.skywave-radio.org website by clicking on Ionosonde under the Current Conditions tab
- Data from a large number of ionosonde sites is available
- For California the regional F2 height is obtained by clicking on Point Arguello, CA h_mF2
- This chart shows h_mF2 for the past 5 days, yesterday, and today in UT time
- At the time of this chart (Jan 31, 2024 @ 03:00 UT) h_mF2 Blue Trace was 250 km

Elevation Angles for San Bernardino & Sacramento

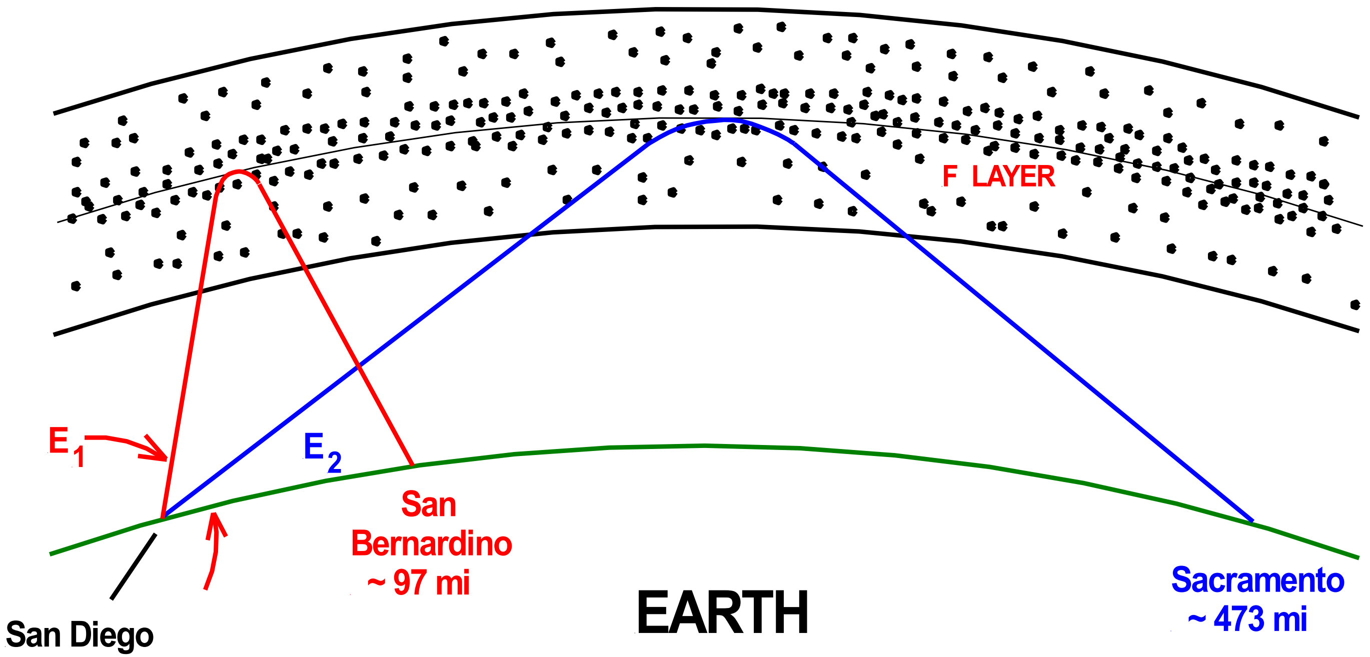
- For San Bernardino distance 97 miles, E = 75º at a F2 layer height of 250 km
- For Sacramento distance 473 miles, E = 30º



Author

$$\text{MUF} = \frac{f_c}{\sin E}$$

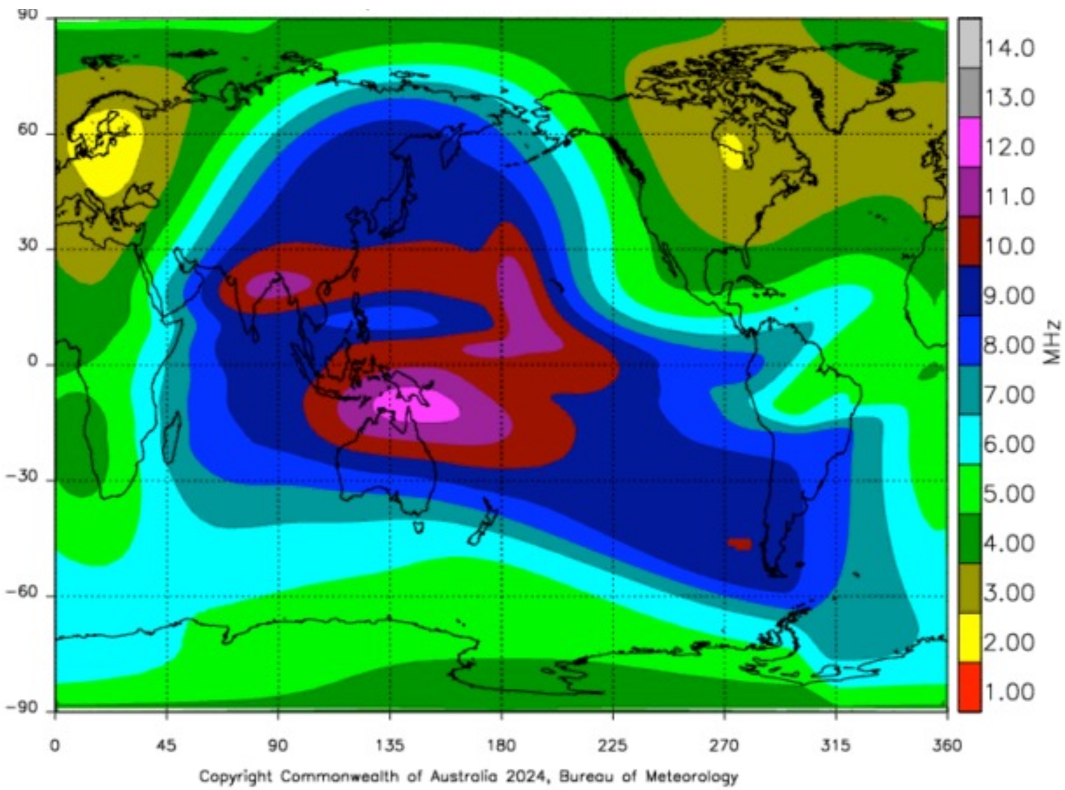
For MUF Next Determine Critical Frequency



- E1 = 75 deg
- E2 = 30 deg
- f_c = ?

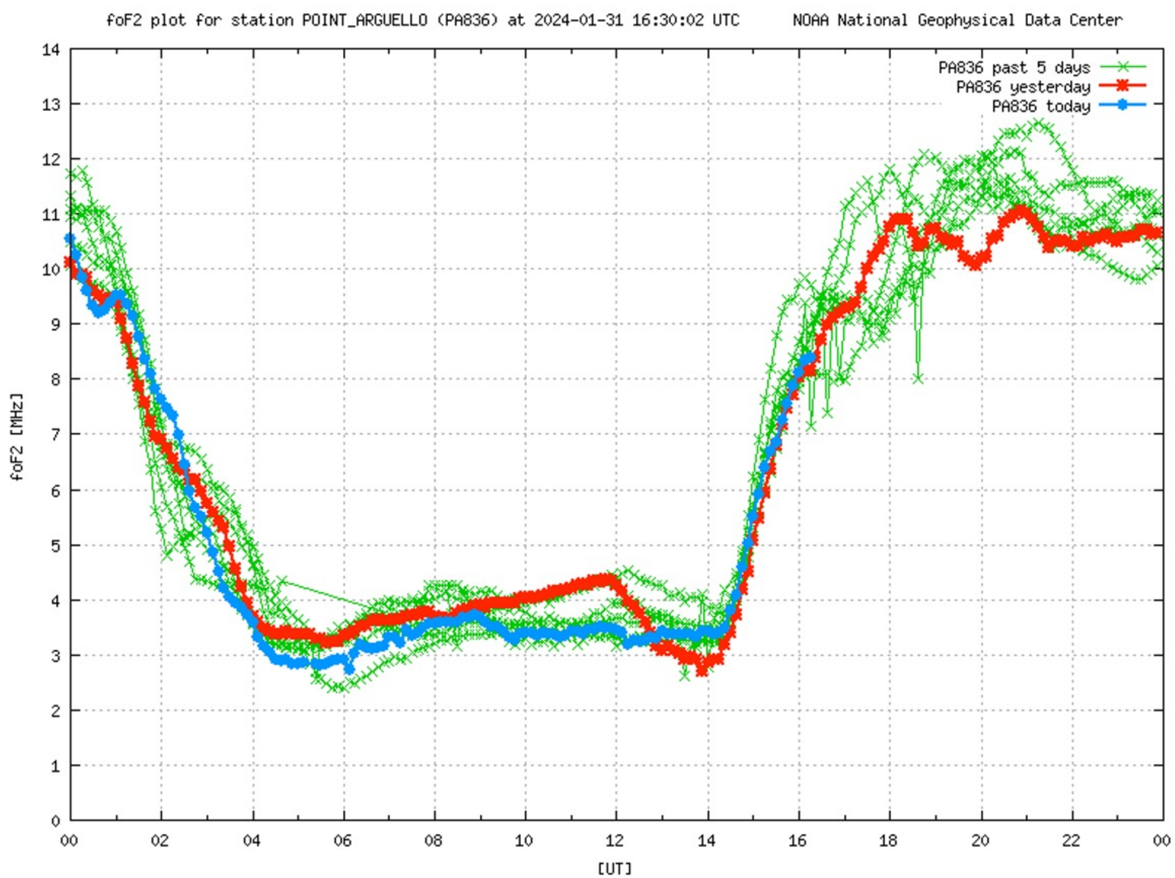
$$\mathrm{MUF} = \frac{f_c}{\sin E}$$

Determining Current F2 Critical Frequency



- To determine the critical frequency go to the global critical frequency map available under Current Conditions on the www.skywave-radio.org website
- This chart shows the Critical Frequency for January 31, 2024 at 03:00 UT
- Over California the Critical Frequency was between 4 to 5 MHz

Ionosonde F2 Critical Frequency Data

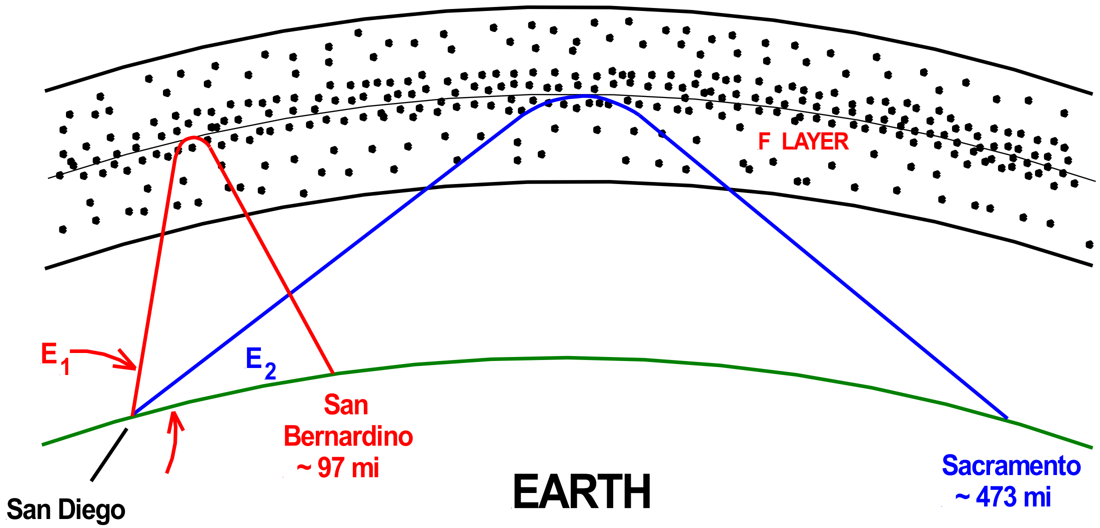


- Detailed regional critical frequency data is also available on the www.skywave-radio.org website by clicking on Ionosonde under the Current Conditions tab
- For California the regional critical frequency data is obtained by clicking on Point Arguello, CA FoF2

This chart shows foF2 for the past 5 days, yesterday, and today in UT time

At the time of this chart (Jan 31, 2024 @ 03:00 UT) foF2 Blue Trace was 5 MHz

Calculate MUF



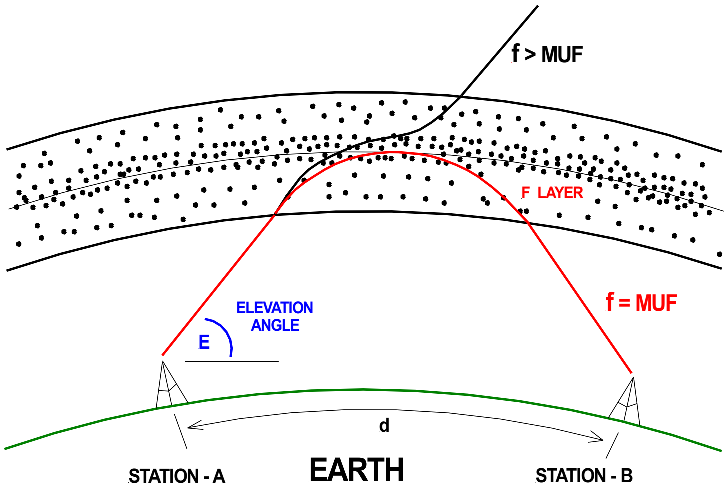
Net Operating Freq = 7.230 MHz

$$MUF_1 = \frac{f_c}{\sin E_1} = \frac{5\ MHz}{\sin 75°} = 5.18\ MHz$$

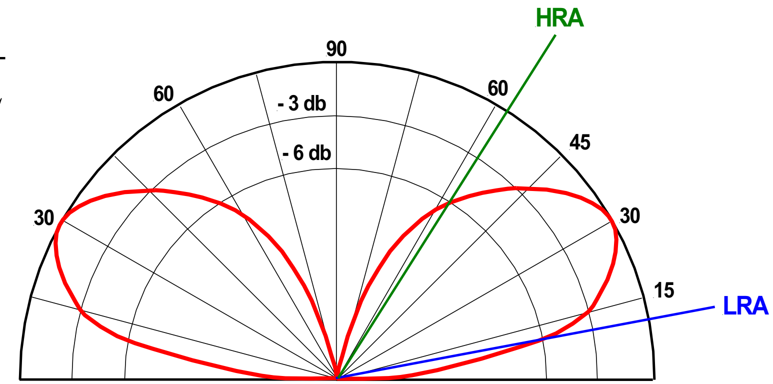
$$MUF_2 = \frac{f_c}{\sin E_2} = \frac{5\ MHz}{\sin 30°} = 10\ MHz$$

- At an operating frequency of 7.230 MHz (40 meters) San Diego can not reach (or hear) San Bernardino because the MUF for that path is less than the 7.230 MHz operating frequency. That is, signals from San Diego "skip over" San Bernardino
- Sacramento can be easily reached since its MUF is greater then the 7.230 MHz operating frequency

Published Maximum Usable Frequency



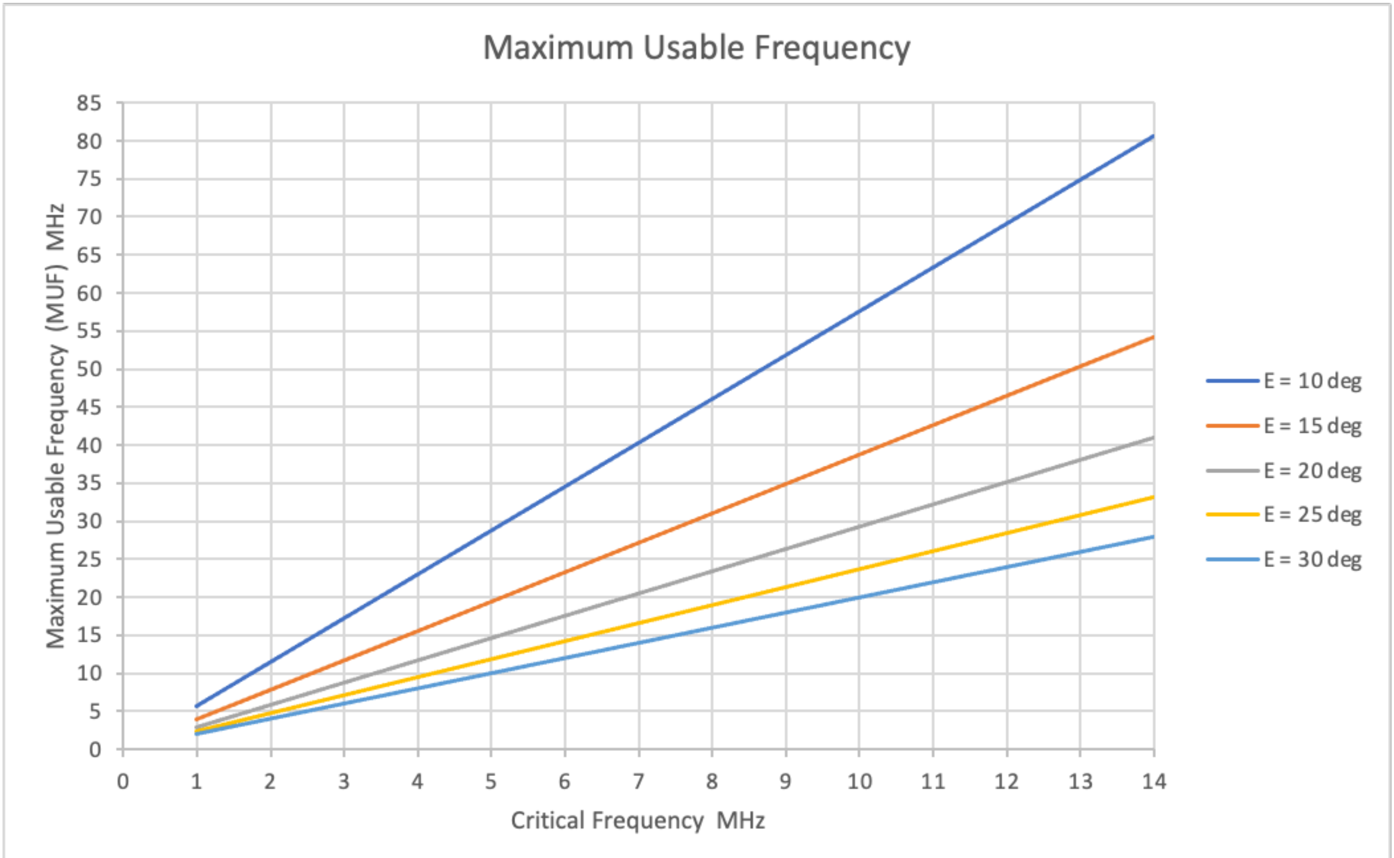
$$MUF = \frac{f_c}{\sin E}$$



author

- As we have seen, maximum usable frequency depends directly on critical frequency f_c and on the elevation angle E at which a signal is transmitted
- A signal transmitted at a very low angle, say $E = 5^o$, will have a much higher MUF than a signal transmitted at an elevation angle of 20^o
- Published MUF values are for signals transmitted at very low angles $< 5^o$
- Most amateur radio operators can't achieve published MUF values because the lowest angles that their antennas can transmit at (LRA) are generally10^o or more
- For a published MUF of 10 meters, the highest frequency band that you can communicate on may be 15 meters because of antenna limitations

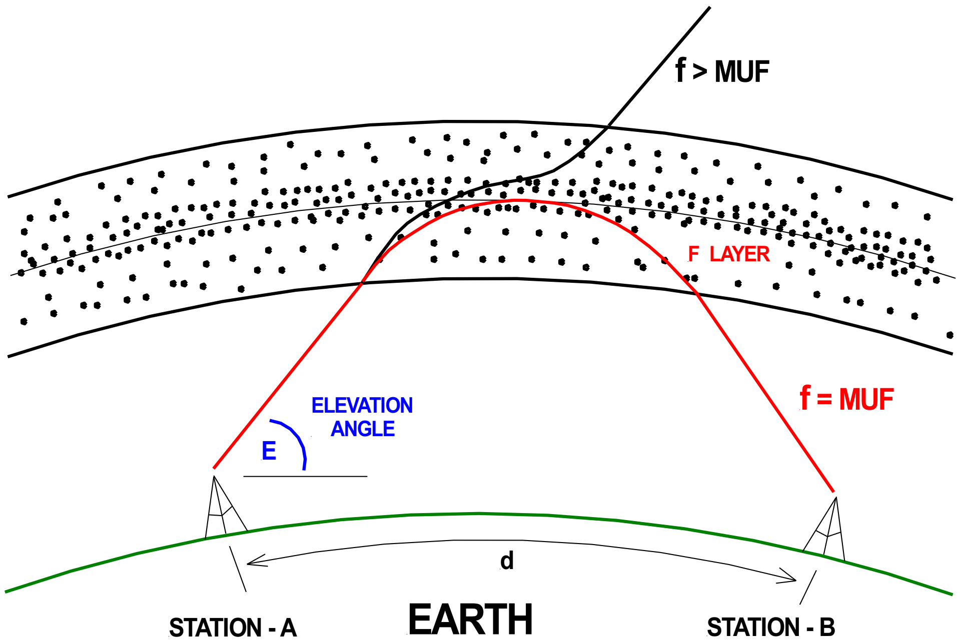
Critical Frequency & Elevation Angle Determine MUF



Author

- A high MUF results from a high critical frequency and transmitting at a low elevation angle E
- For example, at a critical frequency of 8 MHz, the MUF is approximately 30 MHz when transmitting at an elevation angle of 15^{o} (red trace)

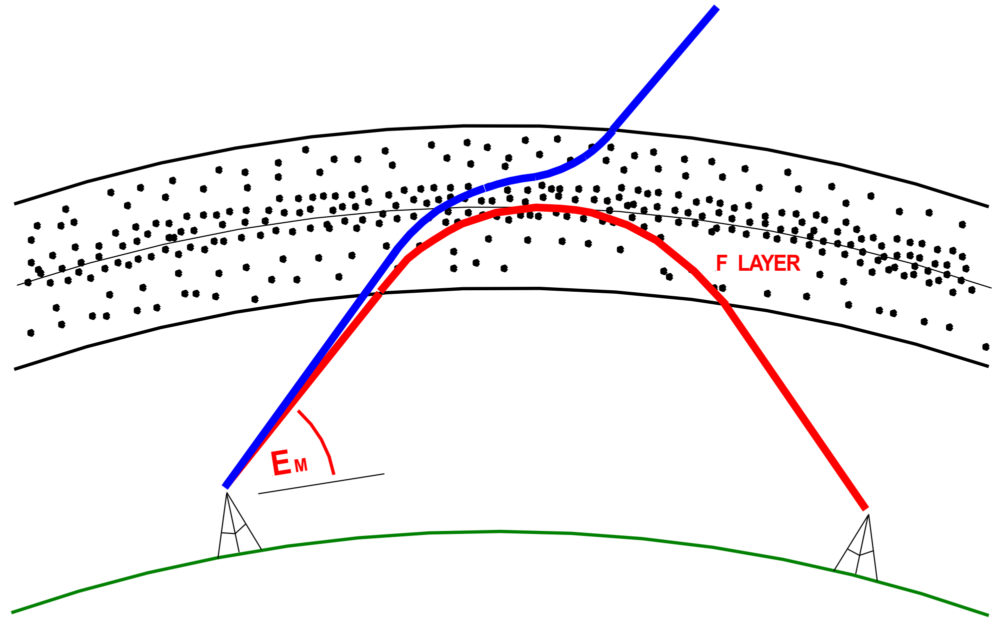
Frequency of Optimum Transmission (FOT)



- Working at the Maximum Usable Frequency is literally "living on the edge"
- Small changes in critical frequency and other ionospheric parameters cause the MUF to be in a continuous state of change often varying by 5 to 10 %
- Signals transmitted at the MUF typically fade in and out
- For stable operation it is generally accepted that the FOT is 80 to 85% of the MUF

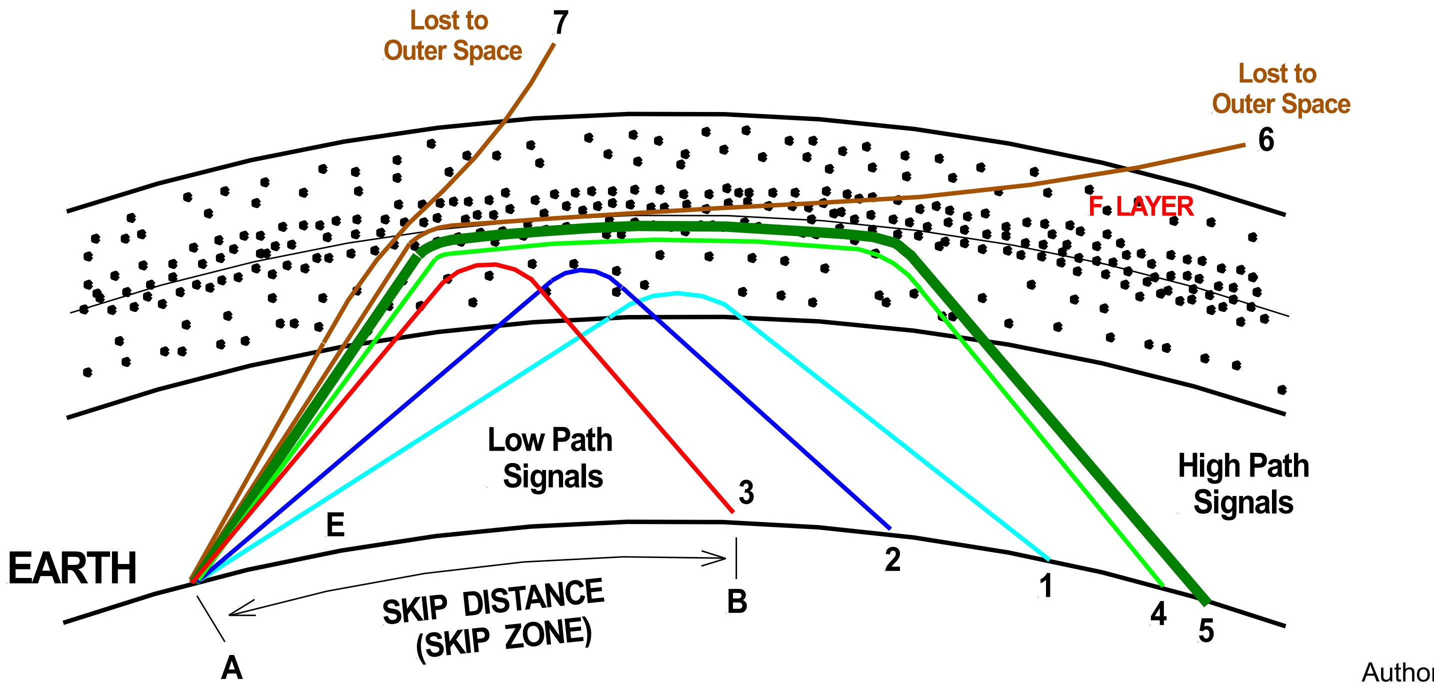
Maximum Usable Angle

$$MUA = E_M = \sin^{-1}\left(\frac{f_c}{f_o}\right)$$



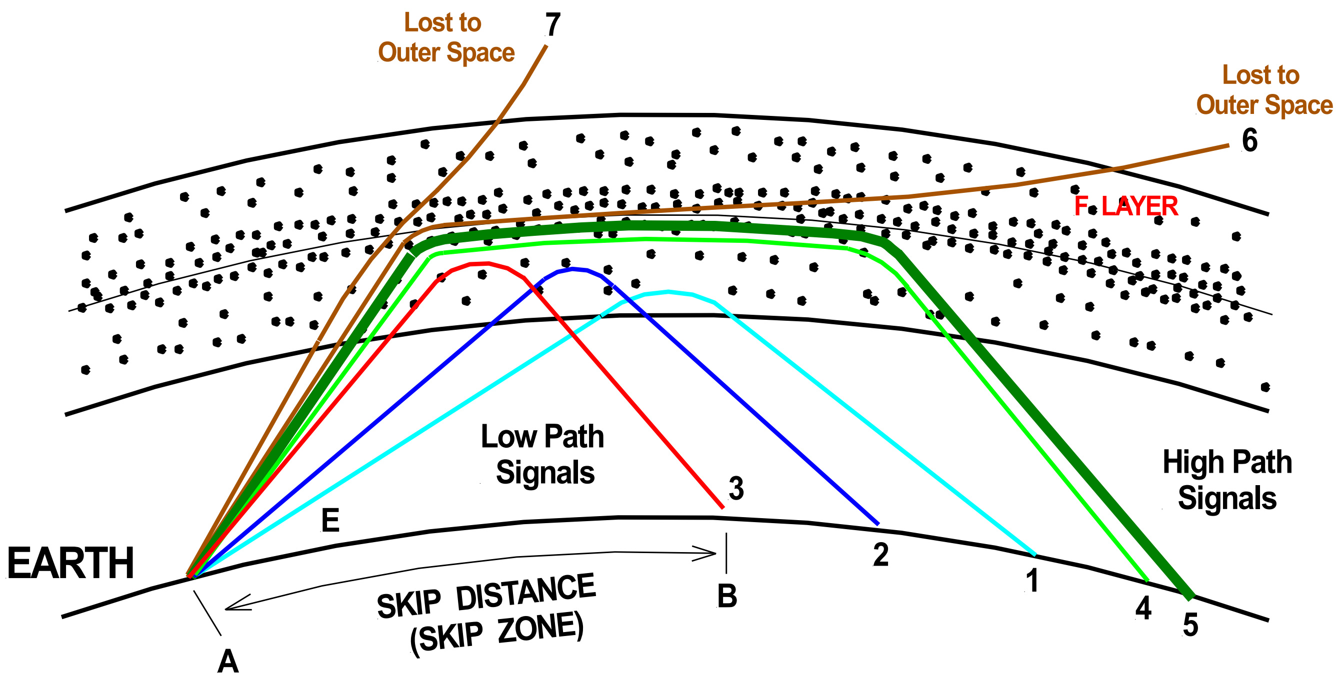
- Maximum Usable Angle (MUA) is the highest angle signal that can be transmitted,
- At an operating frequency of f_o , and
- Still be refracted by the ionosphere if the critical frequency is f_c

High and Low Ray Paths



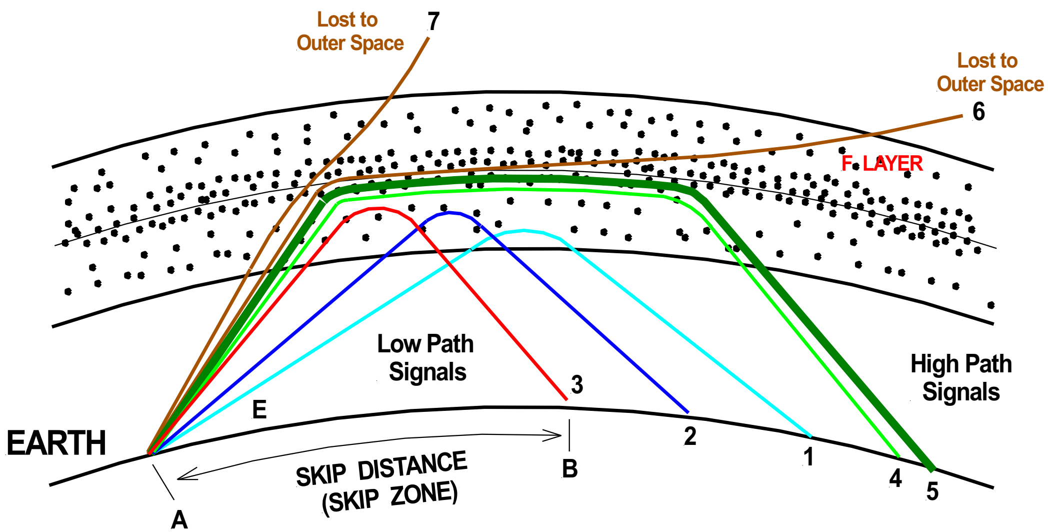
- Increasing angle E shortens the distance transmitted in a single hop, for example from point 1 to point 2 to point 3 as E increases

High and Low Ray Paths continued



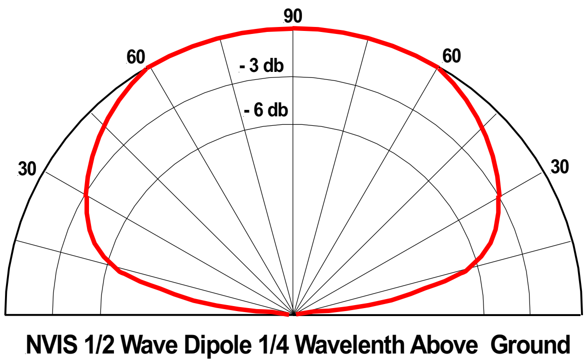
- Increasing E a little more causes a strange thing to happen
- Instead of the distance becoming shorter, it becomes dramatically longer, reaching points 4 and 5 instead
- Increasing E slightly more causes the signal to penetrate the densest part of the ionosphere and be lost to outer space as illustrated by ray 6

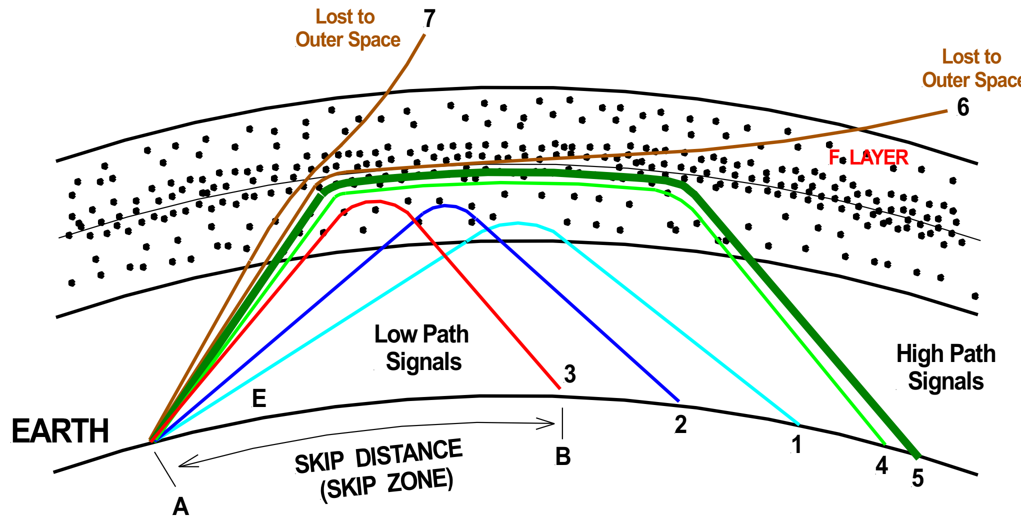
Ray Path Representing The MUA



- Elevation angle E_5 (elevation angle for ray 5) is the Maximum Usable Angle, MUA
- Since an elevation angle E slightly greater than E_5 causes a signal to penetrate the ionosphere and be lost to outer space
- The difference between E_5 and E_3 (the elevation angle for ray 3) is very small
- Consequently, E_3 is frequently defined as the MUA, because
- Ray 3 is special, it is the shortest possible ray and the ray at which the high and low paths coincide producing a relatively strong stable signal

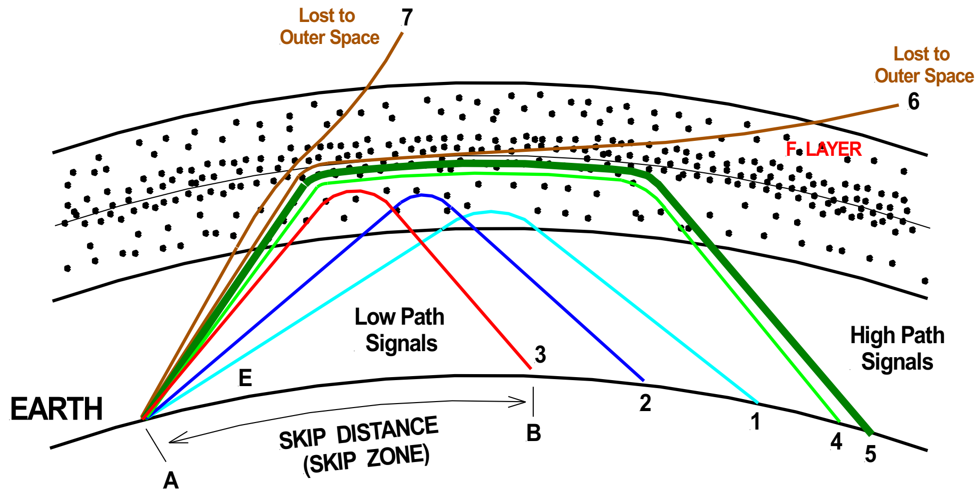
A Typical Transmission Includes Both High & Low Path Signals





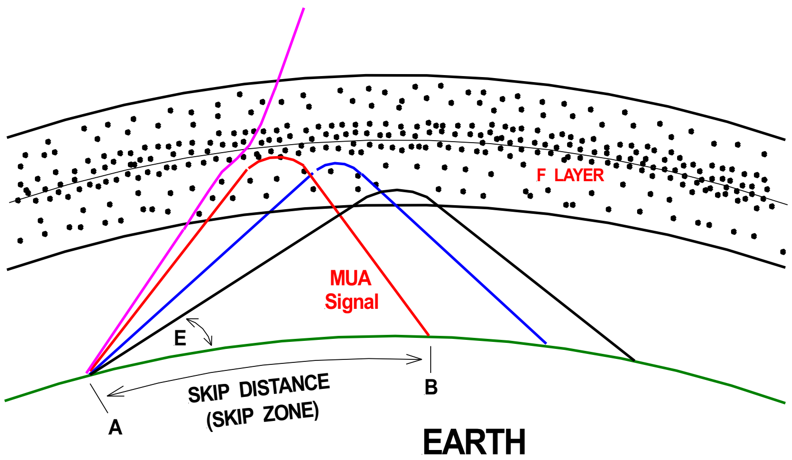
- The signals radiated by radio antennas are not laser beams !
- Amateur radio antennas in particular are relatively crude devices radiating energy over a wide range of elevation angles (illuminating a large region of the sky)
- Consequently, the various propagation paths 1 through 5 are always present making possible communications with many different radio stations

Skip Zone

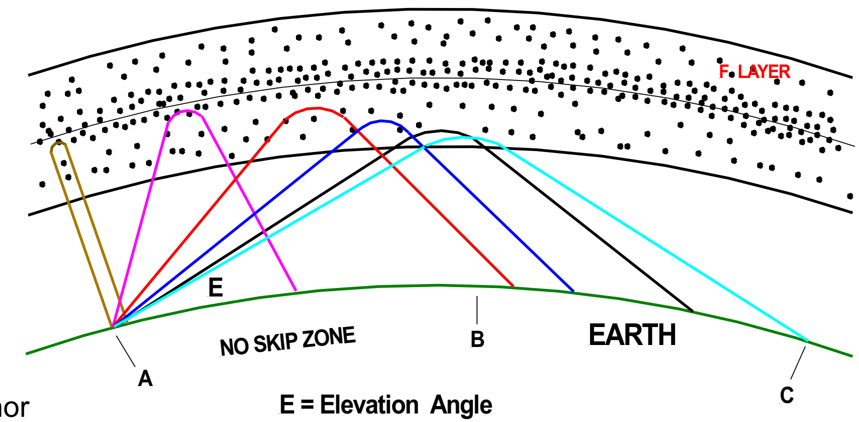


- Ray 3 is the shortest possible path for a signal transmitted from Point A
- Increasing E_3 slightly increases the hop distance to point 4
- Decreasing E_3 also increases the hop distance, this time to point 2
- Station A can not transmit a signal to any location closer than Station B
- Thus the region from Station-A to Station-B is the skip zone
- Stations in the skip zone can not hear Station A and visa versa, they are skipped over

When Will A Skip Zone Be Present ?



author

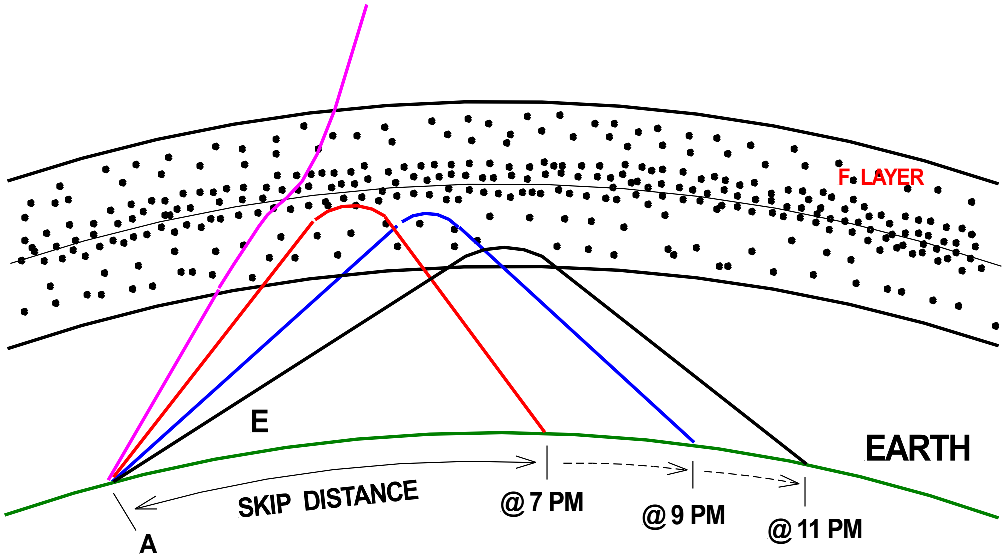


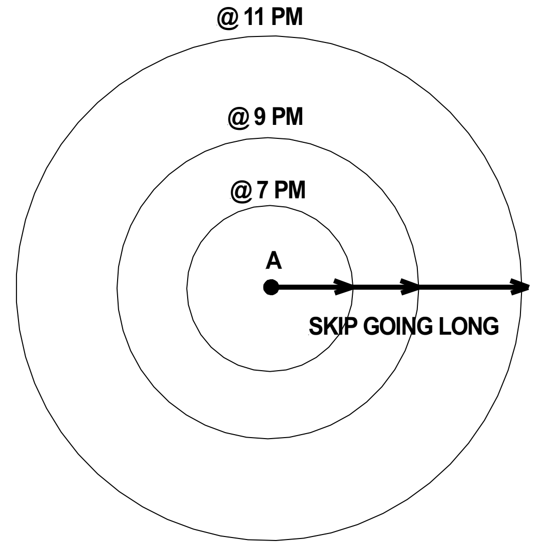
Skip Zone Present if $f_c < f_o$

No Skip Zone if $f_c > f_o$

- A skip zone exists ONLY if the ionosphere's critical frequency f_c is below a station's operating frequency f_o that is if $f_c < f_o$
- A skip zone will not exist if the critical frequency is above the operating frequency, i.e. if $f_c > f_o$
- In that case, a station utilizing Near Vertical Incident Skywave (NVIS) propagation can communicate with all stations from the base of its antenna out hundreds of miles

Skip Going Long

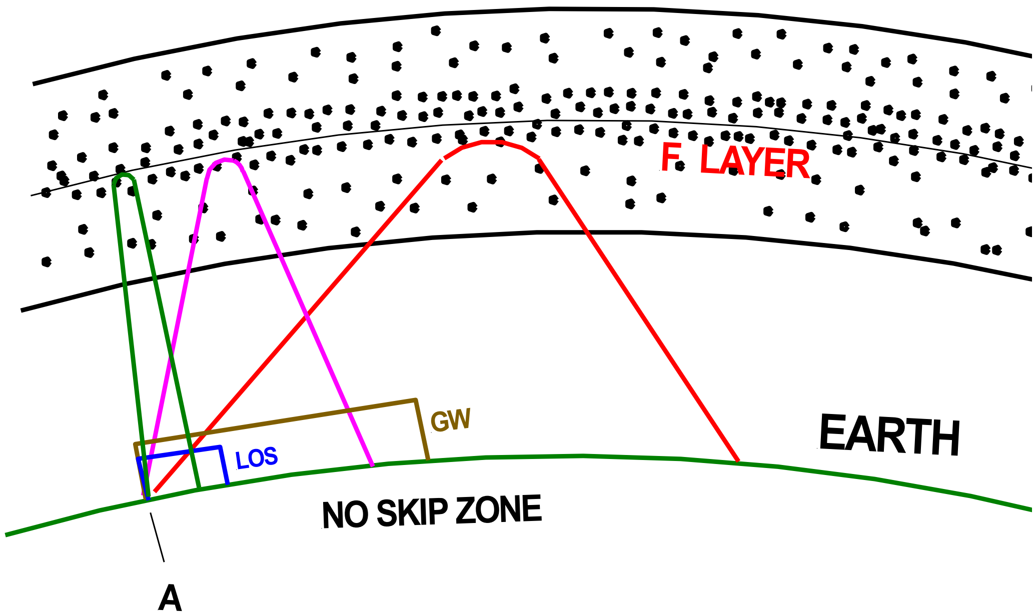




author

- When a skip zone exists, it typically becomes larger at night, producing a longer skip distance, as the critical frequency drops further and further below the operating frequency
- That is, ”the skip distance goes long” at night as the critical frequency drops

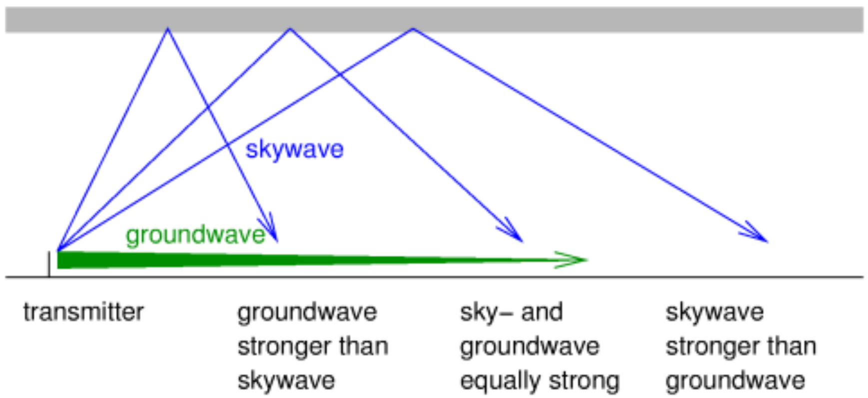
Close-in Multipath NVIS Problem



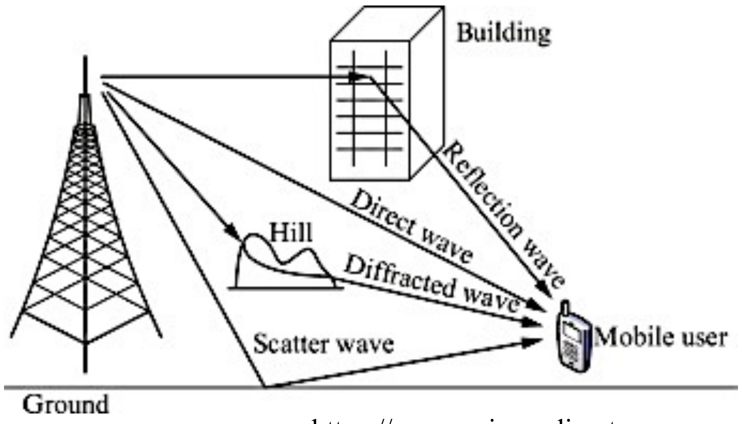
author

- If there is no skip, all NVIS stations can be reached from the base of your antenna outward for many hundreds of miles
- However, like it or not, line-of-site (LOS) and ground wave (GW) propagation always exist from your antenna out 30 to 40 miles or so
- Consequently, multi-path interference problems between NVIS, ground wave, and line-of-site propagation can cause signal degradation and fading problems close-in when NVIS conditions are otherwise excellent

Close-in Multipath Problems



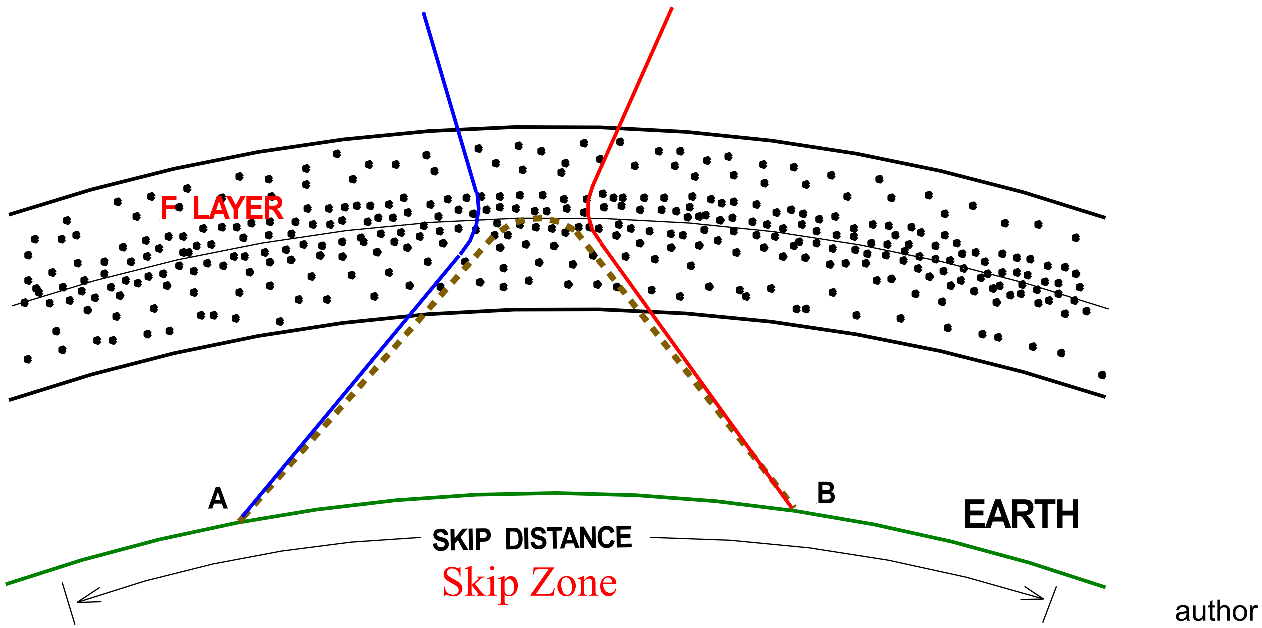
PA3FWM pa3fwm@amsat.org



https://www.sciencedirect.com

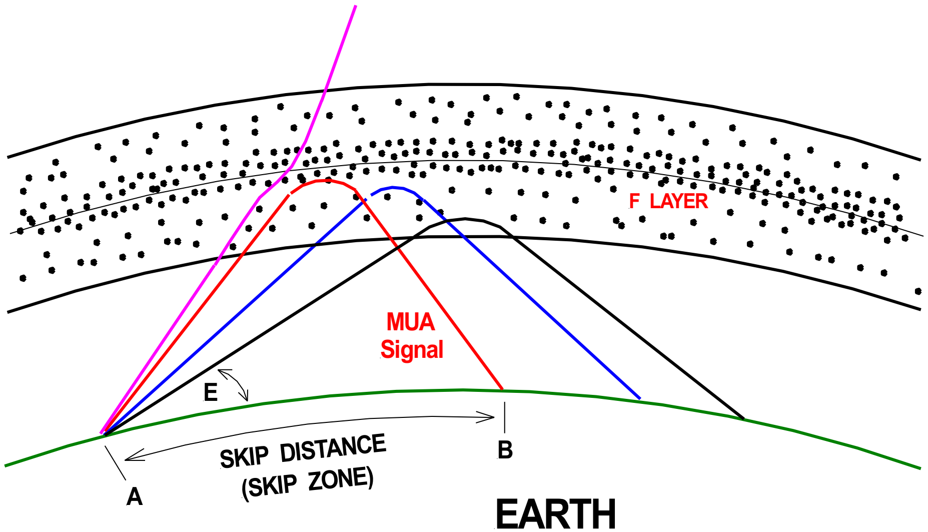
- Multi-path interference problems between NVIS skywave and ground wave propagation is most severe when skywave and ground wave signals are equally strong
- HF line of sight signals suffer the same reflection, diffraction, and scattering problems as VHF and UHF signals
- In addition to interference from ground and skywave signals
- All resulting in distortion and fading

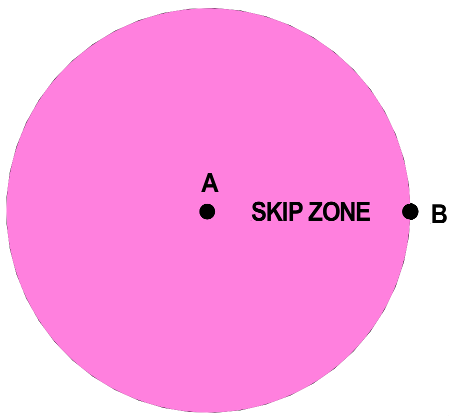
No NVIS Between Stations Within Skip Zone



- When Stations A and B are located within the skip zone the desired NVIS communications along the dotted brown propagation path is impossible
- The high elevation angles required for NVIS between two such stations cause the signals to penetrate the ionosphere and be lost to outer space
- Under these conditions **line-of-site** and **ground wave** are the only propagation modes available provided the stations are located close to one an other (within about 40 miles or so)

For HF Comm The Skip Distance Must Be Known

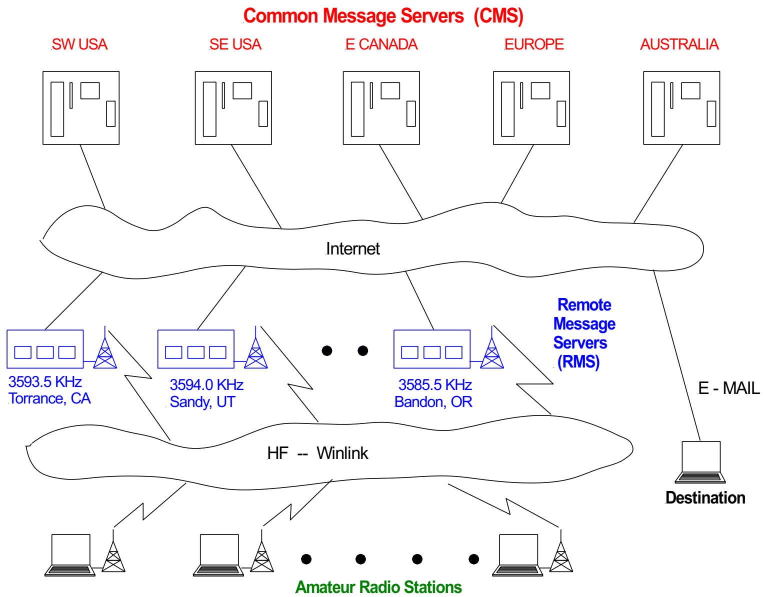


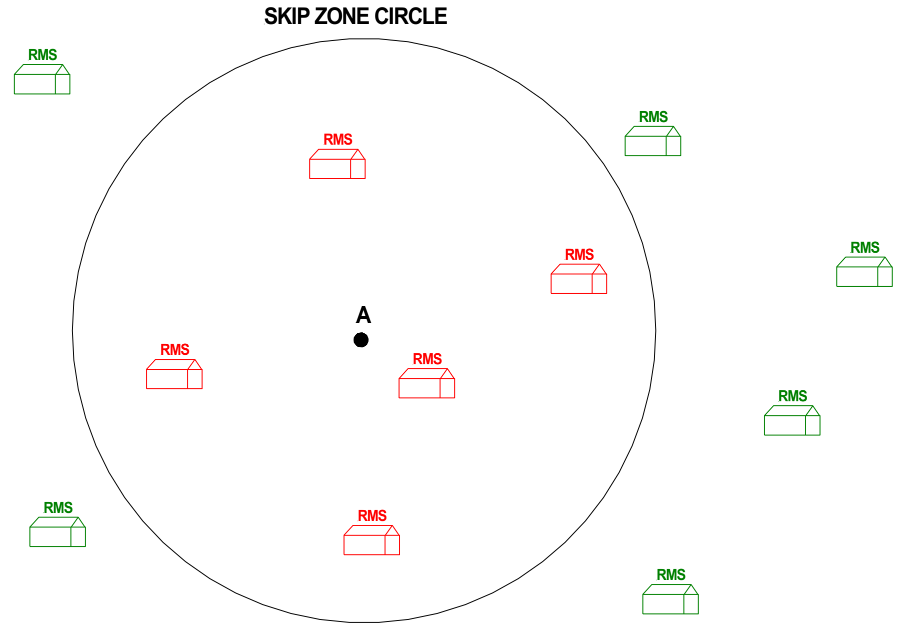


author

- When a skip zone exists, it is important to know where the edge of the skip zone is to determine what stations can be reached
- That is, the skip distance must be known

Winlink Emergency Communications Example



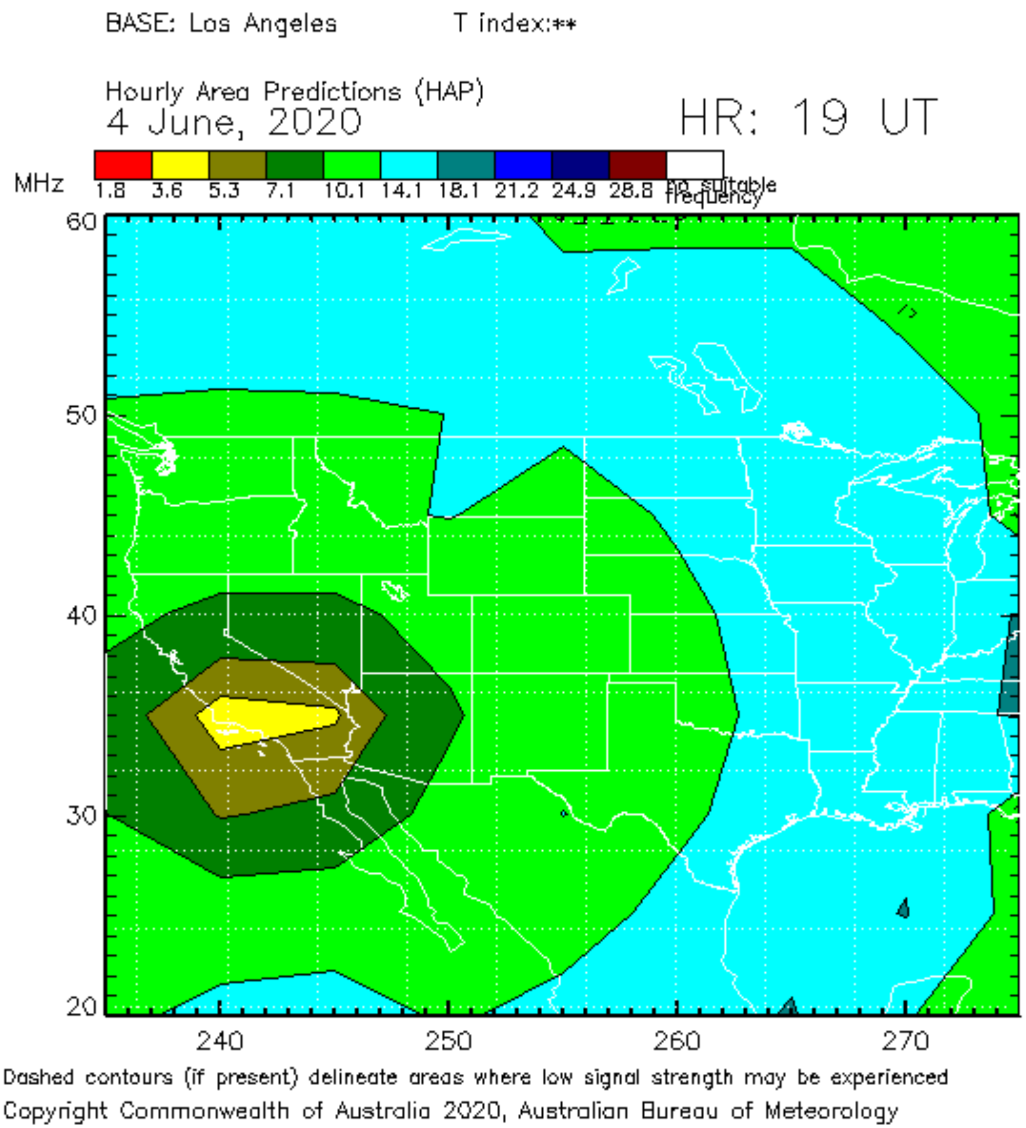


author

- Stations within the skip zone (red RMS houses) can not be reached by Station A
- Stations that can be contacted are outside the skip zone (green houses)
- The size of the skip zone, that is the skip distance, must be known to determine which RMS stations can be reached during an emergency and which can not

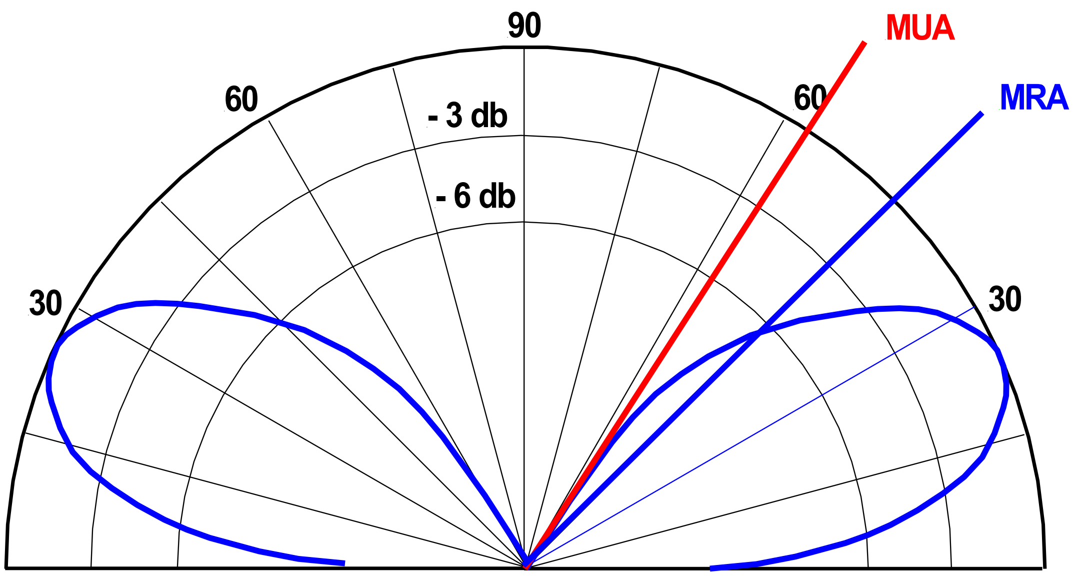
HAP Charts and Skip Distance

- Hourly Area Prediction - HAP charts - can be used to estimate skip distance.
- HAP charts are provided by the Australian Government
- They are available and explained under the Tools tab on the www.skywave-radio.org website
- In this HAP chart centered on Los Angles, California
- **The dark green region is the area of optimum 40 meter coverage**
- 40 meter coverage also extends into the light green and blue regions although multi-path problems may occur
- The brown and yellow areas are the 40 meter skip zone on this particular day and time of day



Sometimes Skip Distance Determined by Antenna

- Skip distance will be determined by your antenna
- IF
- The maximum radiated angle of your antenna MRA
- Is less than the MUA determined by the critical frequency f_c
- MRA = - 6db point



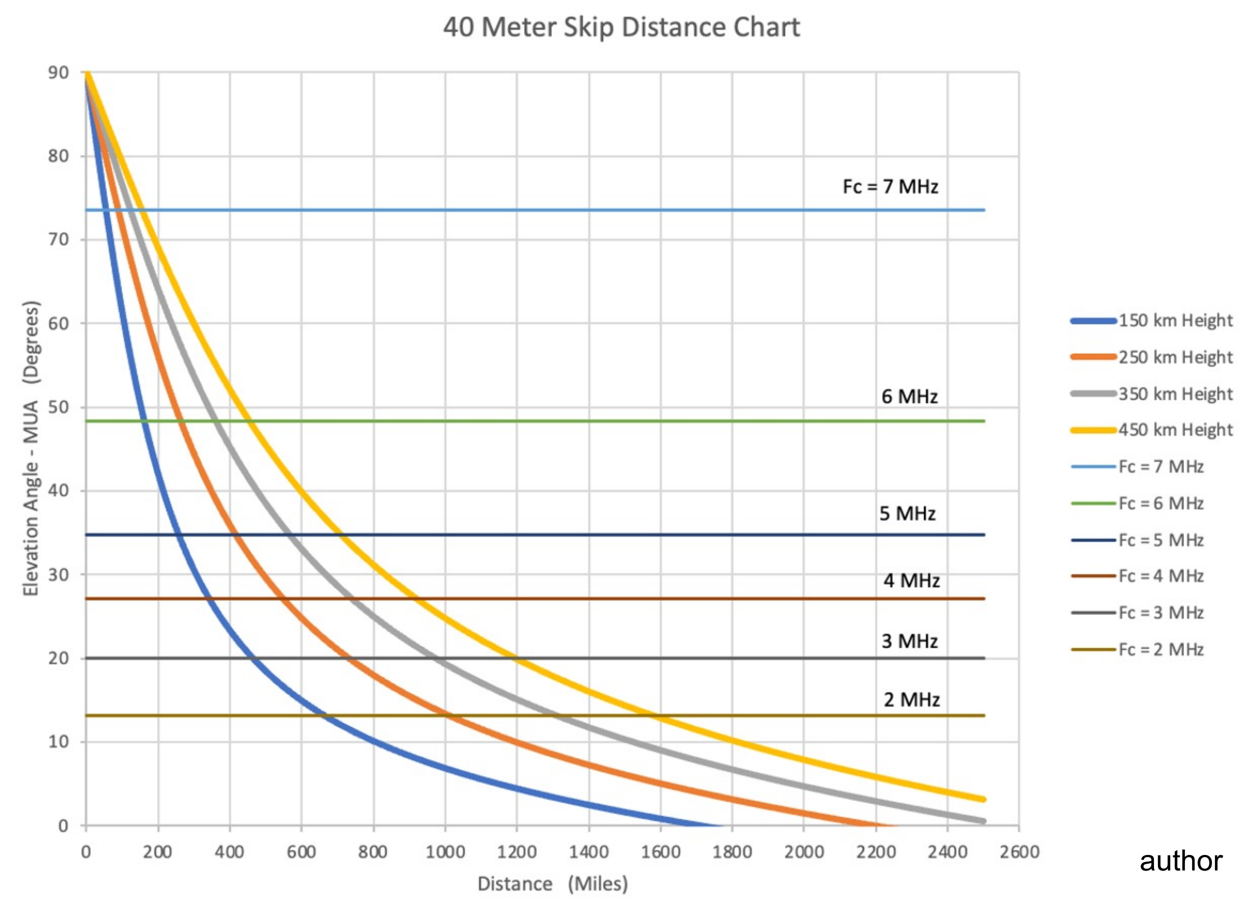
1/4 Wave Vertical Antenna

author

Example, skip distance at MUA = 60 degrees is about 170 miles (see next slide)

But the skip distance for a 40 m vertical antenna with an MRA of 45 deg is approximately 300 miles. Stations closer than 300 miles will be skipped over by the vertical antenna – a vertical is not a very good NVIS antenna

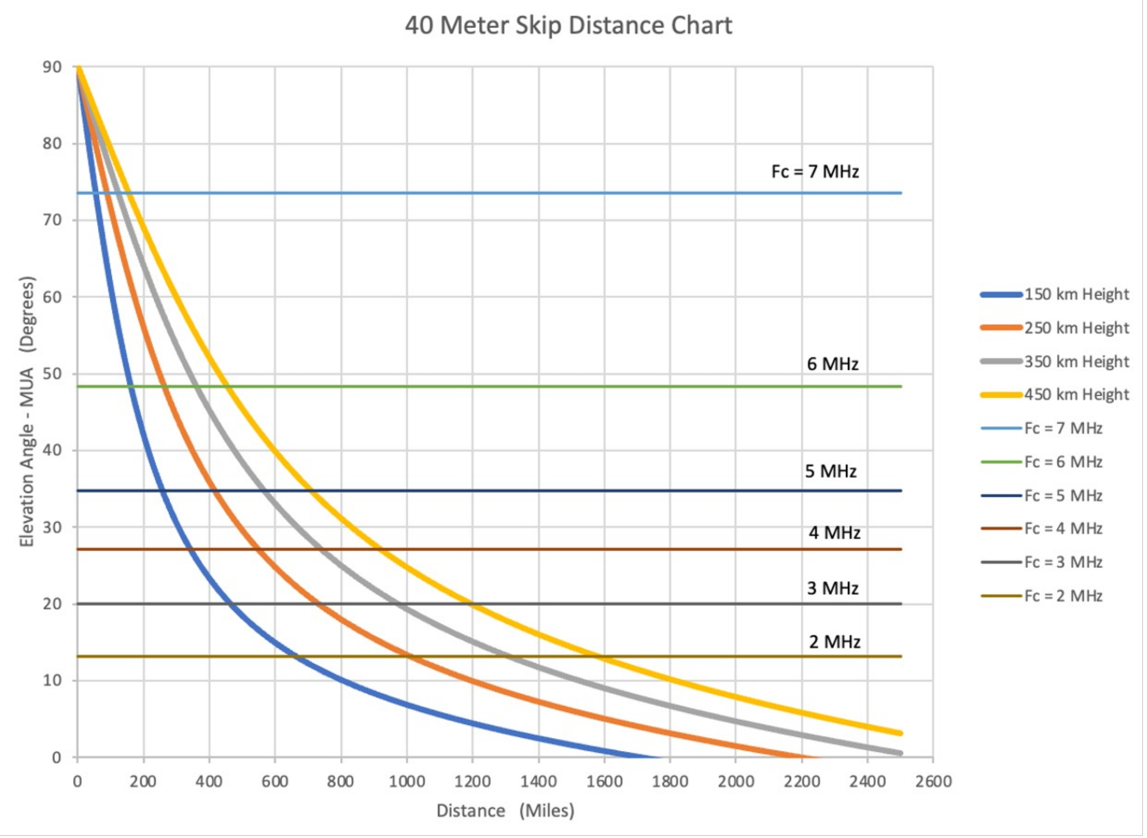
Skip Distance Charts



author

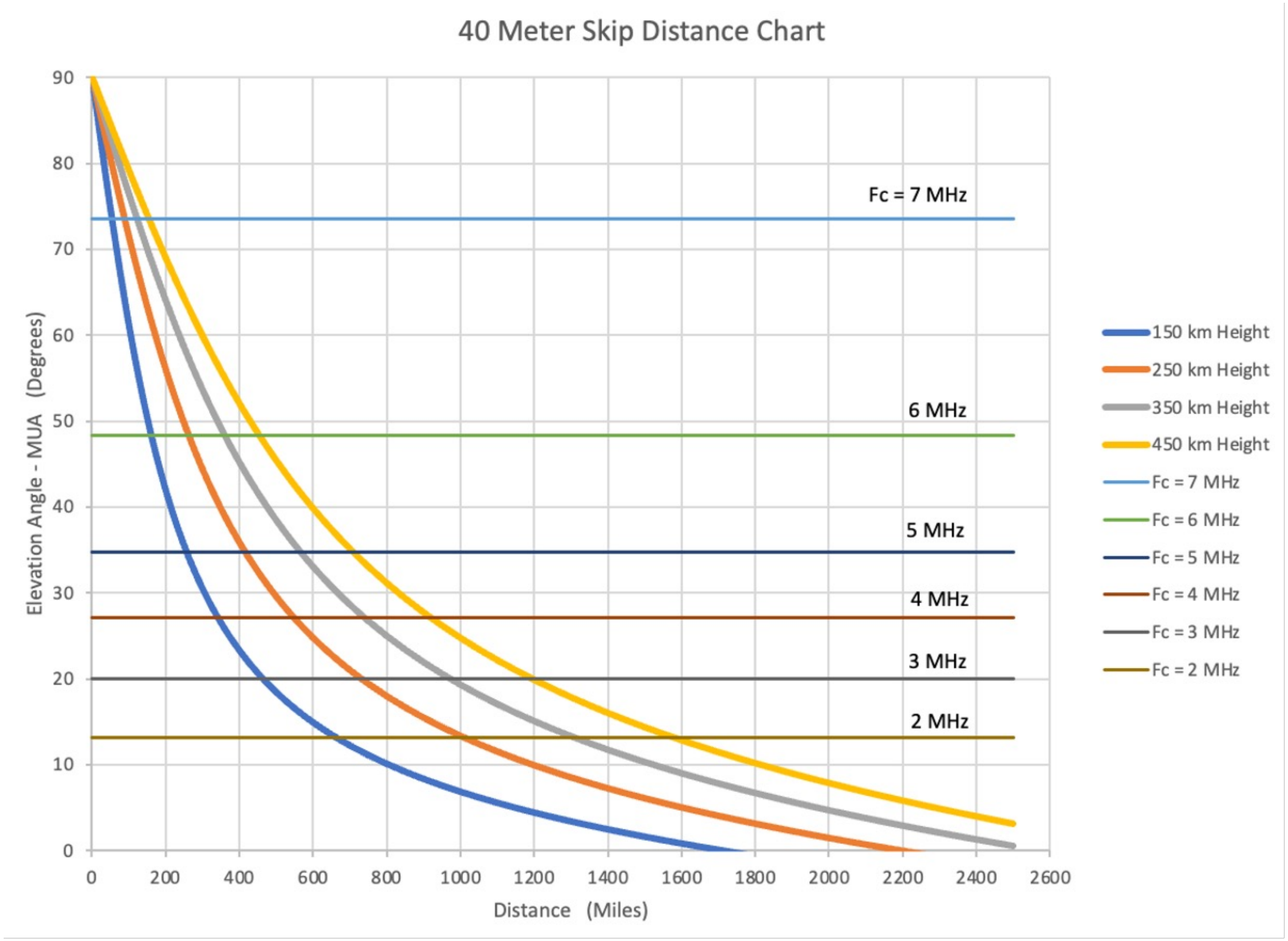
- Skip distance charts, like the one shown here, can be created for each frequency band and are available under the Tools tab of the website www.skywave-radio.org
- The chart provides single hop Distance vs Elevation Angle based on the height of the ionosphere's F2 layer (4 heights are illustrated)
- Example: A hop distance of 600 miles will be obtained when a signal is transmitted at an elevation angle of 25^{o} and the height of the F2 layer is 250 km

Skip Distance Chart continued



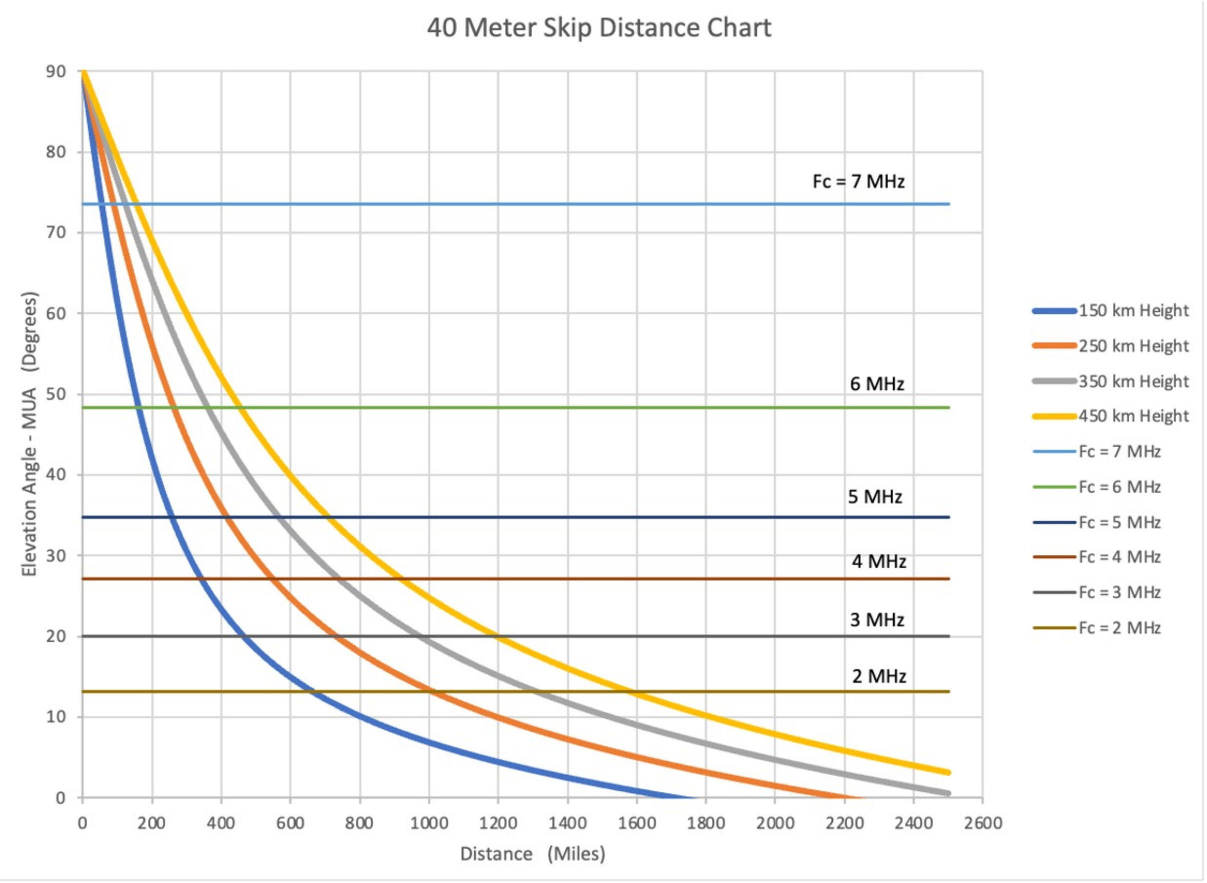
- The distance covered by a single hop becomes shorter as the elevation angle of the transmitted signal increase
- However, the current critical frequency places a cap on how short the hop distance can become by specifying the Maximum Usable Angle (MUA)
- Signals transmitted at angles greater than the MUA will penetrate the ionosphere and be lost to outer space

Skip Distance Chart continued



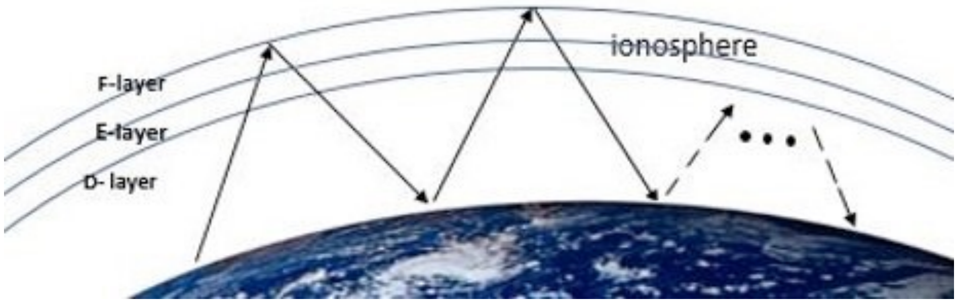
- Example: At a critical frequency of 5 MHz the MUA is 35°
- Signals transmitted at angles higher than this can not be used for communications since they will be lost to outer space

Skip Distance Chart continued



- Consequently, the intersection of the appropriate height curve h_mF2 read from an Ionosonde Site and the current critical frequency defines the shortest possible hop
- 400 miles is the shortest possible hop for a critical frequency of 5 MHz and a F2 height of 250 km – the 35^o MUA prevents you from transmit a shorter distance
- By definition the length of this hop is the skip distance

Long Distance Skywave Communications

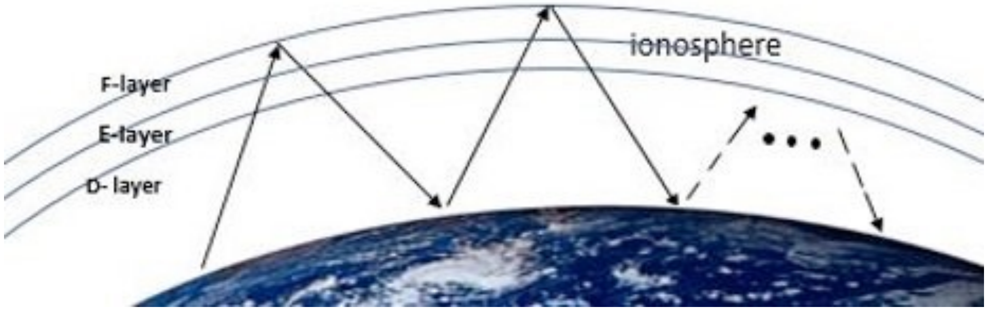


ResearchGate

- Long distance communications consists of multiple hops through the ionosphere
- The strength of a signal decreases with each hop due to:
  - The energy lost (absorbed) in each pass through the D region, and
  - Ground losses with each reflection from the Earth's surface (~ 3db from poorly conducting ground and ~ 0.5 db for reflections from the ocean)
- 3 to 4 hops are typical for most long distance skywave communications
- Under ideal conditions, 5 to 6 hops may be possible particularly over the ocean
- Usually, however, more than 4 hops result in signals which are too weak to be received
- Long distance communications depends on each hop being as long as possible
- Enhanced by using high transmitting power and high gain directional antennas

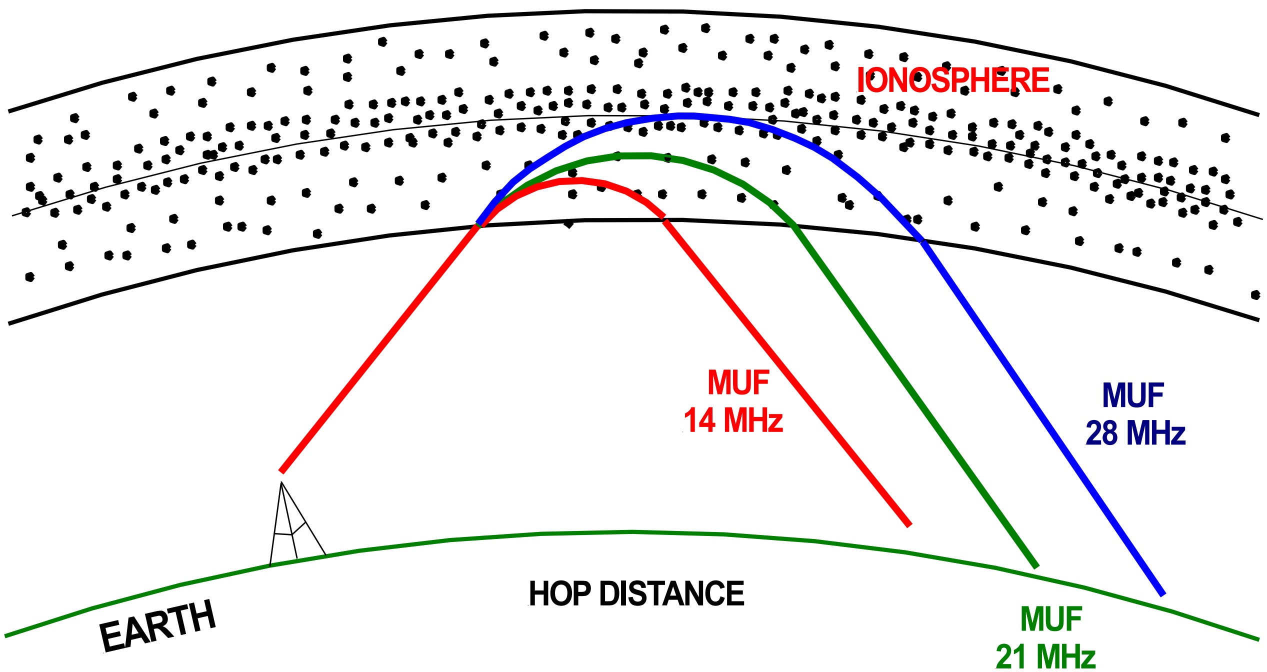
Hop Distance

ResearchGate



- The distance traveled on each hop depends on:
  - Operating frequency: operating at the Maximum Usable Frequency (MUF) produces the longest hops
  - The current critical frequency: MUF is determined in part by the current critical frequency, a high critical frequency results in a high MUF
  - The height of refraction: longer hops result from signals refracting back to Earth higher in the ionosphere
  - The elevation angle at which signals are transmitted: low angle signals travel further

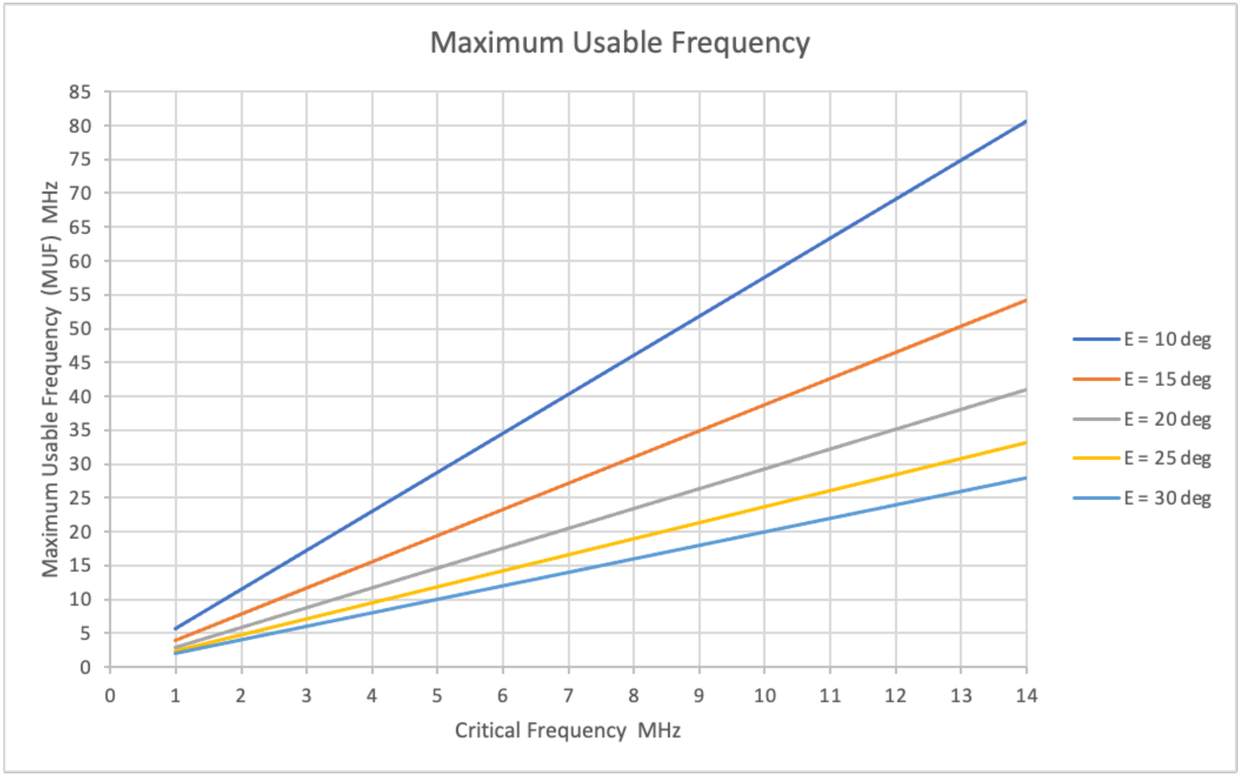
Operating Frequency



Author

- Signals travel progressively higher into the ionosphere as the MUF increases producing longer hop distances
- Example, the hop distance at a MUF of 28 MHz is longer than at a MUF of 14 MHz

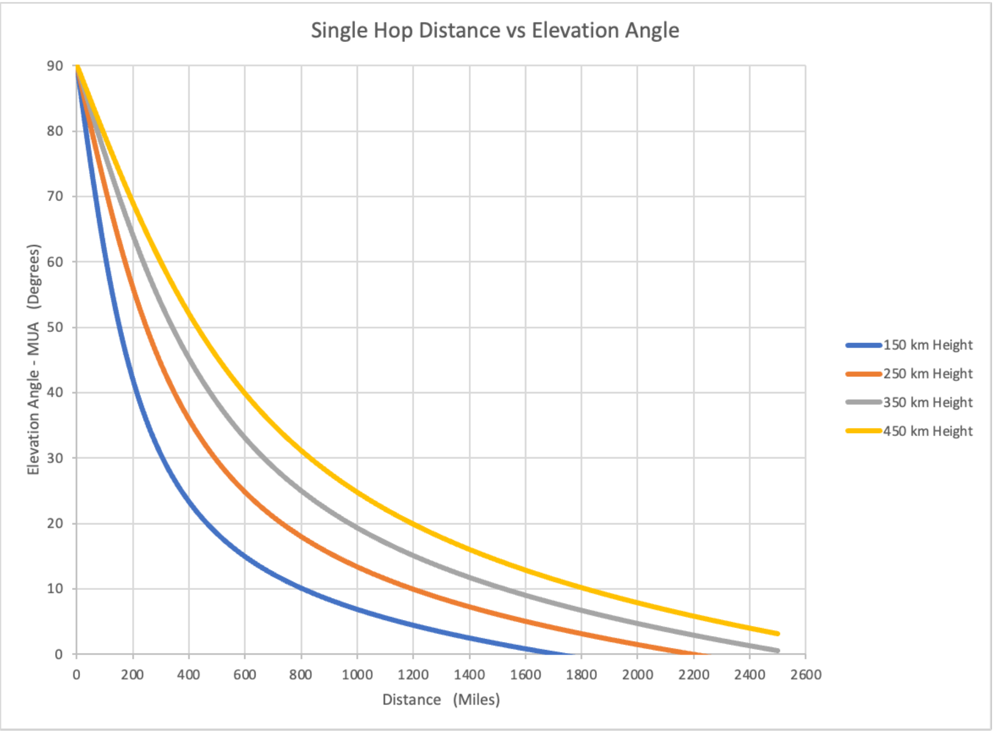
Critical Frequency – Impact on MUF



Author

- A high MUF results from a high critical frequency and transmitting at a low elevation angle E
- For example, at a critical frequency of 8 MHz, the MUF is approximately 30 MHz when transmitting at an elevation angle of 15º (red trace)
- At this MUF, the 20 through 10 meter frequency bands should be open

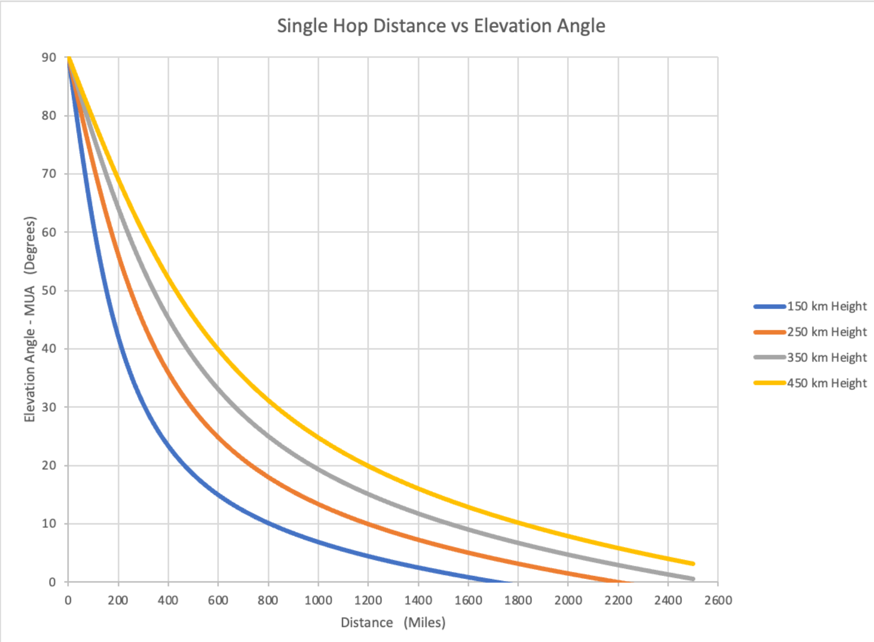
Elevation Angle and Height of Refraction

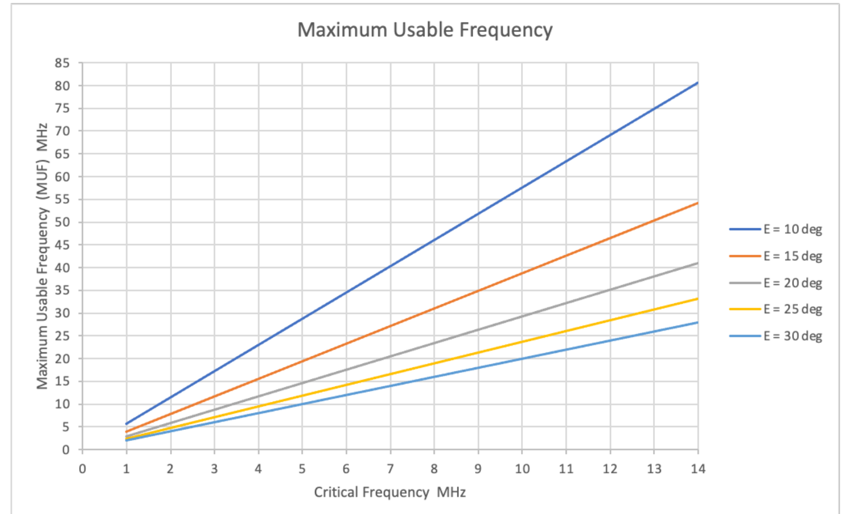


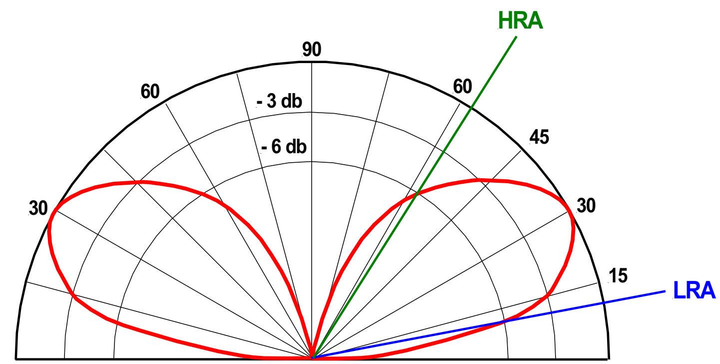
Author

- Hop distance depends on the angle at which a signal is transmitted and the height at which the signal is refracted back to Earth
- For example, the hop distance of a signal transmitted at an elevation angle of 15^o will be approximately 1,200 miles when the refraction height is 350 km (gray trace)
- Note that the height at which a 10 meter signal refracts back to Earth is higher than that of a 20 meter signal resulting in the 10 meter signal having a longer hop distance

Your MUF and Hop Distance



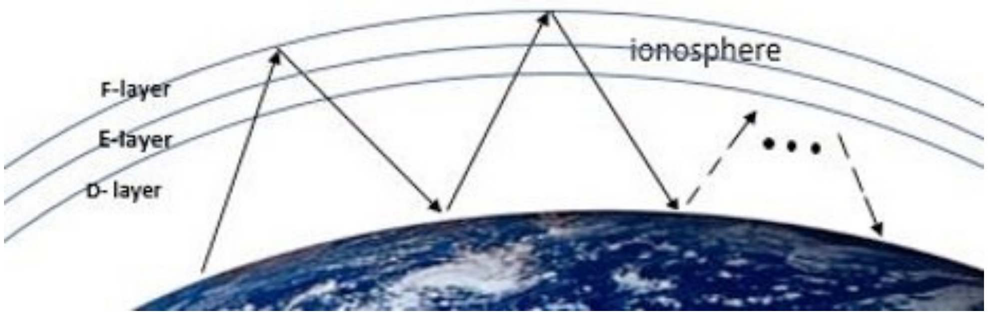




- YOUR maximum usable frequency and the hop distance that YOU achieve depends on the lowest angle at which YOUR antenna is capable of radiating a signal (LRA)

- MUF and hop distance are personal characteristics of YOUR radio station

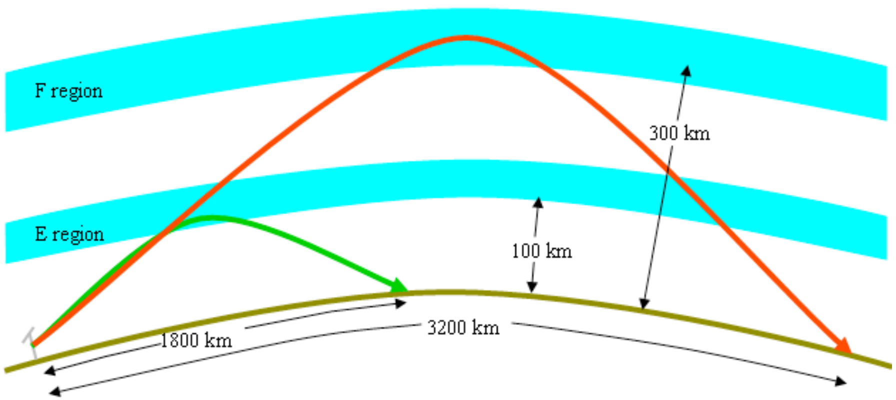
Propagation Modes



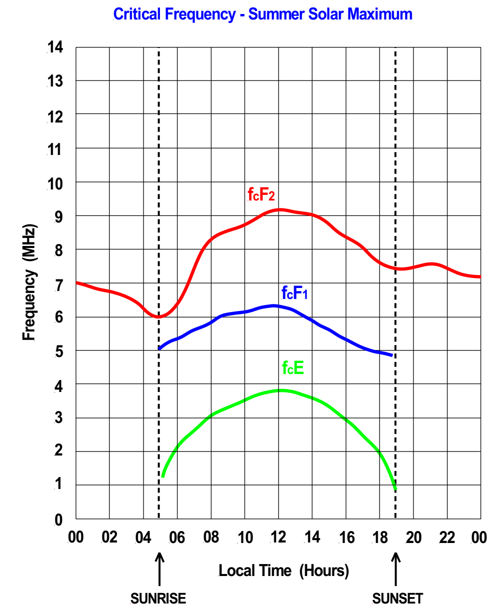
ResearchGate

- We usually assume (as above) that skywave communications consists of multiple hops through the ionosphere's F region
- However, other propagation modes are also possible including:
- E mode propagation,
- Sporadic E propagation,
- Multi-path propagation,
- Backscatter,
- Great Circle propagation,
- Gray Line propagation,
- Equatorial Sporadic E propagation,
- Transequatorial Propagation (TEP),
- Ionospheric Ducting

E Mode Propagation

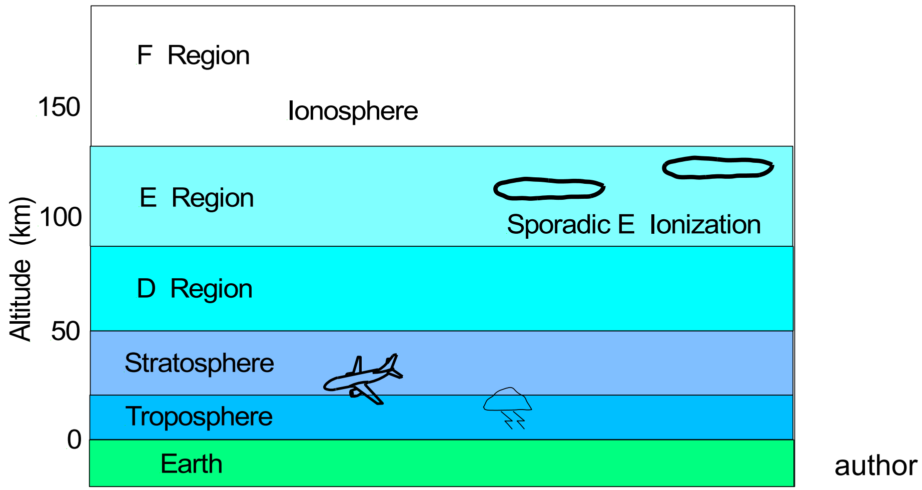


Space Weather Service



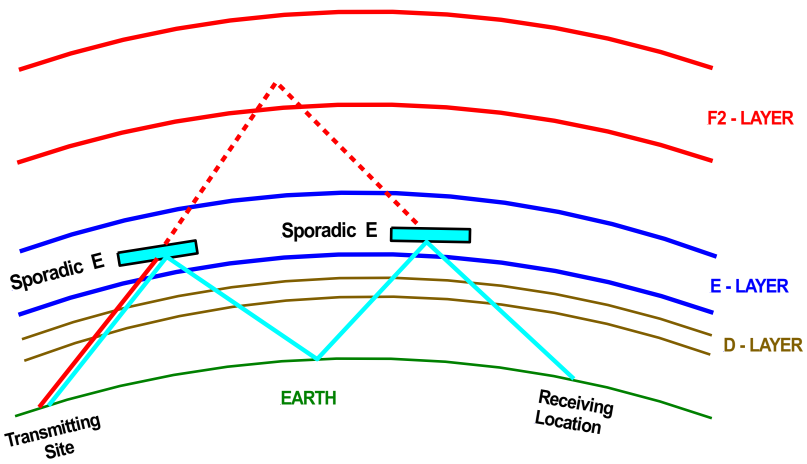
- Radio waves refract back to Earth from both the ionosphere's E and F regions
- E region hops are shorter than hops through the F layer
- The E region mid day critical frequency of 3 to 4 MHz causes signals transmitted at low angles to refract in the E region
- Blocking low angle signals from reaching the F layer (this is called screening)
- Screening causes hop distance to drop from typical F region distances of 700 miles to E region hop distances of only 250 miles
- E region screening has a more detrimental affect on 40, 30, and 20 meter mid day DX than D layer absorption

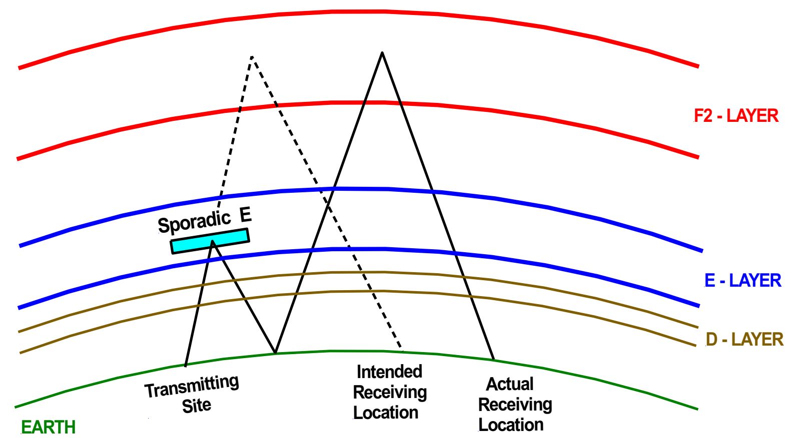
Sporadic E Propagation



- Sporadic E (E_s) formations with abnormally high ionization levels often occur in the E region reflecting HF radio signals at frequencies up to 100 MHz
- They are called sporadic E because they randomly appear in various sizes and shapes, persist for minutes to hours, and occur from one day to the next with little predictability
- Sporadic E zones are relatively large structures about 2 kilometers thick with horizontal dimensions stretching hundreds of kilometers
- In general, sporadic E appearances seem to have little direct relationship to the ionization processes responsible for the E region itself

Sporadic E High Electron Densities

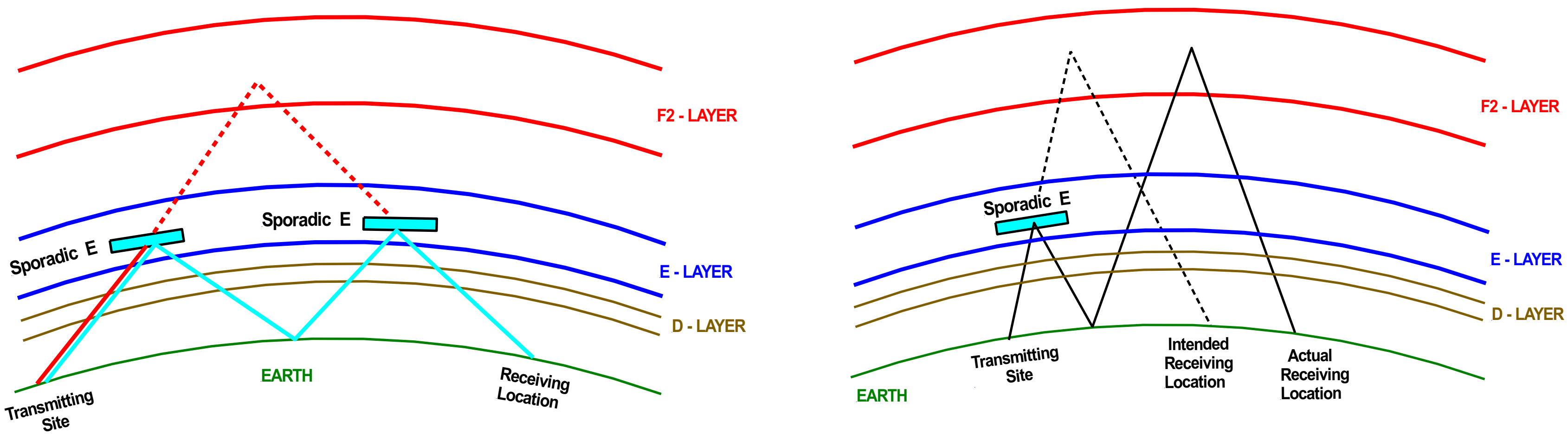




author

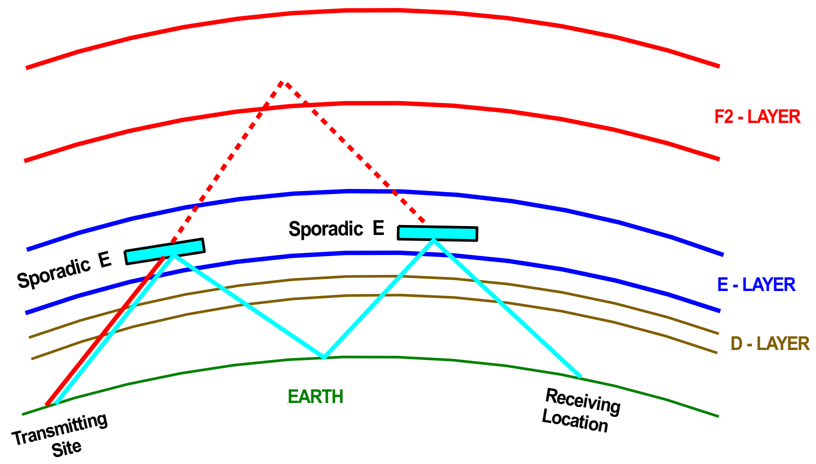
- Sporadic E zones often have electron densities:
  - Far greater than normal E region levels, and
  - At times even greater than in the F region
- High electron densities cause sporadic E patches to be opaque preventing radio signals from reaching the F region

Sporadic E Can Seriously Impact HF Radio Circuits



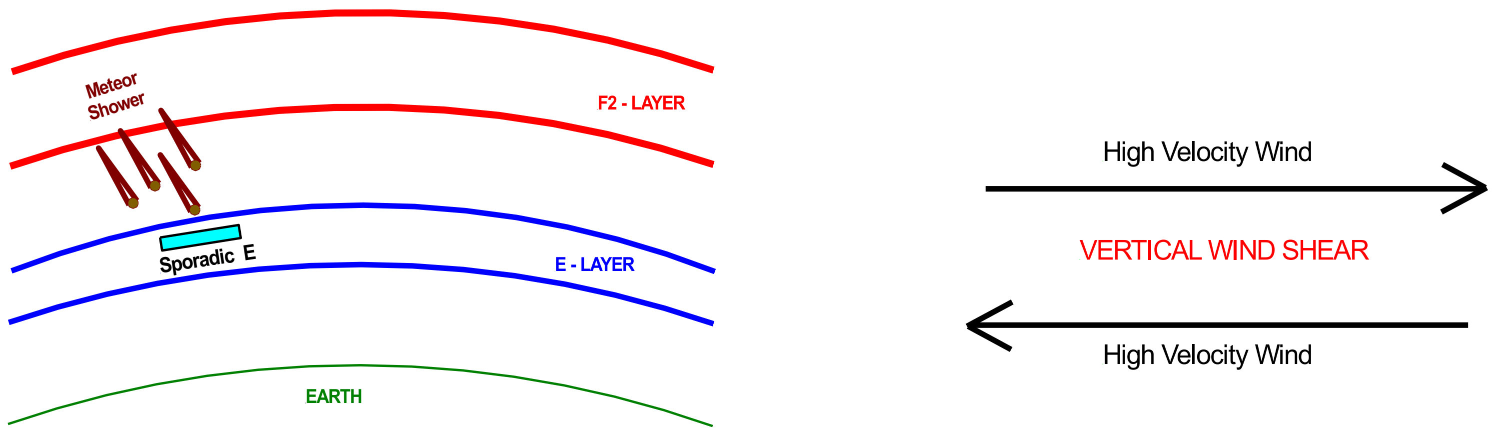
- Instead of allowing signals to pass through to the F layer, sporadic E patches reflect signals back to Earth forcing signals to follow multiple hop paths to the desired destination
- Multiple hops mean more ground reflections and more passes through the attenuating D region seriously degrading received signal levels
- Worse yet, the intended receiving location could be missed altogether
- Sometimes radio signals reach the F2 Layer through rapidly changing gaps between sporadic E patches causing the destination to receive weak or fluctuating signals
- Increasing operating frequency often does not avoid sporadic E propagation

Mid Latitude Sporadic E Zones



- At mid latitudes sporadic E zones tend to be weaker than in the equatorial and polar regions
  - Their occurrence is subject to diurnal and seasonal variations
  - They tend to be more prevalent during the summer than in winter
  - They tend to occur more during the day than at night, particularly in mid-morning and near sunset

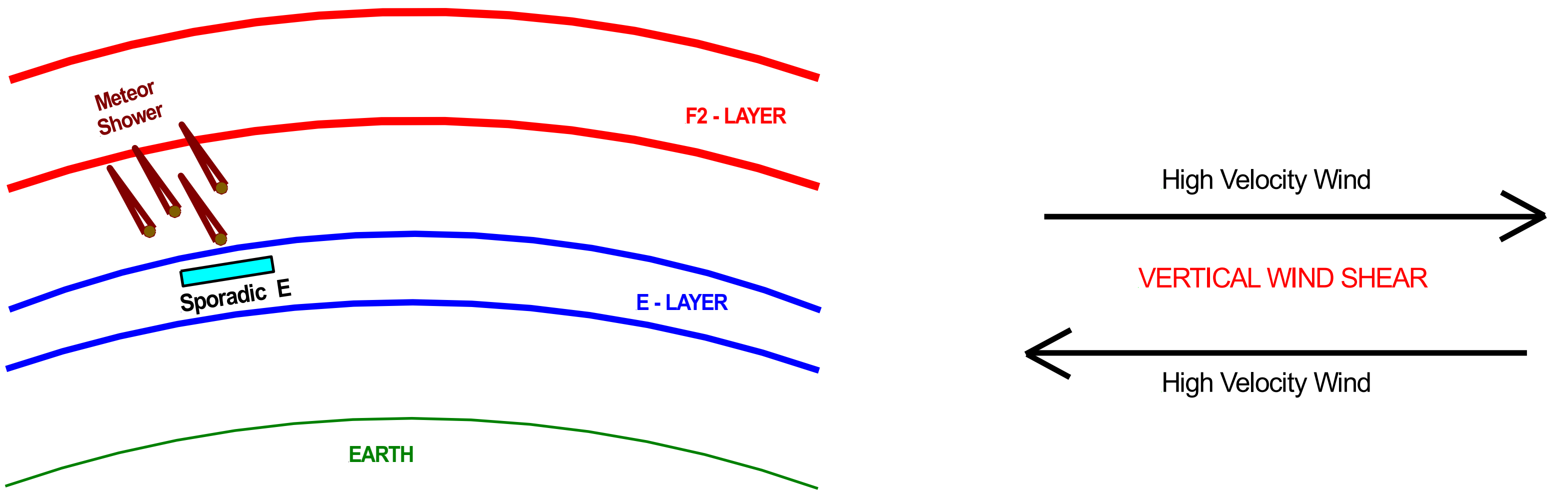
Formation of Mid Latitude Sporadic E Zones



author

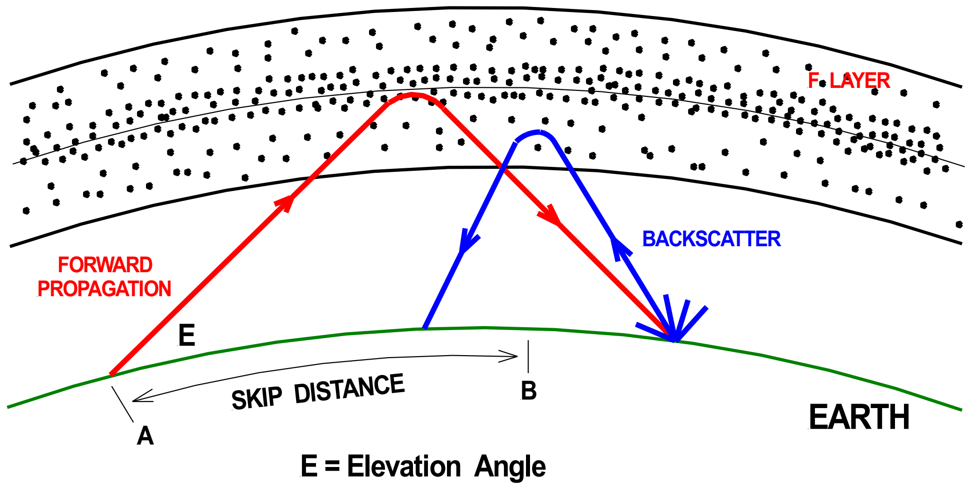
- It is believed that sporadic E patches at mid latitudes form as the result of wind shear in the upper atmosphere in combination with meteoric debris
- Enormous numbers of meteors burn up in the E region of the atmosphere
- The meteoric debris is largely monatomic metallic ions
- These ions become trapped between high velocity winds traveling in opposite directions within the E region

Formation of Mid Latitude Sporadic E Zones continued



- Metallic ions are much smaller than the molecular ions that make up most of the E region
- Because of their small size, their rate of electron-ion recombination is low compared to molecular ions
- Resulting in high, sometimes much higher, concentrations of electrons in the sporadic E patches than in other parts of the E region

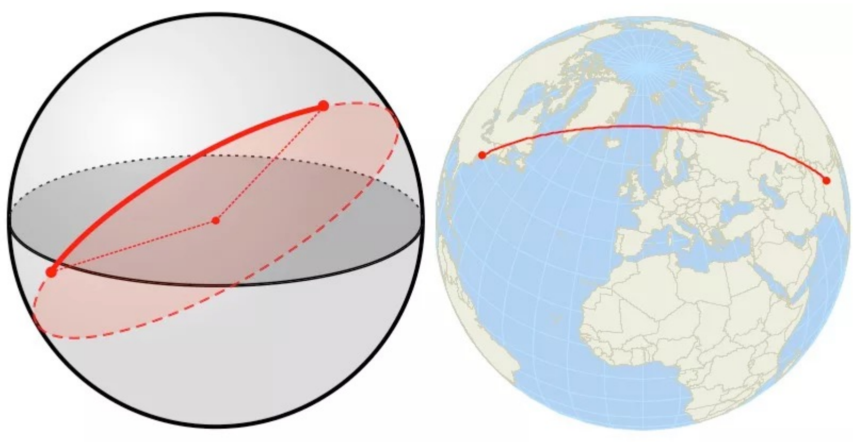
Backscatter



author

- Part of a radio signal is scattered when it impacts the Earth
- Some of the scattered signal may travel back through the ionosphere toward the transmitting site
- This is known as backscatter
- It is not unusual for some of the backscattered signal to end up in the skip zone
- When this occurs, some of the stations in the skip zone may hear the transmitting station when normally they would not

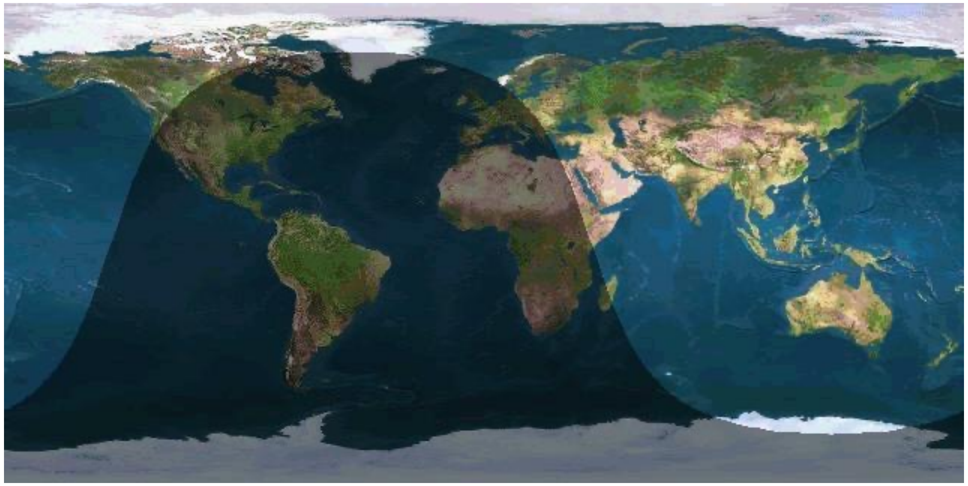
Radio Wave Great Circle Propagation

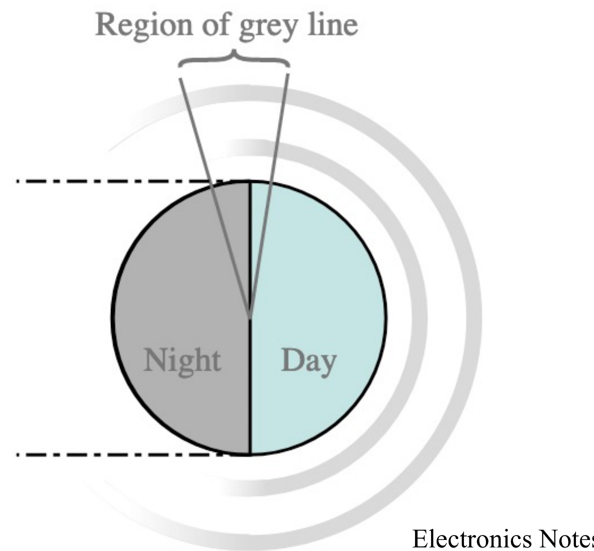


Caliper Corporation

- Normally, radio waves follow great circle paths since a great circle is the shortest distance between the transmitting and receiving stations
- However, ionospheric irregularities in the polar regions including, ionospheric troughs, high latitude spread F, Traveling Ionospheric Disturbances etc. can seriously alter signal propagation paths causing signals to end up in unexpected places
- In general, great circle paths become less meaningful for signals propagating through Earth's polar regions

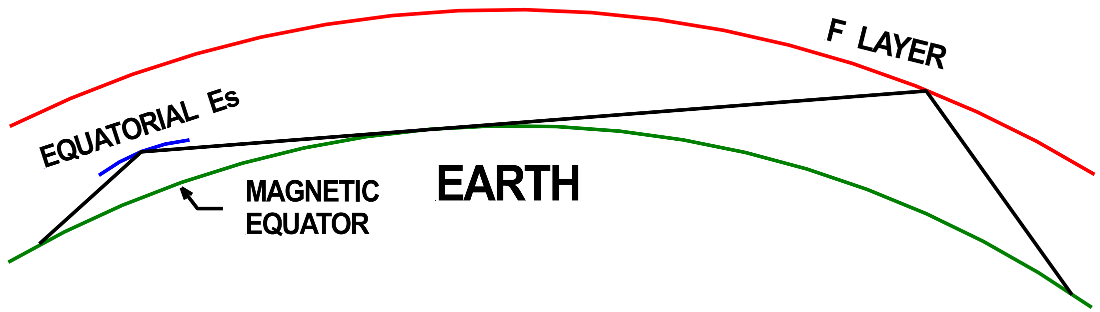
Gray Line Enhanced Communications



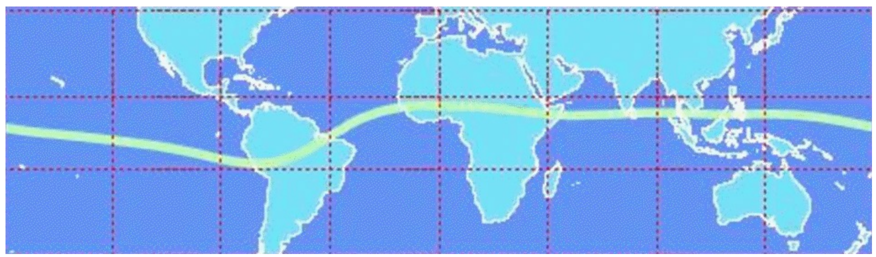


- The delay between the appearance and disappearance of the D region relative to the F layer provides a period of enhanced communications
- In the morning a strong F region permits excellent communications along the gray line before the signal absorbing D layer has a chance to develop
- In the evening the D layer disappears quickly again permitting a period of excellent communications while the F region is still strongly ionized
- Since D level absorption is inversely proportional to frequency squared, gray line propagation is very important for 80 and 40 meter DX, less so for 20 meters, and usually not relevant for 15 meters

Equatorial Sporadic E Propagation



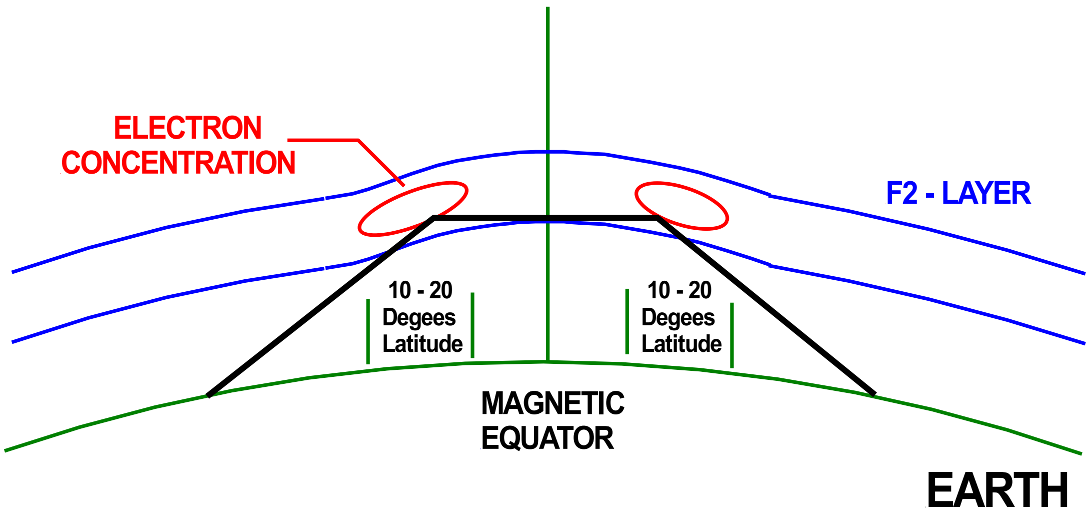
author



gfz-potsdam.de

- At low latitudes, ionization irregularities resulting from the equatorial electrojet are believed to be responsible for creating sporadic E patches
- The patches appear daily in a band about 5^{o} either side of the magnetic equator
- A signal transmitted at a low elevation angle can travel a considerable distance by reflecting from an equatorial sporadic E patch followed by a subsequent F layer refraction

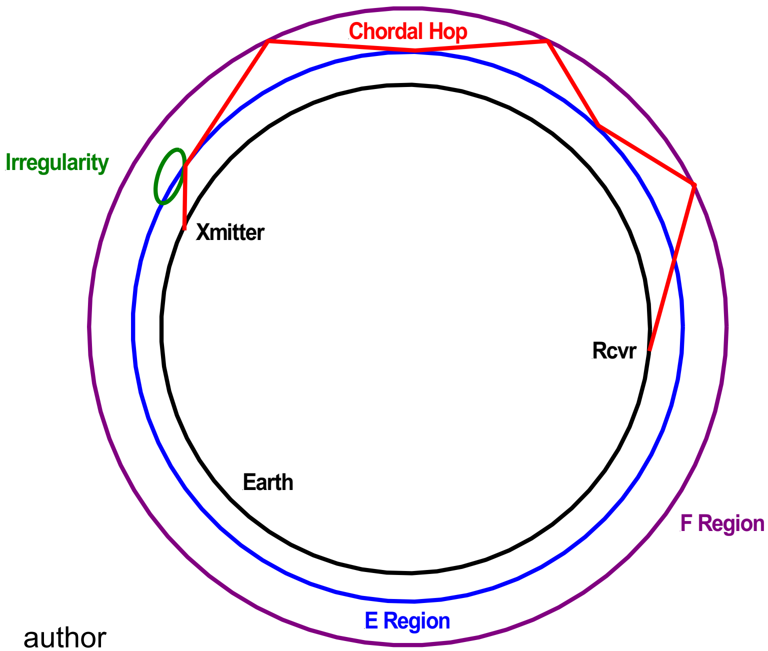
Transequatorial Propagation (TEP)



author

- Typically, a radio signal transmitted from one hemisphere to the other requires multiple hops through the ionosphere to reach its destination, with signal attenuations occurring with each hop
- Transequatorial propagation allows a radio signal to travel the same distance in a single hop, greatly minimizing signal loss
- Transequatorial propagation occurs when a radio signal reflects off regions of high electron concentrations located on opposite sides of Earth’s equator

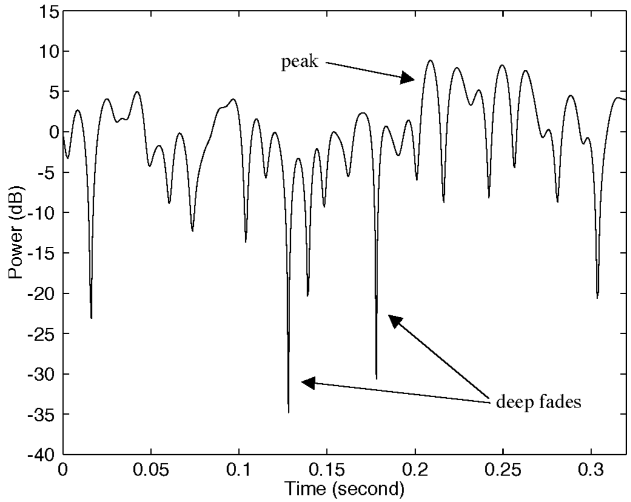
Ionospheric Ducting



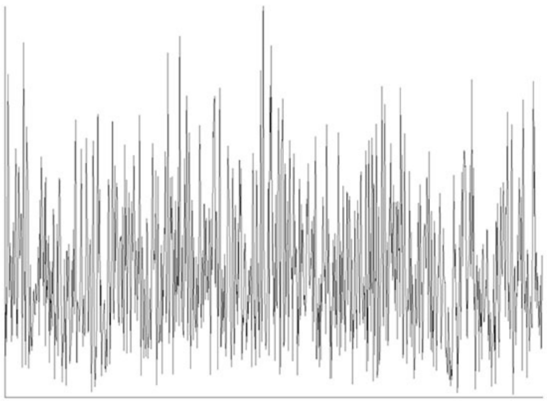
- If a signal is injected into the ionosphere at just the right angle, and under the right conditions, it can become trapped between the F and E layers, reflecting off the bottom of the F and the top of the E layer
- This injection can sometimes occur when a signal reflects from ionospheric irregularities
- A signal traveling in an ionospheric duct avoids multiple passes through the energy absorbing D layer and reflections from the ground
- Consequently, the signal can travel a long distance with little signal loss
- When ducting is present, communications half way around the world can occur with the same signal strength, clarity, and stability as communicating locally on a 2 meter repeater

Signal Fading and Noise

Ericsson Inc.



Signal Fading

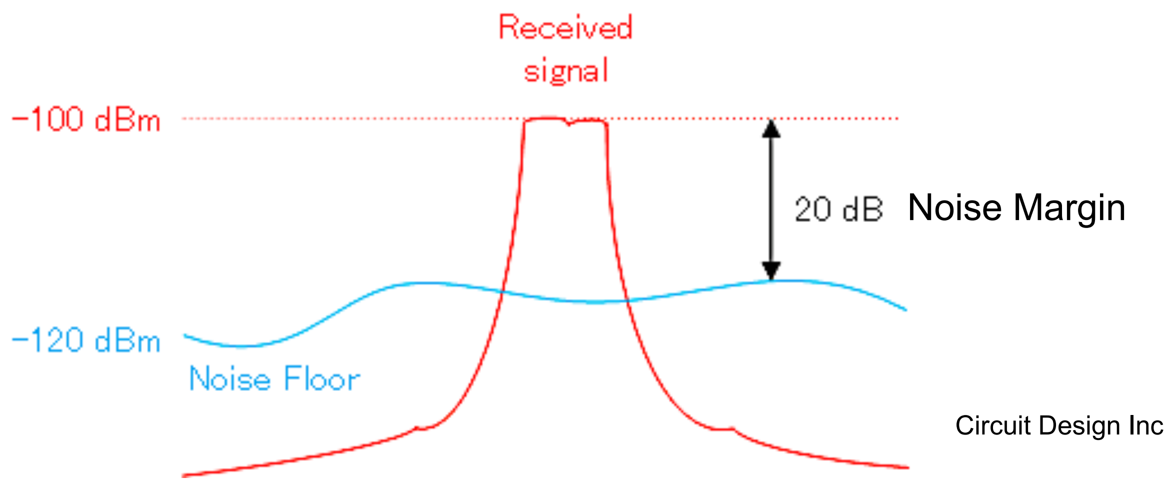


Vitrek

Background Noise

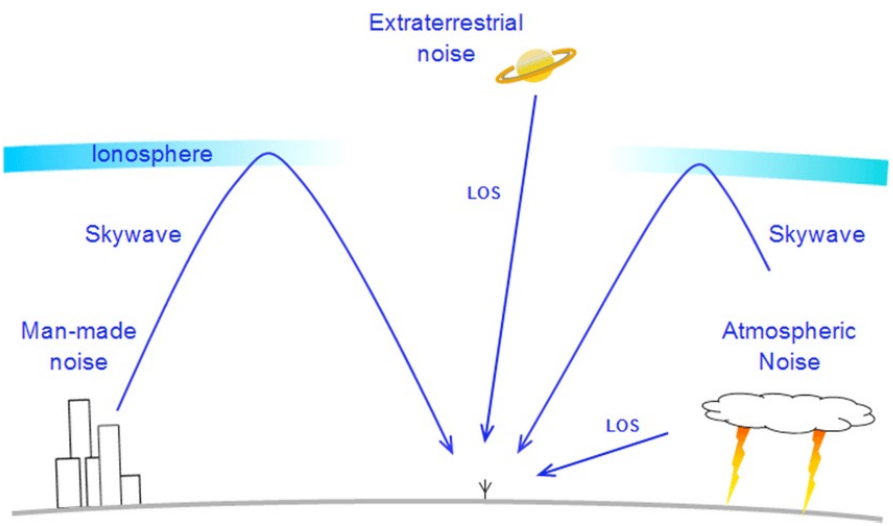
- Signal fading and background noise are two of the most serious problems affecting HF radio communications
- Signals that sink into the background noise can not be received
- Signals that fade in and out are very difficult to copy

Noise Floor



- There is always a certain amount of background noise and interference associated with HF radio communications – it can not be avoided
- Signals weaker than the background noise (below the noise floor) can not be heard
- Successful HF radio communications depends on operating at power levels above the noise floor
- In addition, there must be a sufficient noise margin so that the transmitted signal does not fade below the noise level

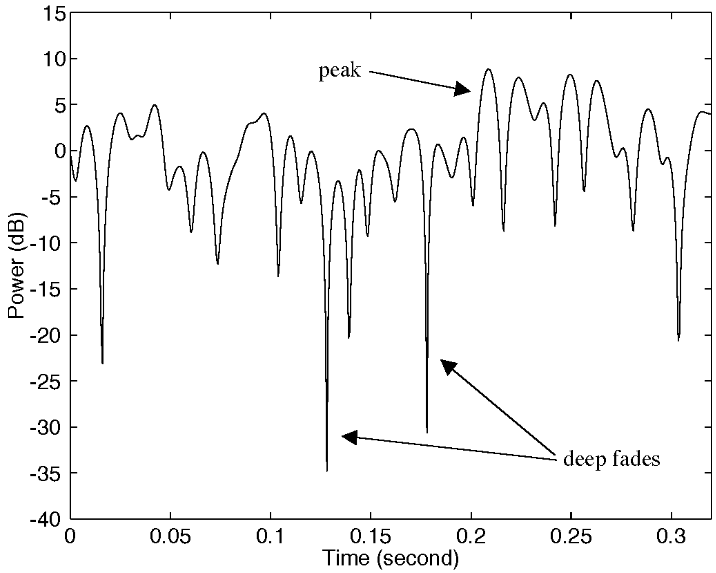
Background Noise Sources



ResearchGate

- The primary sources of background noise include:
  - Atmospheric noise particularly lightning strikes,
  - Galactic Extraterrestrial noise, and
  - Man made noise

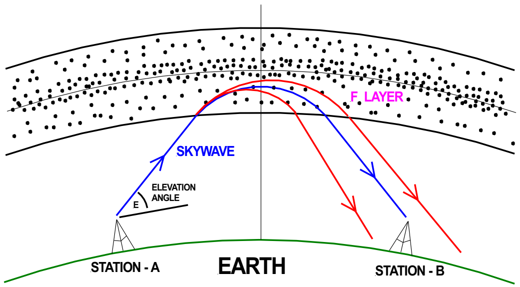
Signal Fading

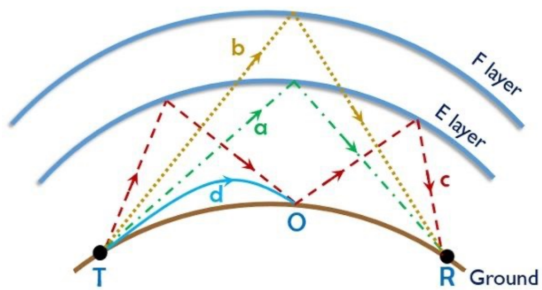


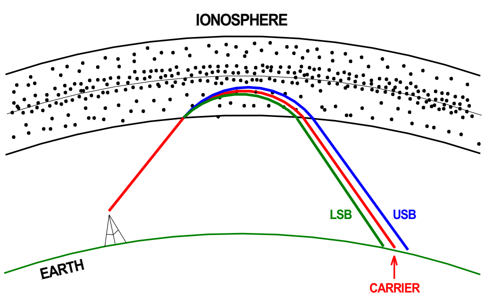
Ericsson Inc.

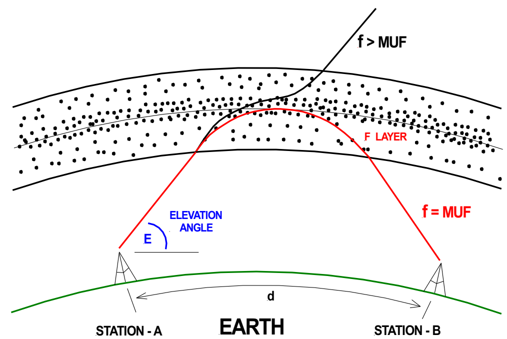
- Signal fading is what makes skywave communications difficult
- We can generally receive a steady signal, even if the signal is weak
- But a signal that repeatedly peaks, fades below the noise level, reappears, and fades again is difficult to deal with
- Fades vary in depth from shallow, only a db or so, to deep, fading more than 40 db
- The duration of fades also varies from short, a fraction of a second, to long lasting fades several hours long

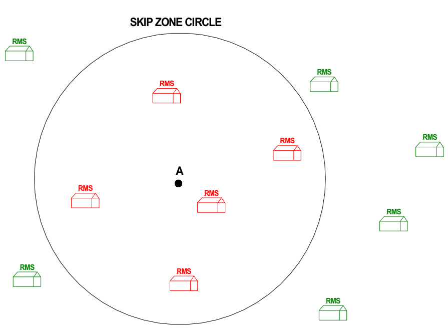
Seven Types of Fading

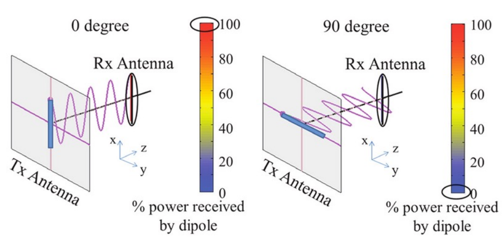


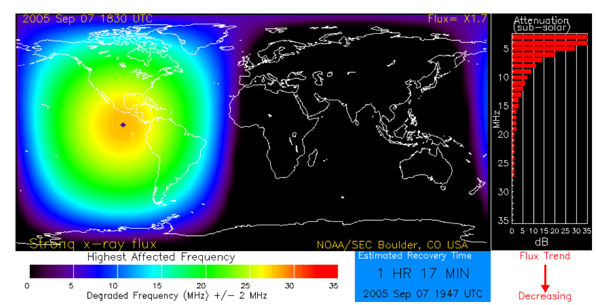






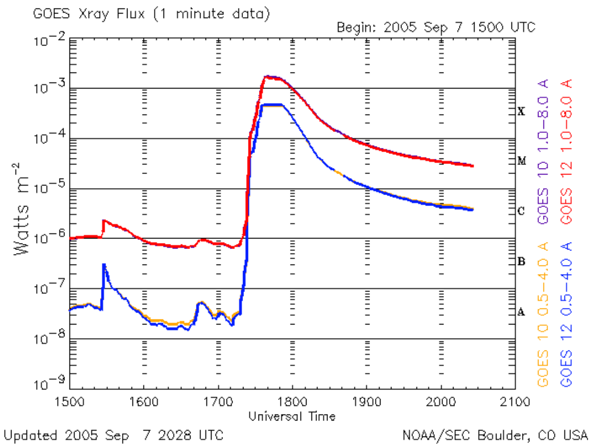


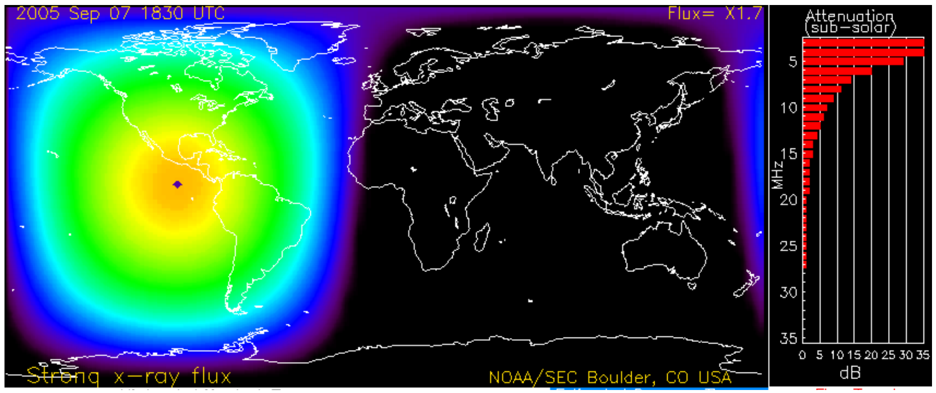




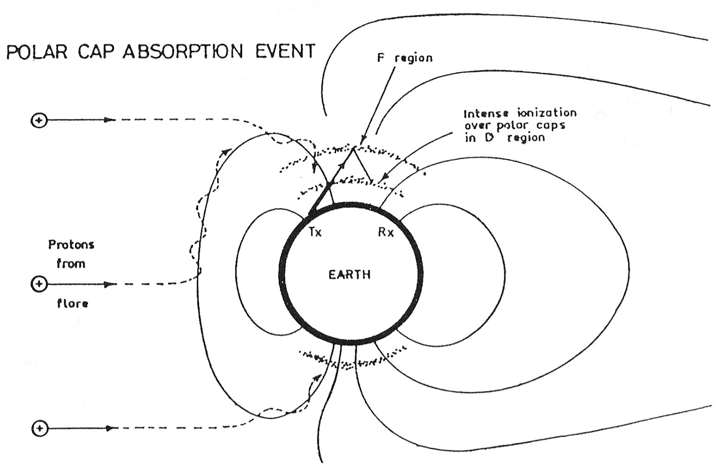
- Ionospheric Path Fading
- Interference Fading,
- Frequency Selective, Fading,
- MUF Fading,
- Skip Fading,
- Polarization Fading,
- Absorption Fading

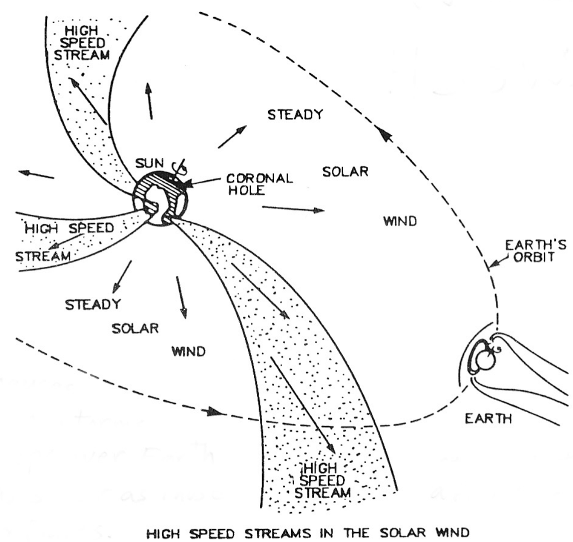
Three Types of Ionospheric Storms





X-ray Radiation Storms





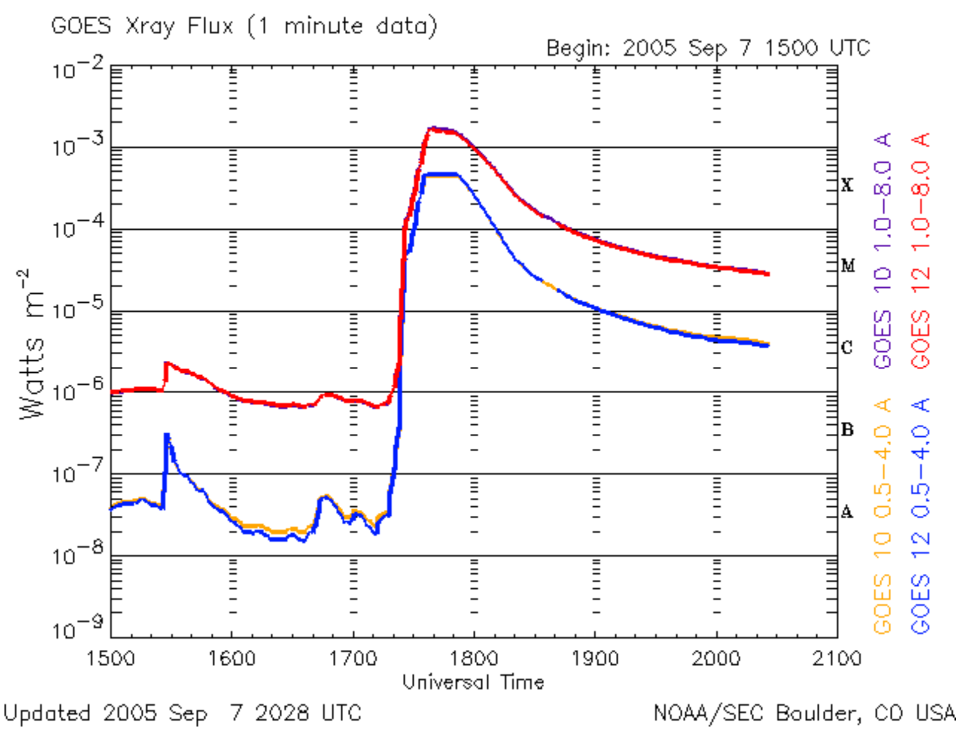
High Energy Particle Storms

Solar Wind Storms

X-ray Radiation Storms

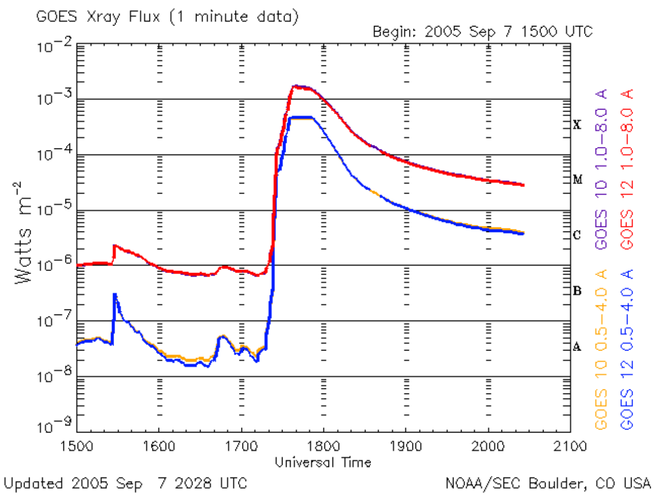
Solar Flare

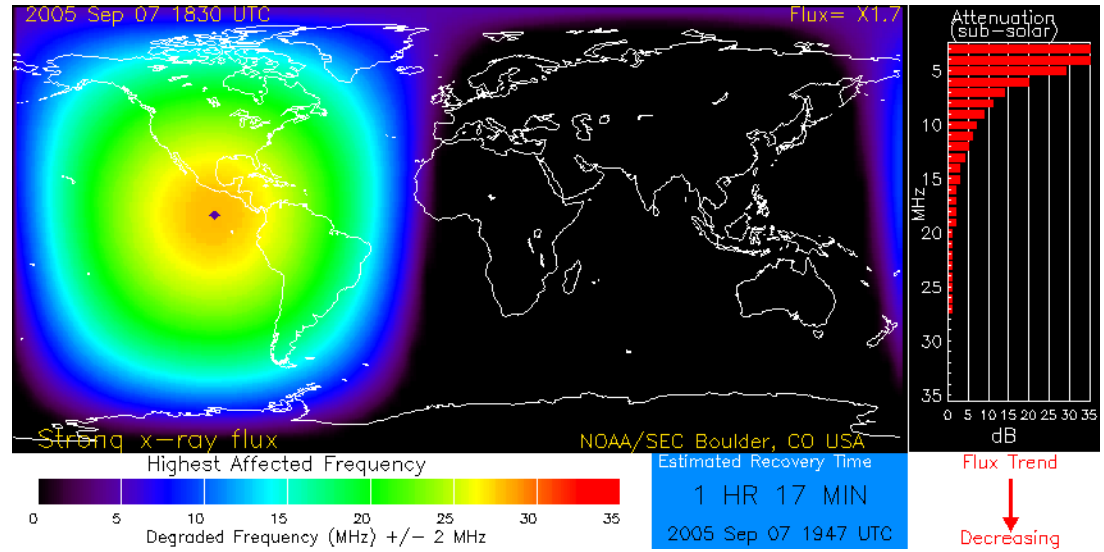
wral.com



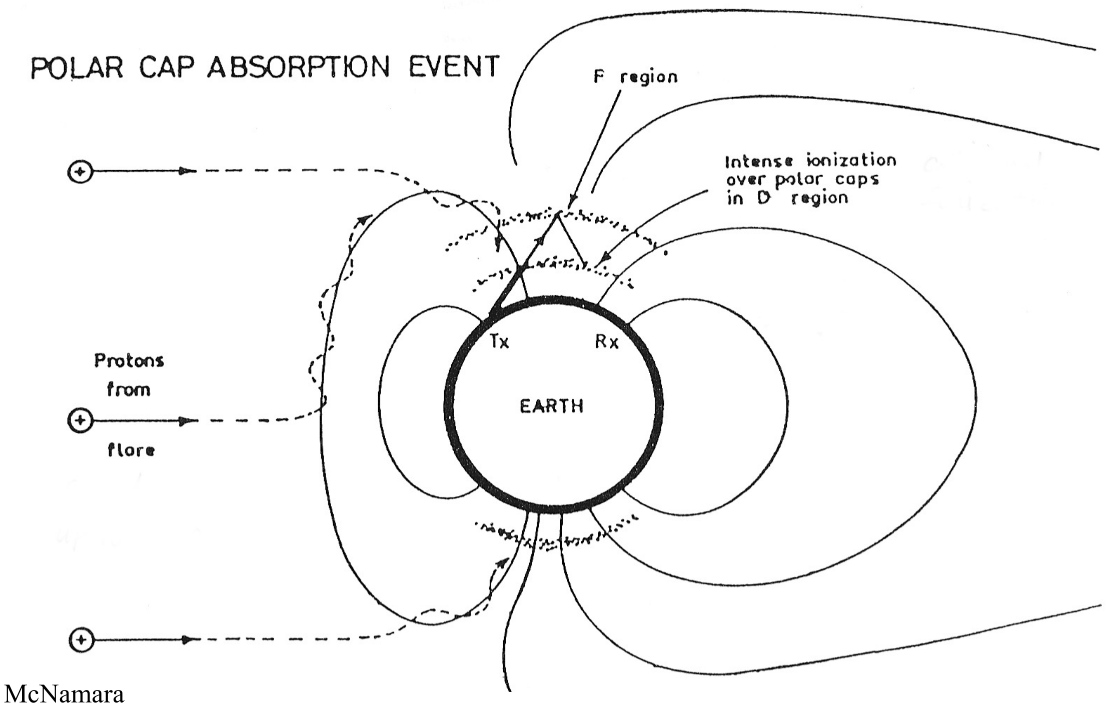
- An x-ray radiation storm is caused by a sudden dramatic increases in x-ray radiation from the Sun
- X-ray radiation storms are produced by solar flares
- X-ray radiation from a solar flare reaches Earth in little over **8 minutes**

X-ray Radiation Storms Heavily Ionizes D Layer





- An x-ray radiation storm heavily ionizes the ionosphere D – region
- Causing extensive absorption of HF radio signals – **low frequencies hit hardest**
- Black diamond represents the Sun's location (local noon)
- Color bar represents the highest frequency bands affected
- Bar graph on right shows signal attenuation by frequency

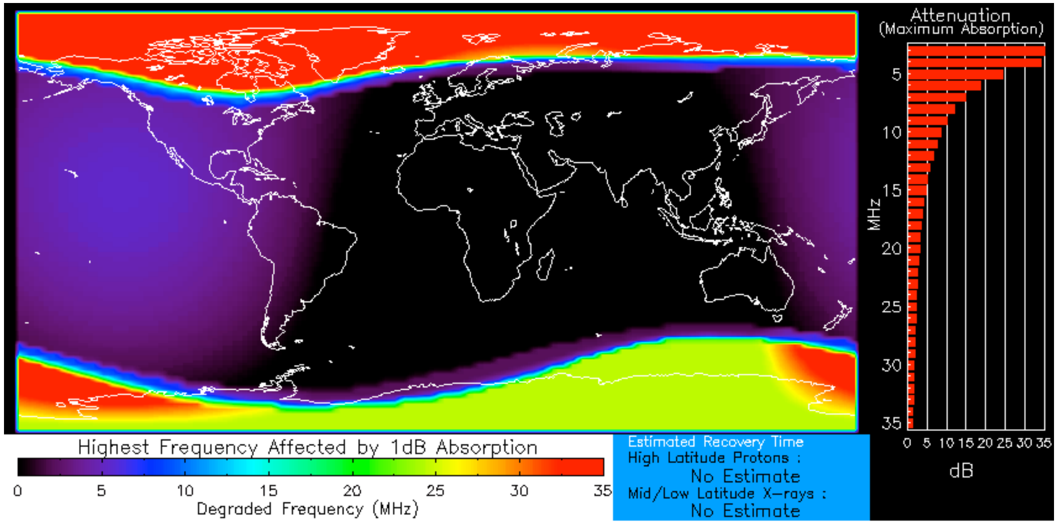


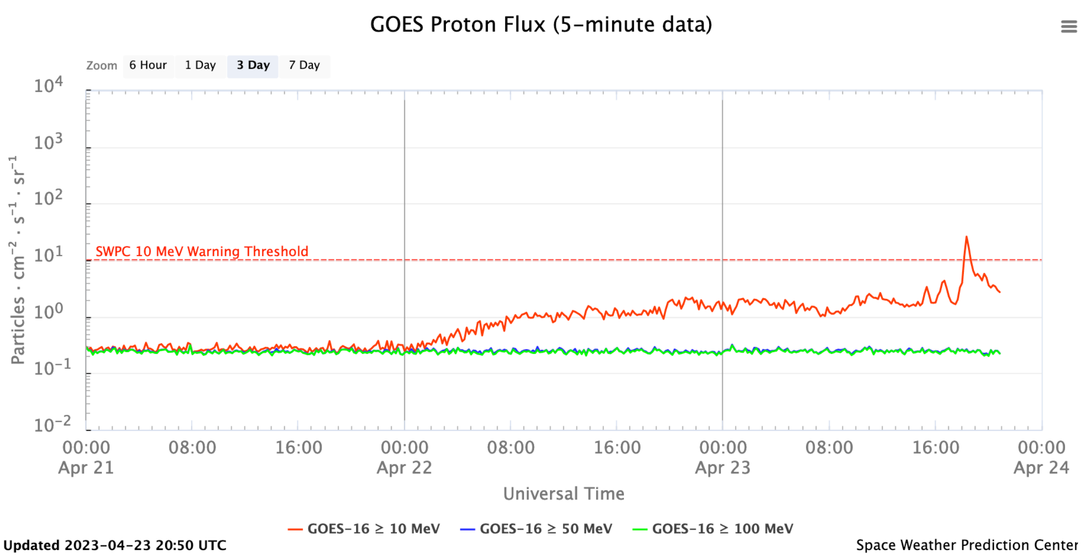
McNamara

High Energy Particle Storms

- Electrically charged particles can not cross Earth's magnetic field lines
- Upon reaching Earth, High Energy Particles are forced to travel along Earth's magnetic field lines, spiraling down into the polar cap regions as the magnetic field lines become vertical.
- High Energy Particles heavily ionize the D layer polar cap ionosphere causing HF radio signals passing through the area to be absorbed, resulting in a Polar Cap Absorption event (PCA)

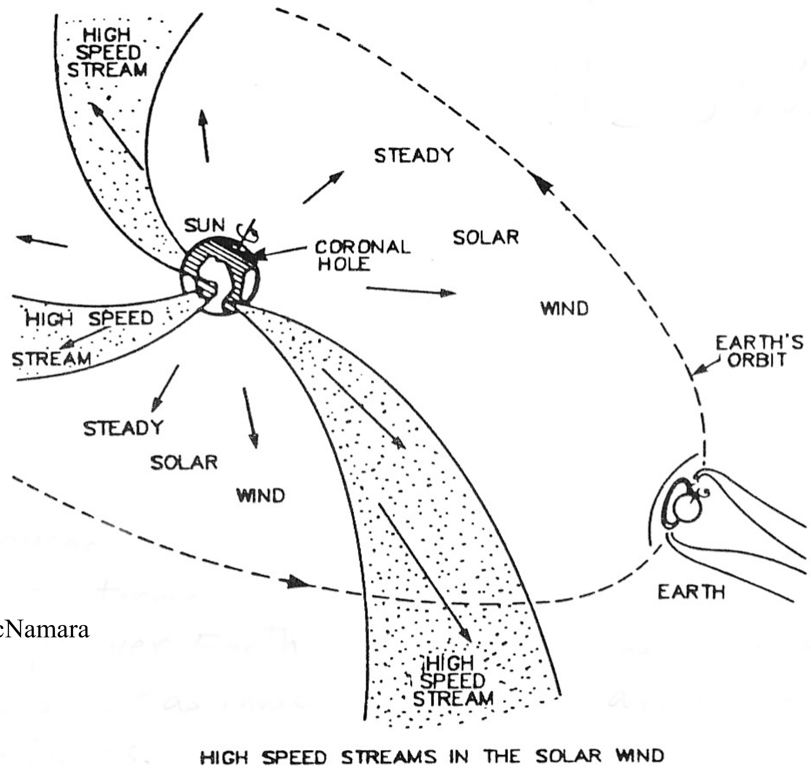
Polar Cap Absorption (PCA) Events





- A PCA occurs when the Proton Flux exceeds 10 MeV Warning Threshold
- PCA (polar region red) heavily absorbs transpolar HF signals
- Lowest frequency signals absorbed the most
- PCAs caused by solar flares and Corona Mass Ejections (CMEs)
- During a PCA avoid transpolar propagation paths

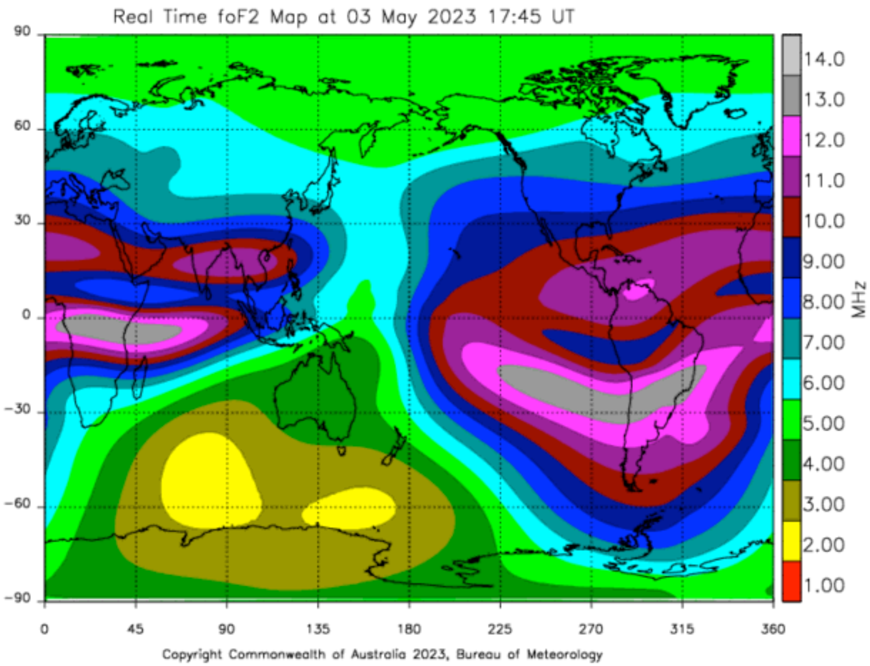
Ionospheric Solar Wind Storms



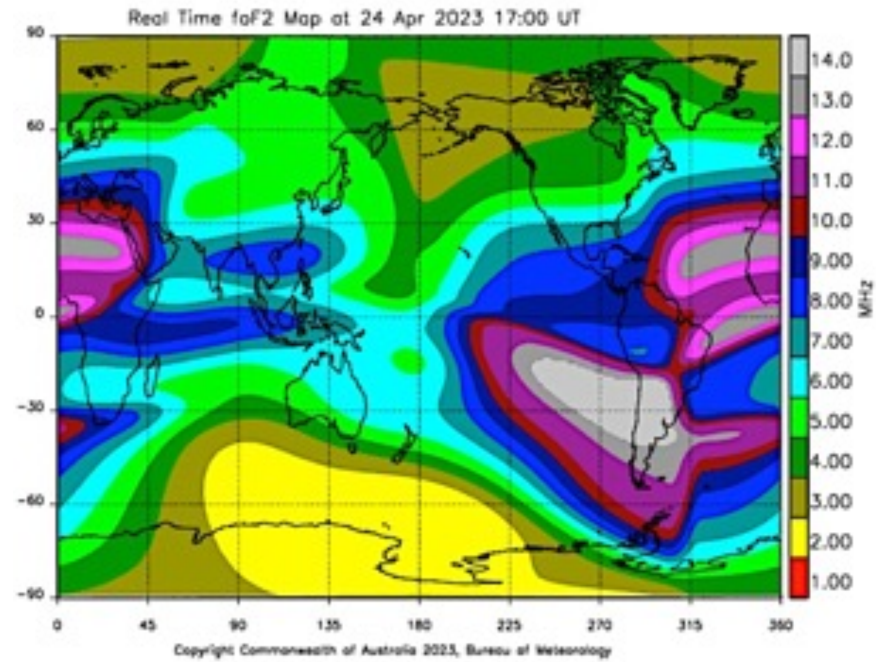
McNamara

- Ionospheric Solar Wind Storms are caused by high speed stream (HSS) solar winds from CMEs, coronal holes, & solar flares sweeping past Earth
- HSS winds arrive in two to four days
- Collisions of solar wind particles with neutral atoms & molecules in Earth's upper atmosphere change
  - The chemical composition of the ionosphere,
  - Heat the atmosphere, and
  - Change the circulation patterns of the thermospheric winds.
- Accelerating ion – electron recombination resulting in serious drops in F2 critical frequencies
- 20 thru 10 meter bands are affected the most

Impact of an Ionospheric Solar Wind Storm



In The Absence of a Storm

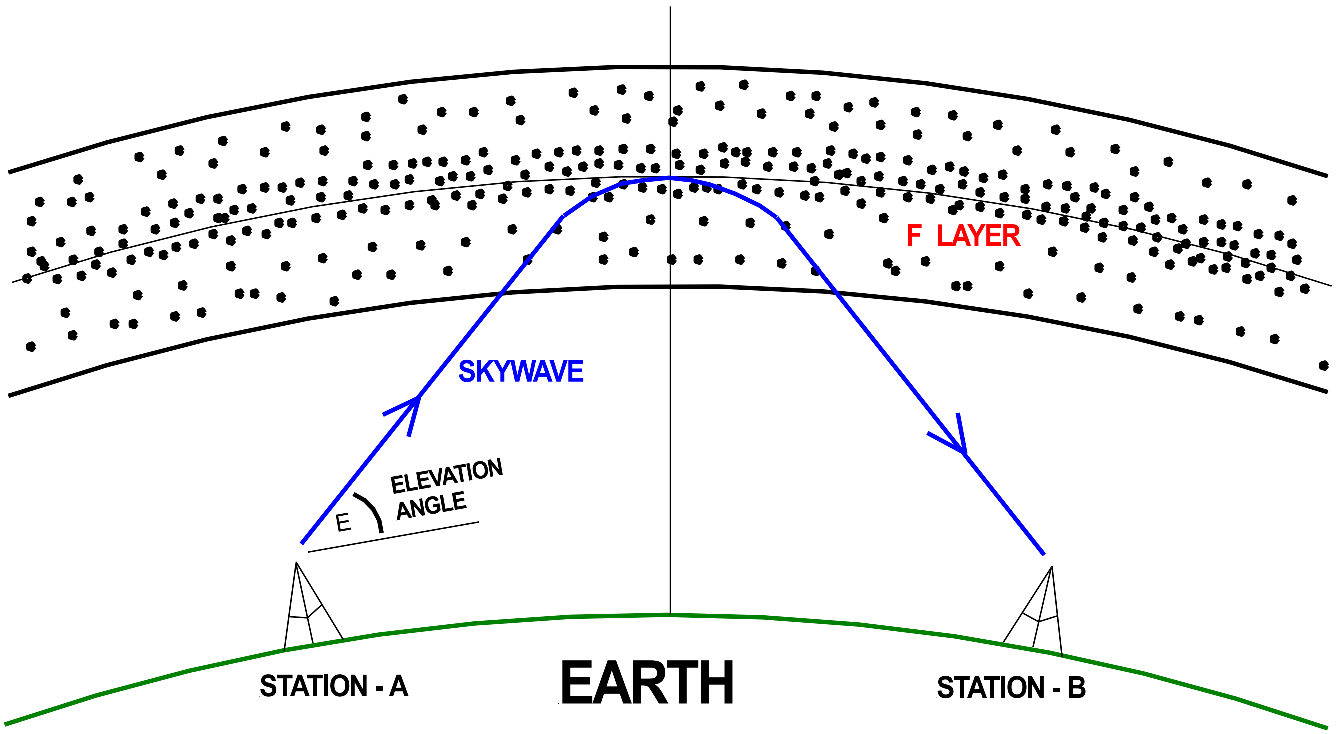


Ionospheric Solar Wind Storm

- In these figures, critical frequencies are relative high in the absence of a storm, ~ 8 MHz in the central part of the United States
- During an ionospheric solar wind storm critical frequencies drop by a factor of ~ 2
- For the above storm critical frequency drops from 8 to around 4 to 5 MHz
- Forcing radio operations to lower frequencies (for example from 20m to 40 meters)

HF Radio Communications

- Transmitting HF radio signals from one place to another can be a real challenge.
- But that is what makes it fun !



HF Radio is a LOT of FUN !