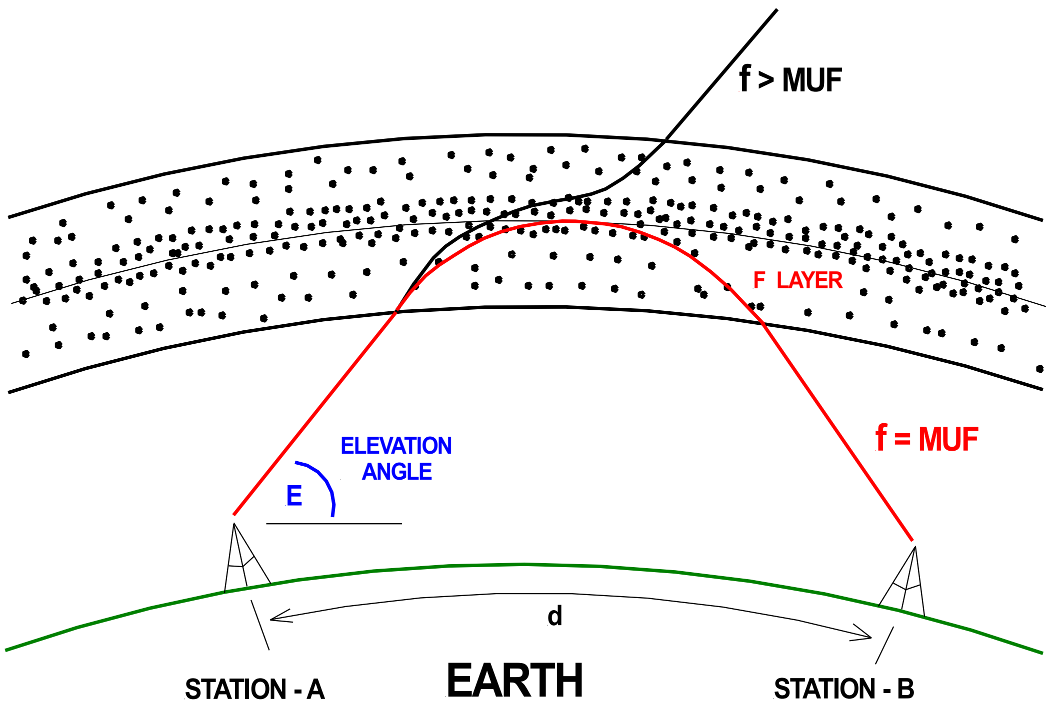
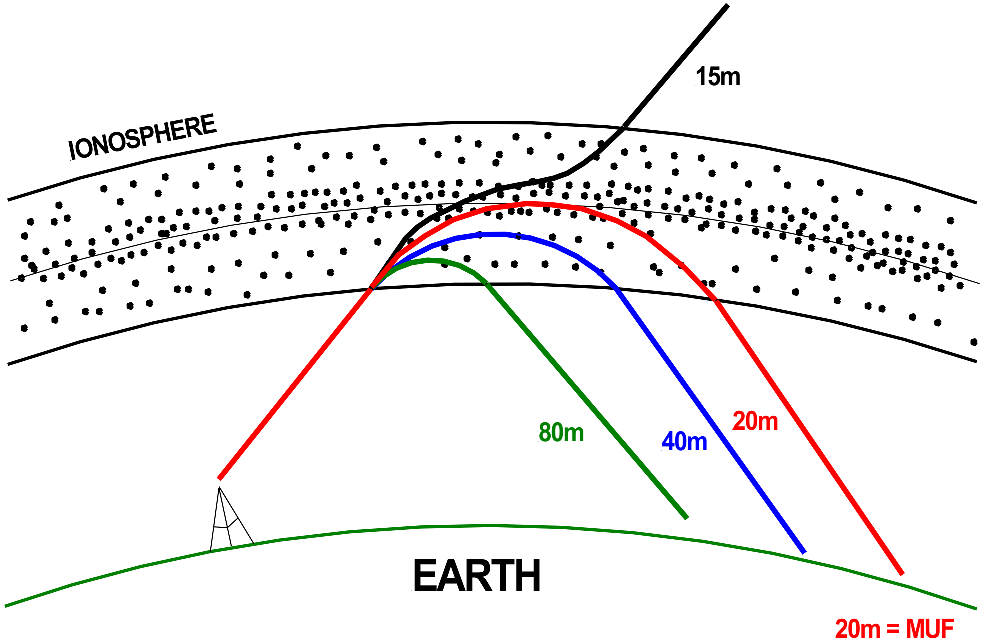
Maximum Usable Frequency



www.skywave-radio.org

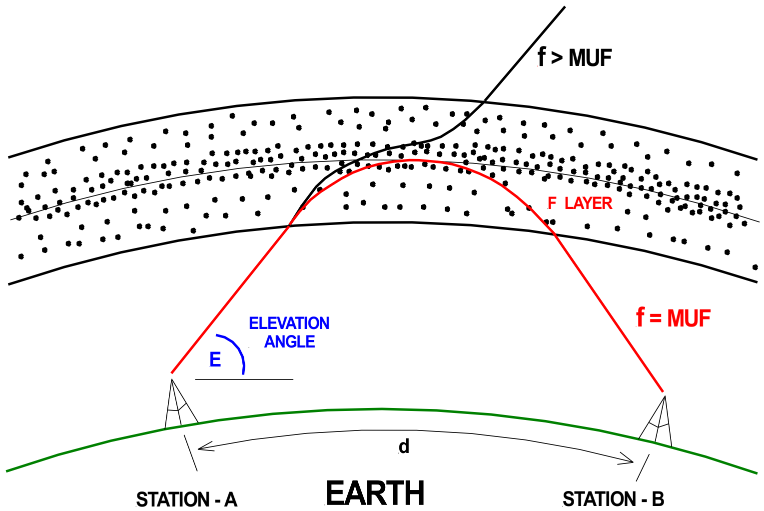
Ken Larson KJ6RZ
March 2024

Maximum Usable Frequency



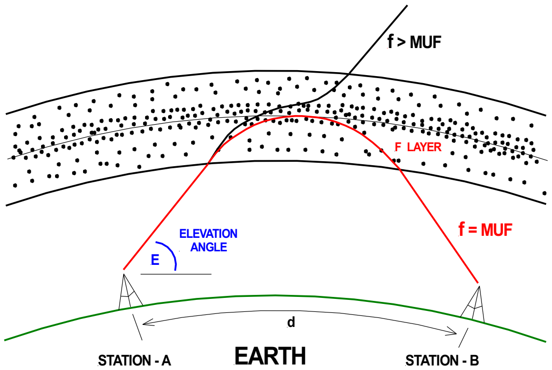
- As the frequency of a radio signal increases, i.e. its wavelength becomes shorter
- It travels progressively higher into to the ionosphere
- Until at some point the signal penetrates the ionosphere and is lost to outer space
- The highest frequency signal that can be transmitted and return to Earth is the Maximum Usable Frequency (MUF)

Maximum Usable Frequency Station Dependency



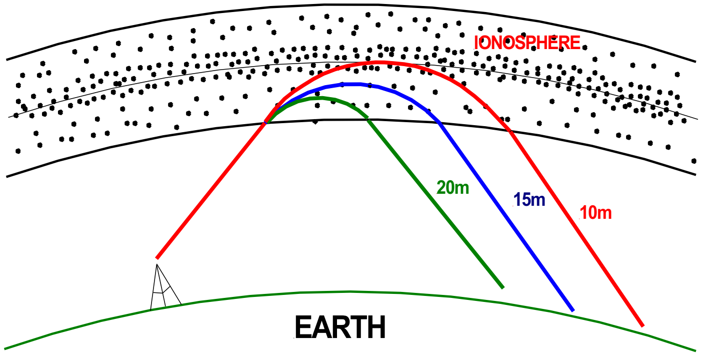
- MUF depends on the particular radio stations involved
- $MUF_{A\text{-}B}$ is the highest possible frequency for communicating from Station A to Station B
- Attempting to communicate between Stations A and B at a higher frequency will cause the radio signals to penetrate the ionosphere and be lost to outer space
- At the same time and day the maximum usable frequency for communicating from Station A to some other Station C ($MUF_{A\text{-}C}$) will be different than the MUF between Stations A and B
- We will show how to determine the MUF between two stations

Published Maximum Usable Frequency Values

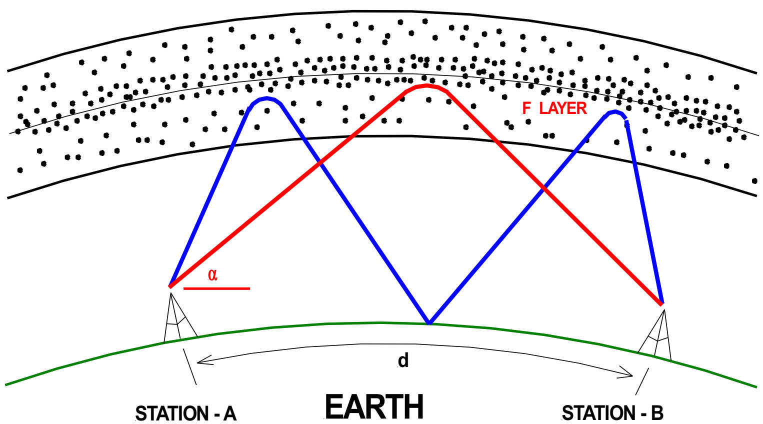


- As we will see later, maximum usable frequency depends directly on the elevation angle E at which a signal is transmitted
- A signal transmitted at a very low angle, say E = 10^o , will have a much higher MUF than a signal transmitted at an elevation angle of 20^o
- Published MUF values are for signal transmitted at very low angles ~ 10^o
- Most amateur radio operators can not achieve the published MUF values because the lowest angles that their antennas can transmit at are generally15^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
- This presentation will show you how to calculate your MUF

Advantages of Operating at the MUF

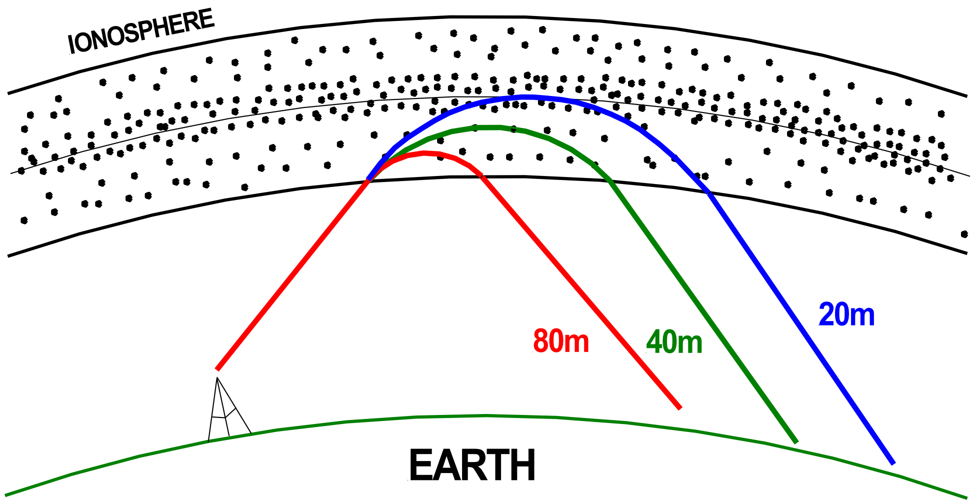


$$\text{Absorption} \propto \frac{1}{f^2}$$



- The longest hops, best DX occurs at or near the MUF
  - DX on 15m is better than on 20m
  - DX is best on 10m
- Operating at the MUF minimizes D Layer absorption
  - D Layer absorption is inversely proportional to frequency squared
  - To avoid absorption, you want to operate at the highest frequency possible
- Operating at the MUF often reduces multi-path interference

Frequency Dependency of Refraction



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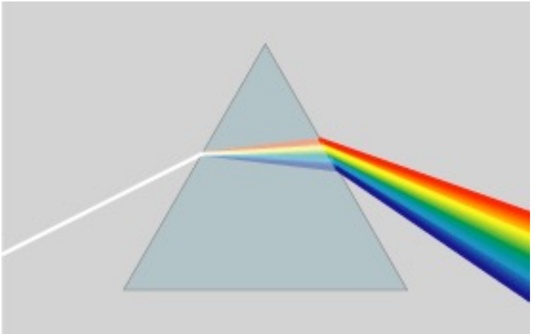


Wikipedia

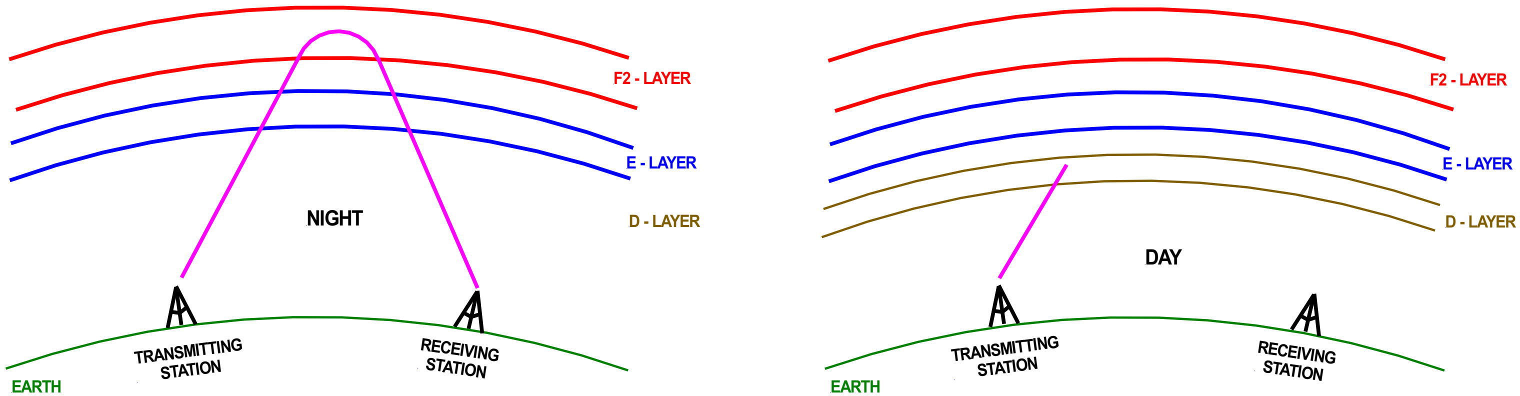
- The ionosphere's index of refraction is wavelength dependent
- Long wavelength 80 meter (3.8 MHz) signals refract in the lower part of the ionosphere producing relatively short hop distances
- Shorter wavelength 20 meter (14.2 MHz) signals travel further into the ionosphere before refracting back to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

Absorption vs Frequency

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

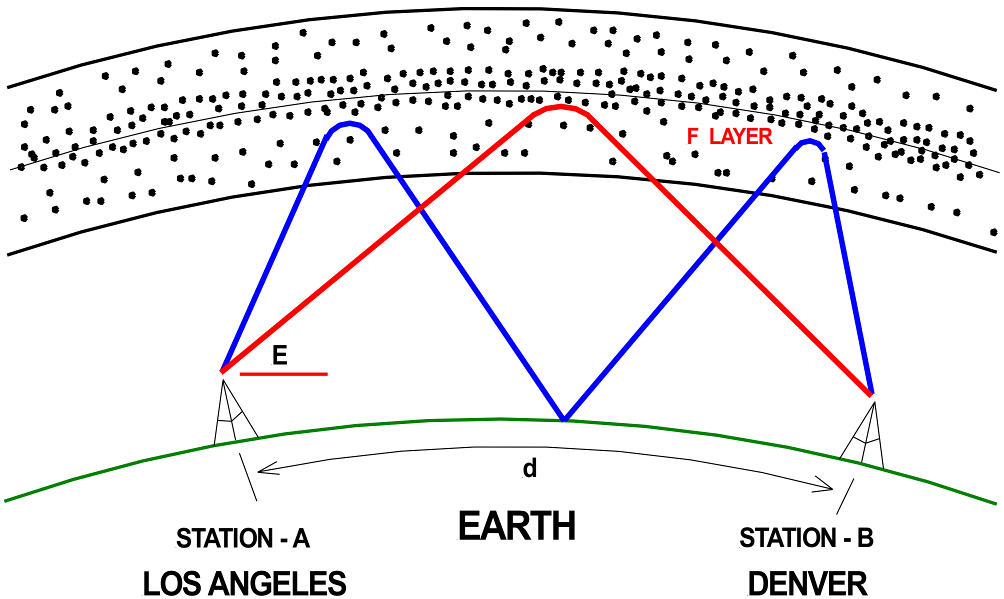
- D Layer absorption is inversely proportional to frequency squared
- Absorption on 40 meters is only 1/4 that on 80 meters
- Absorption on 20 meters is only 1/16 that on 80 meters
- And D Layer absorption on 15 meters is insignificant
- To avoid absorption, you want to operate at the highest frequency possible

Anatomy of Absorption



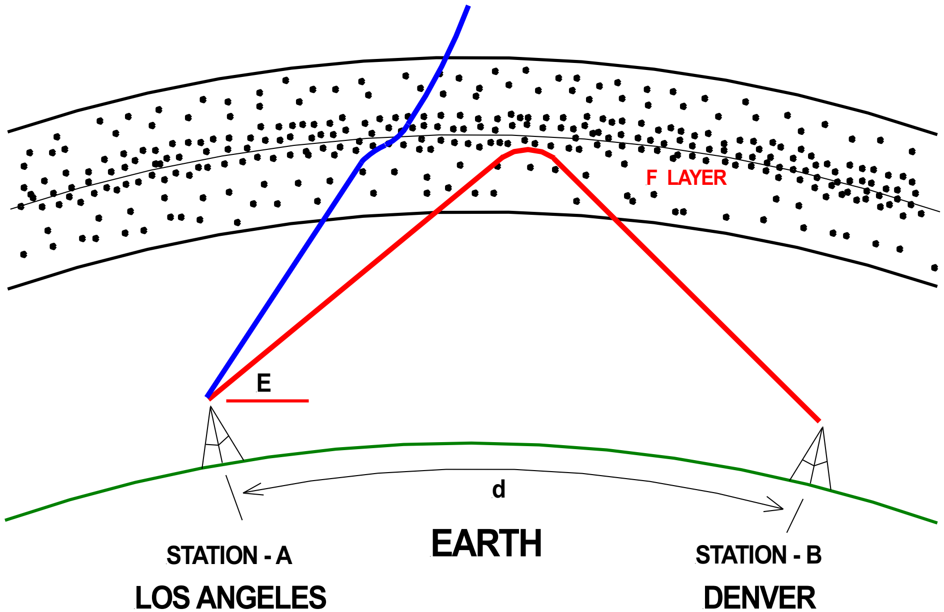
- Radio waves are absorbed as they pass through the ionosphere
- Free electrons absorb energy from the passing radio waves causing the
- Electrons to vibrate at the same frequency as the radio waves
- In the process vibrating electrons reradiating the absorbed radio energy
- Consequently little radio energy lost in the ionosphere's E and F regions
- **D Layer is different**
- Electrons recombine with ions so fast in the D region that electrons do not have time to reradiate their absorbed radio wave energy
- Instead, absorbed radio wave energy is dissipated as heat in D Layer

Example of the Multi-path Problem



- Communications between Los Angeles and Denver on 40 meters, a distance of 830 miles, often occurs by both single hop and double hop propagation.
- The double hop path is much longer than the single hop path causing it to be received out of phase with the single hop signal
- Result: destructive interference between the single and double hop propagation paths can seriously weaken and distort LA to Denver communications

Solving The Multi-path Problem



- By moving to a higher frequency (for example 20 meters) the high elevation angle (E) double hop 20m path penetrates the ionosphere and disappears into outer space
- The lower angle single hop 20m path is the only path remaining eliminating multi-path interference
- Operating at the highest possible frequency (MUF) often solves multi-path problems

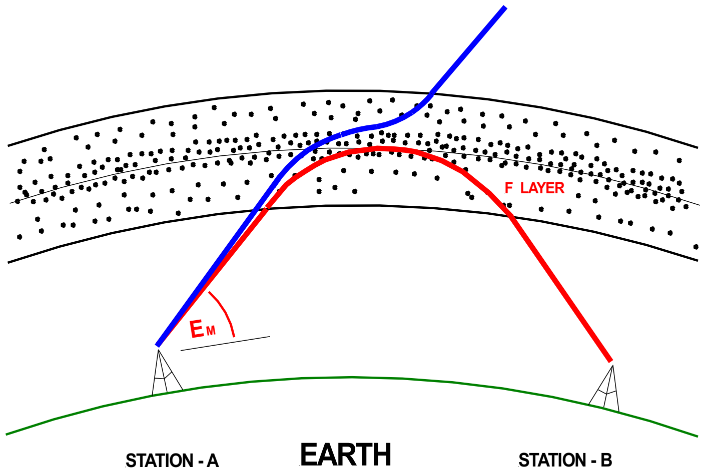
MUF Equation

- The equation for determining the Maximum Usable Frequency (MUF) is:

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

- MUF = Maximum Usable Frequency
- E = Elevation angle of the signal radiating from your antenna.
- f_c = The ionosphere's Critical Frequency

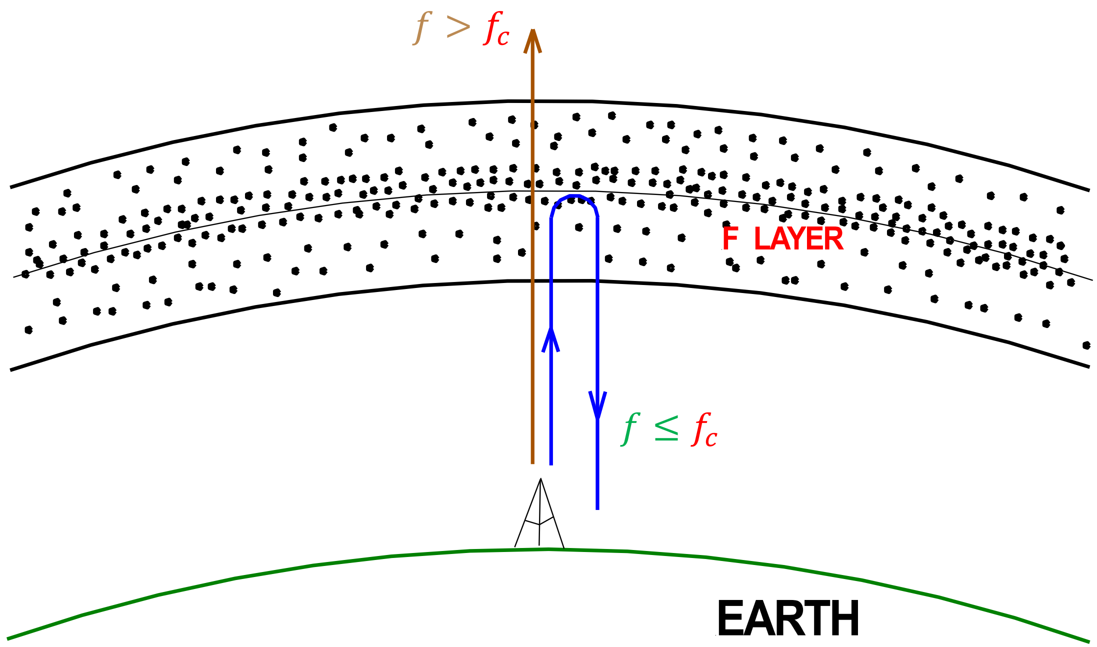
Elevation Angle E



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

- 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), at a particular frequency, that can be transmitted and still be refracted back to Earth
- Signals transmitted at higher elevation angles (blue signals) penetrate the ionosphere and are lost to outer space
- Consequently both frequency (MUF) and angle (MUA) determine if a signal will penetrate the ionosphere

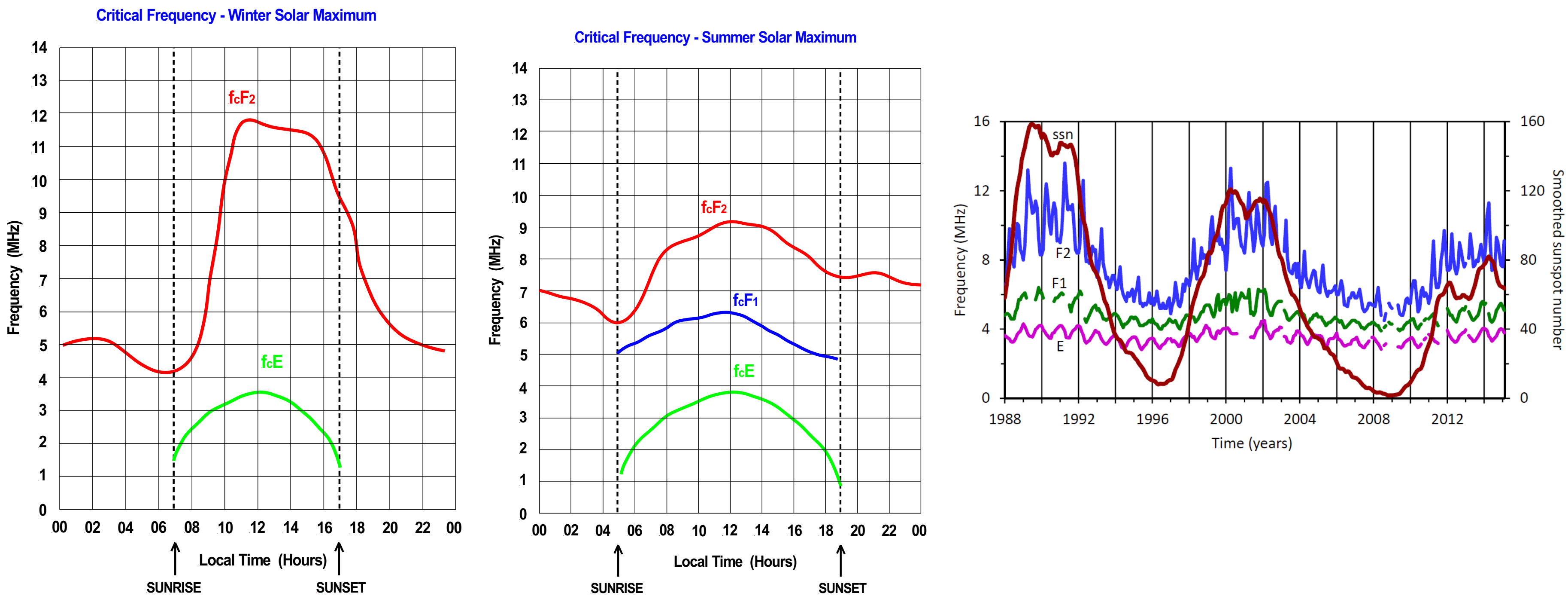
Critical Frequency f_c



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

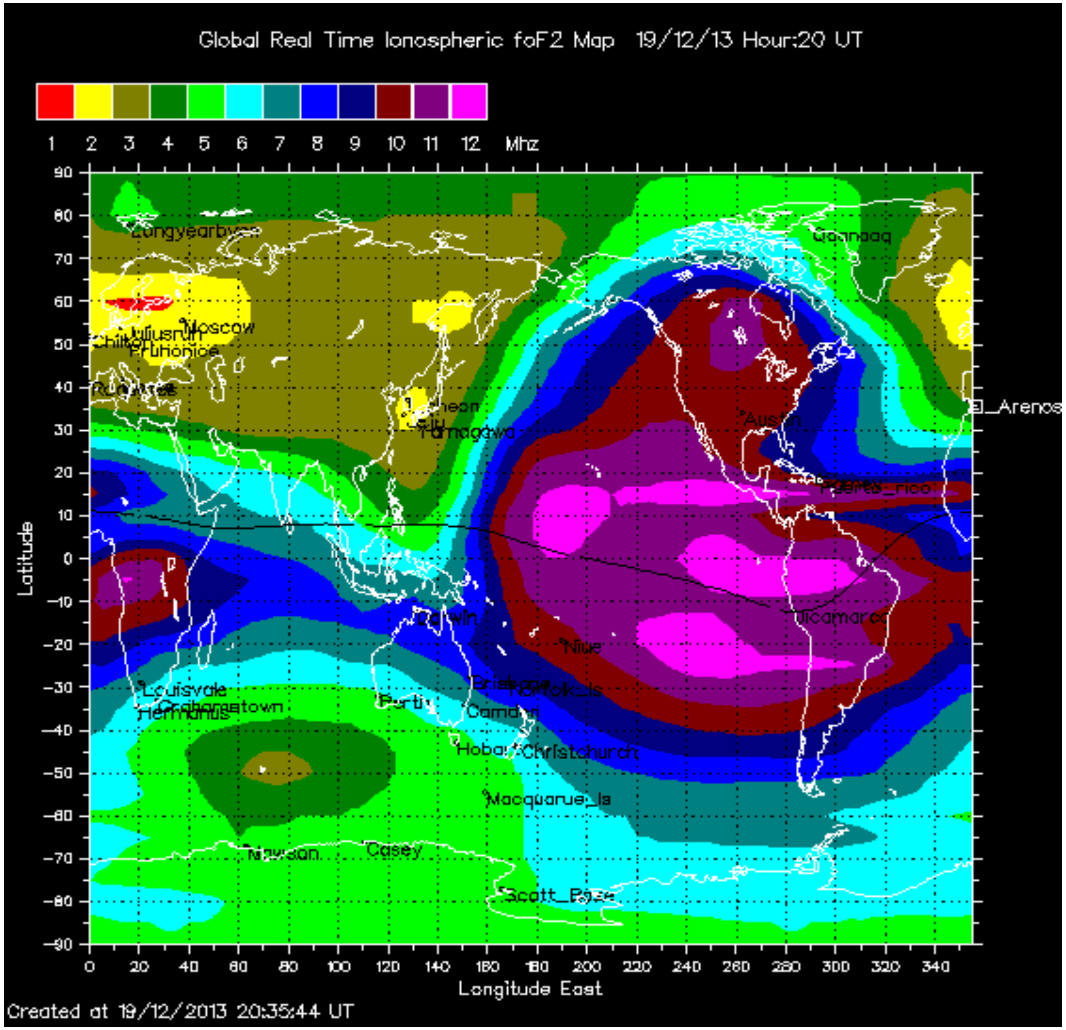
- Critical Frequency $\mathbf{f_c}$ is the **highest** frequency signal that can be transmitted straight up and reflected back down to Earth.
- All signals lower in frequency than $\mathbf{f_c}$ will also be reflected back to Earth
- But, signals higher in frequency transmitted straight up will penetrate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

Critical Frequency Varies



- 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

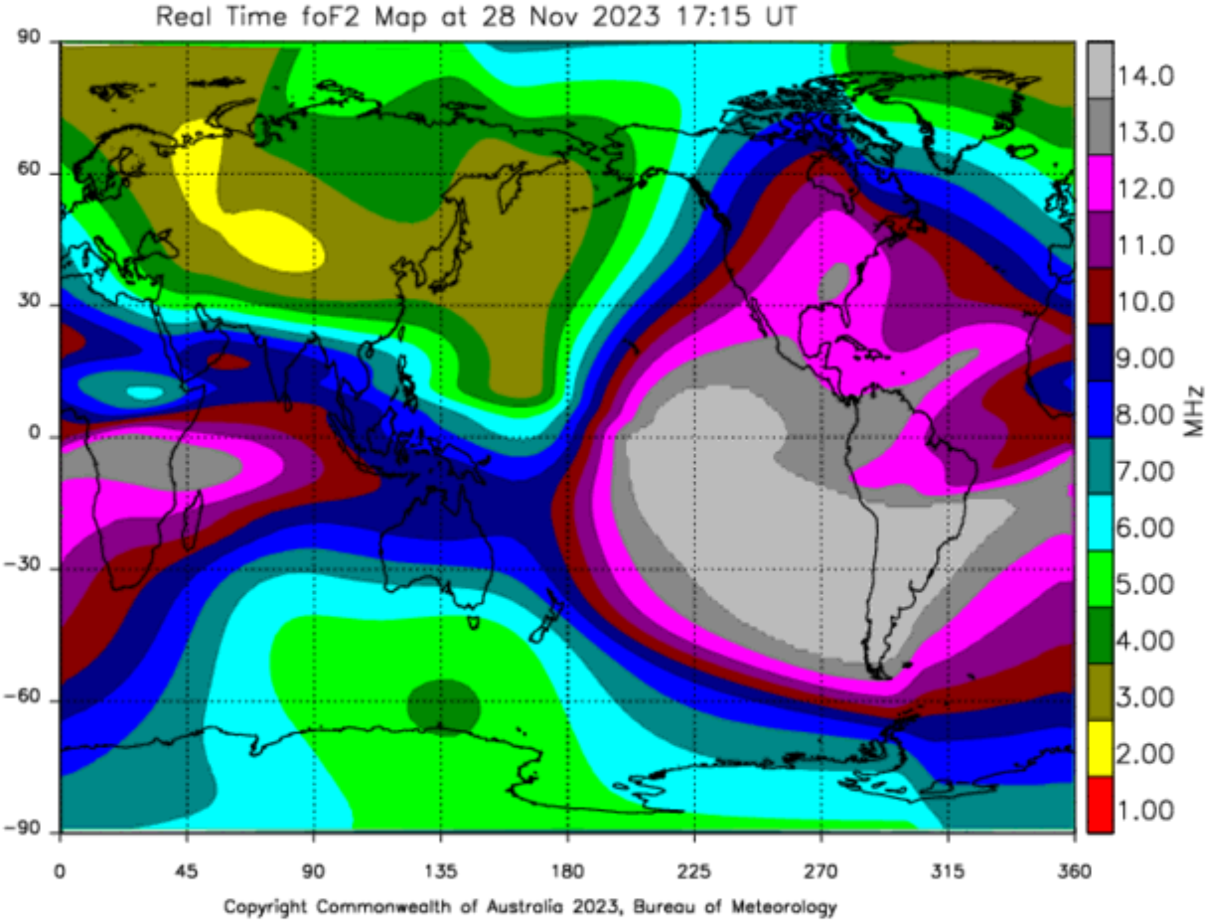
Determining F2 Critical Frequency



- 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)

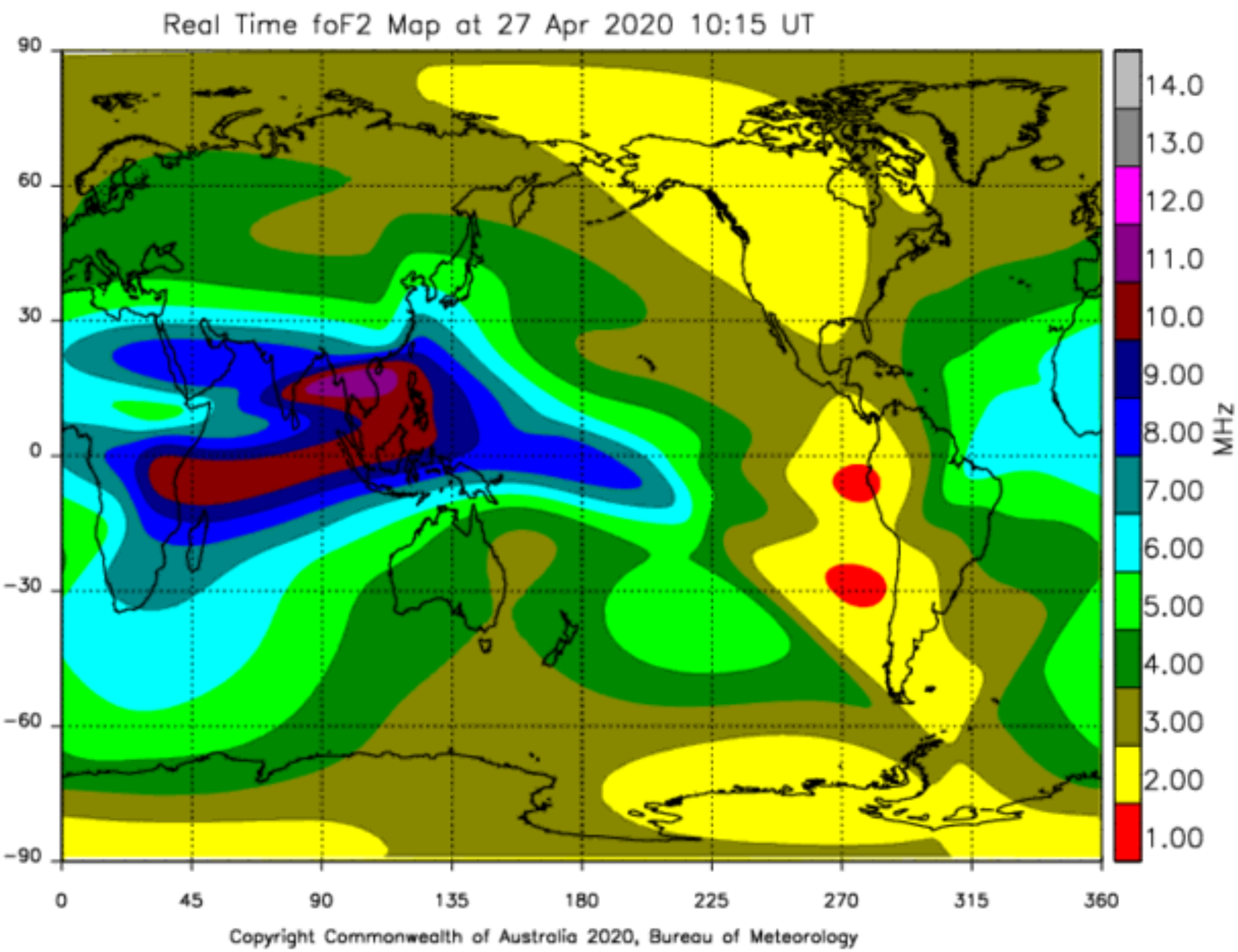
- At the time and date of this map f_c = 10 MHz over central U.S. & 2 MHz in Moscow, Russia

How High Can The Critical Frequency Get?



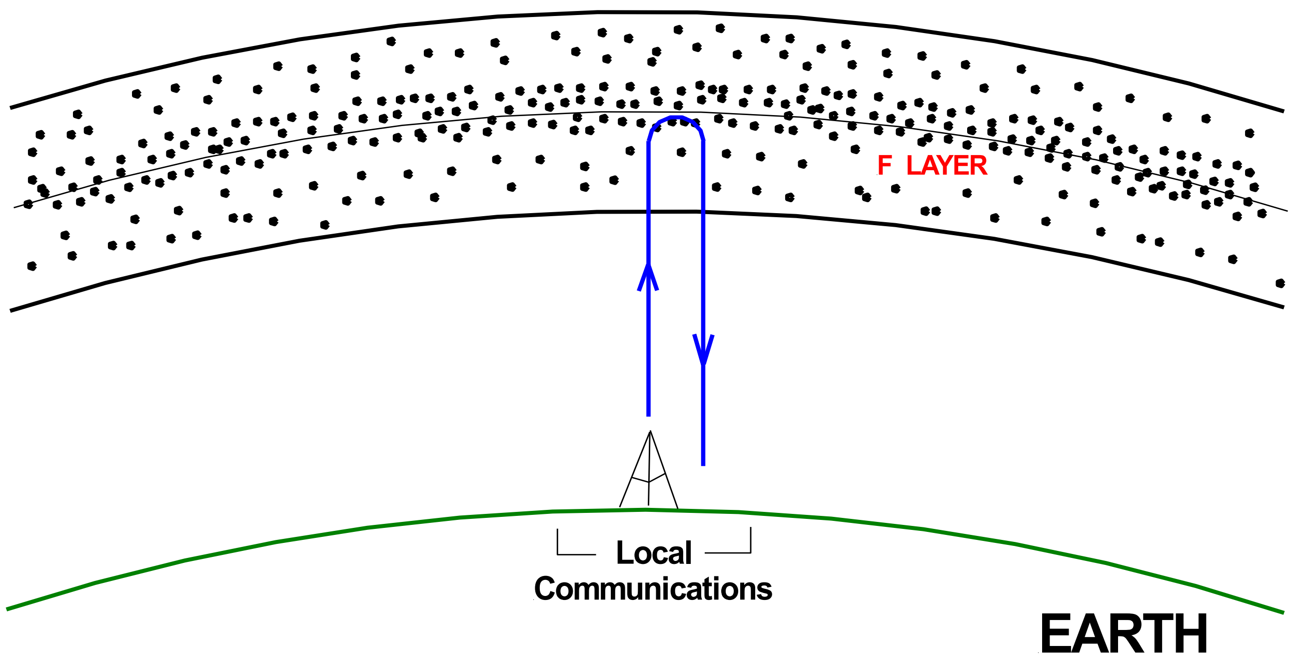
During solar maximum critical frequencies can be very high, approaching 14 MHz as illustrated in this map

How Low Can The Critical Frequency Get?



During solar minimum the critical frequency can easily get down to 2 MHz at night and at times down to even 1 MHz

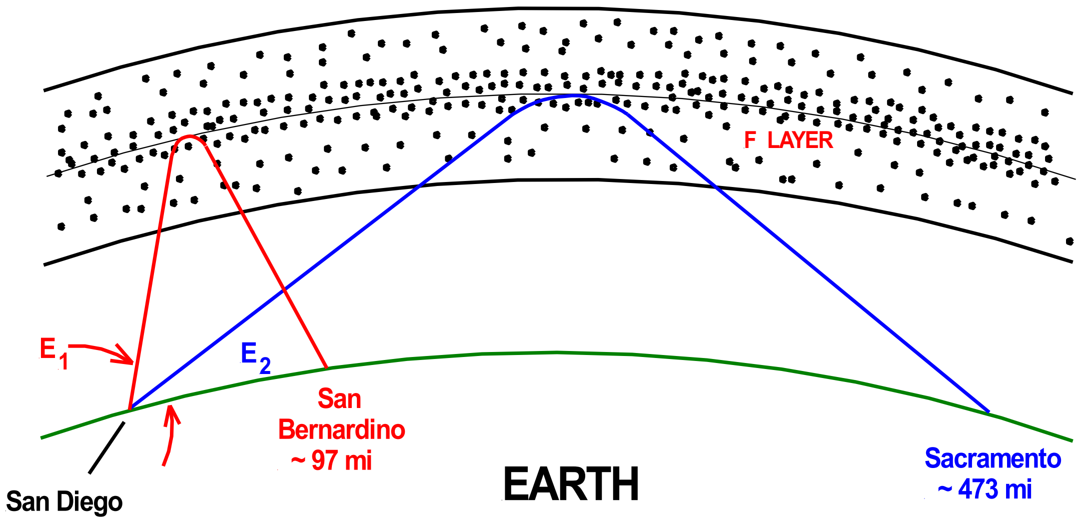
MUF is Greater Than or Equal To f_c



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

$$MUF = \frac{f_c}{\sin E} = \frac{f_c}{\sin 90^o} = \frac{f_c}{1} = f_c \qquad MUF = \frac{f_c}{\sin E} = \frac{f_c}{\sin 45^o} = \frac{f_c}{0.707} = 1.41\, f_c$$

MUF Depends on the Path

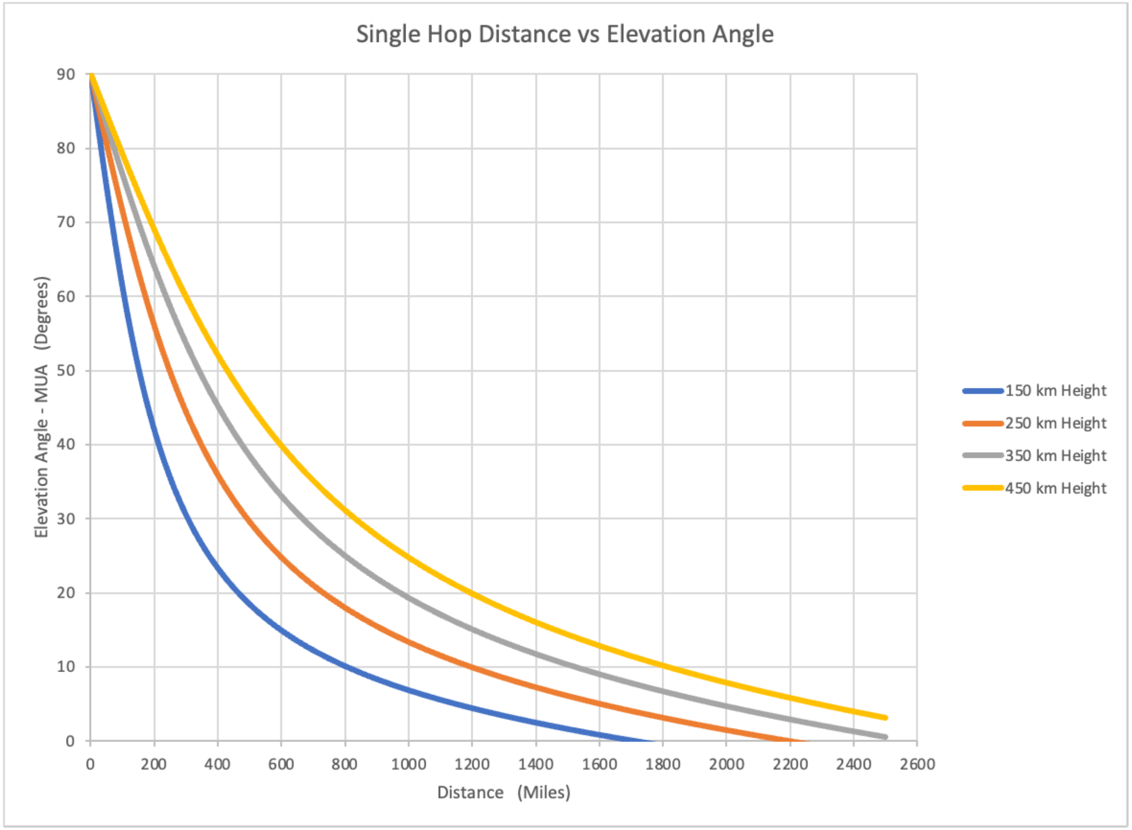


$$MUF = \frac{f_c}{\sin E}$$

- 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 = 20º will travel a little over 700 miles



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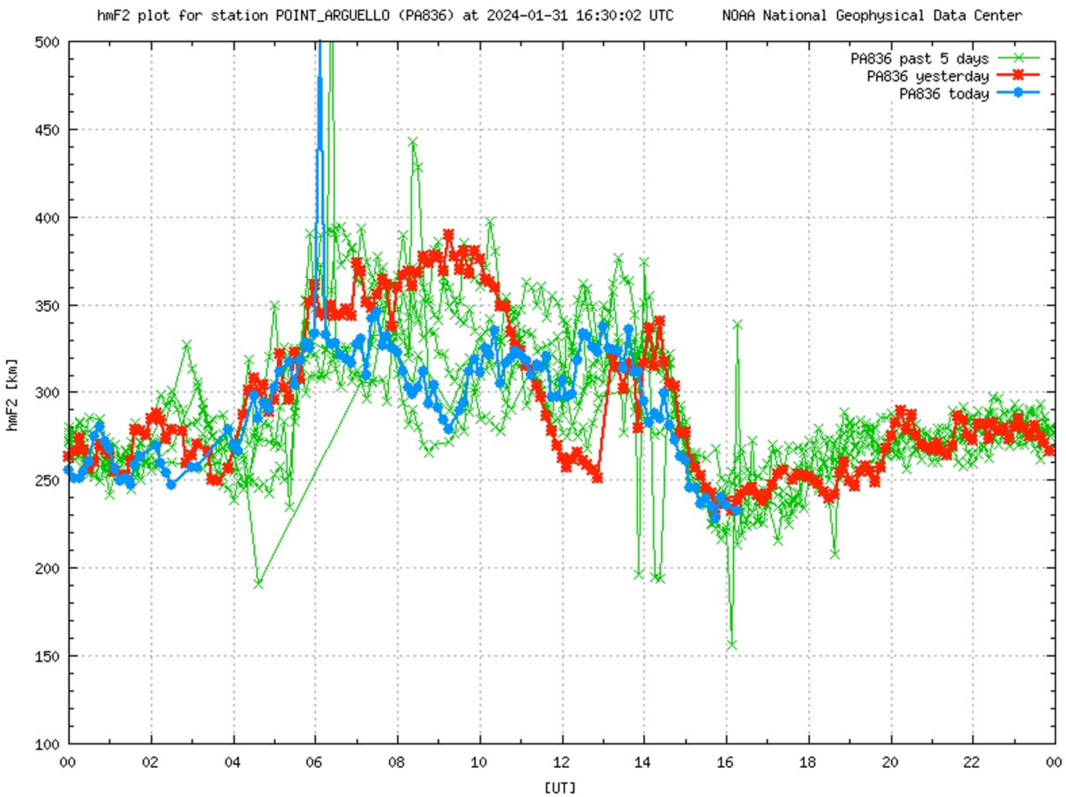
$$\mathrm{MUF} = \frac{f_c}{\sin E}$$

Height of Ionosphere's F2 Layer

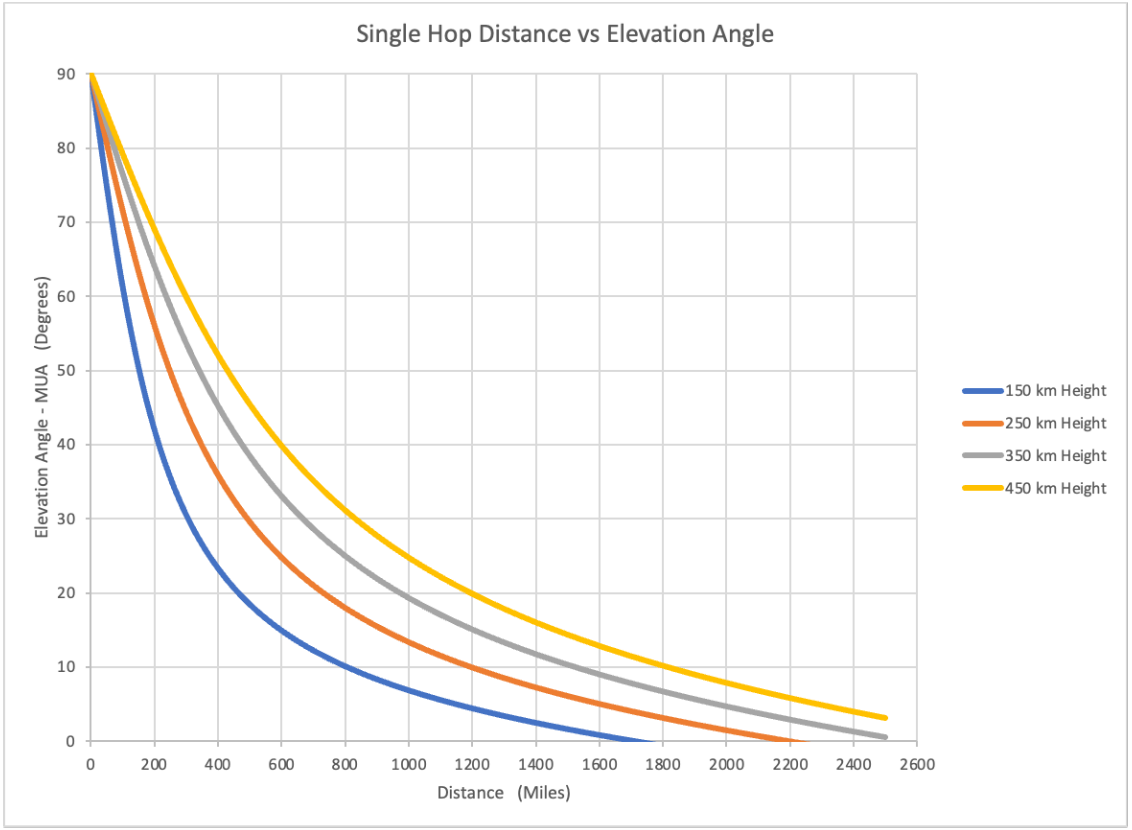


- The current height of the F2 layer is available on the www.skywave-radio.org website by clicking on Ionosonde under the Current Conditions tab
- Data from a large number of ionosonde sites is available
- For California the regional F2 height is obtained by clicking on Point Arguello, CA h_mF2
- This 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 = 75^o at a F2 layer height of 250 km

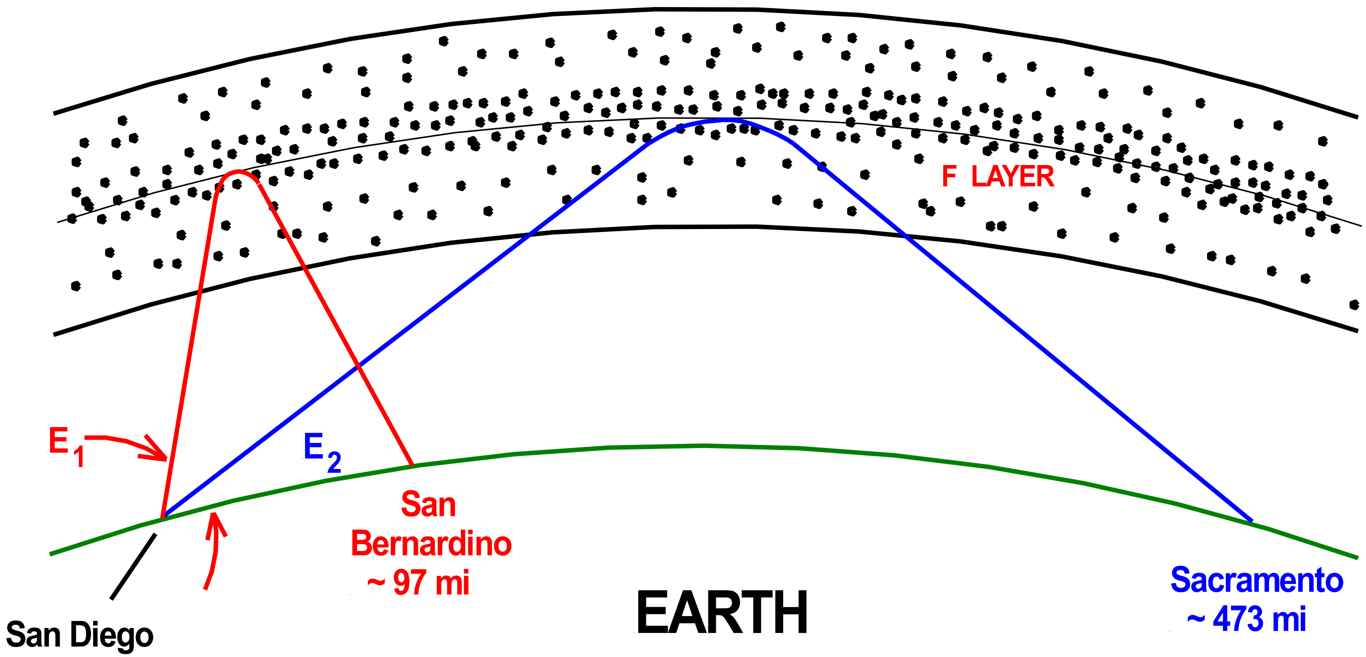
- For Sacramento distance 473 miles, E = 30^o



Author

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

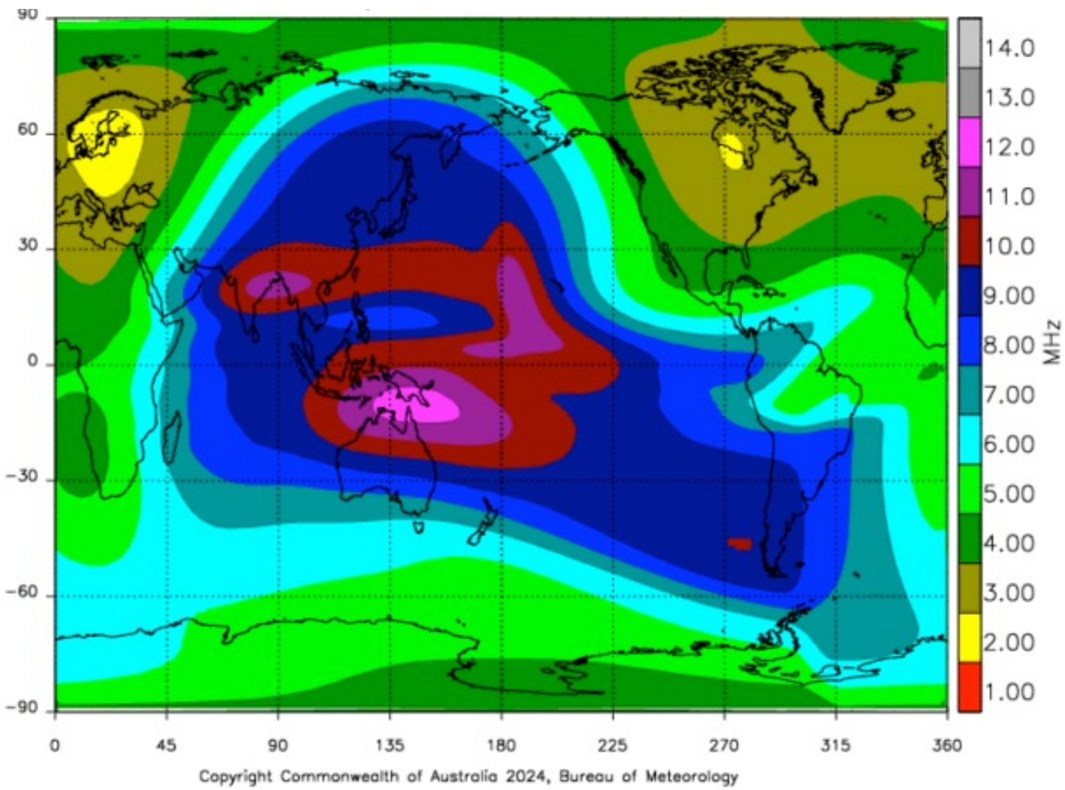
For MUF Next Determine Critical Frequency



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

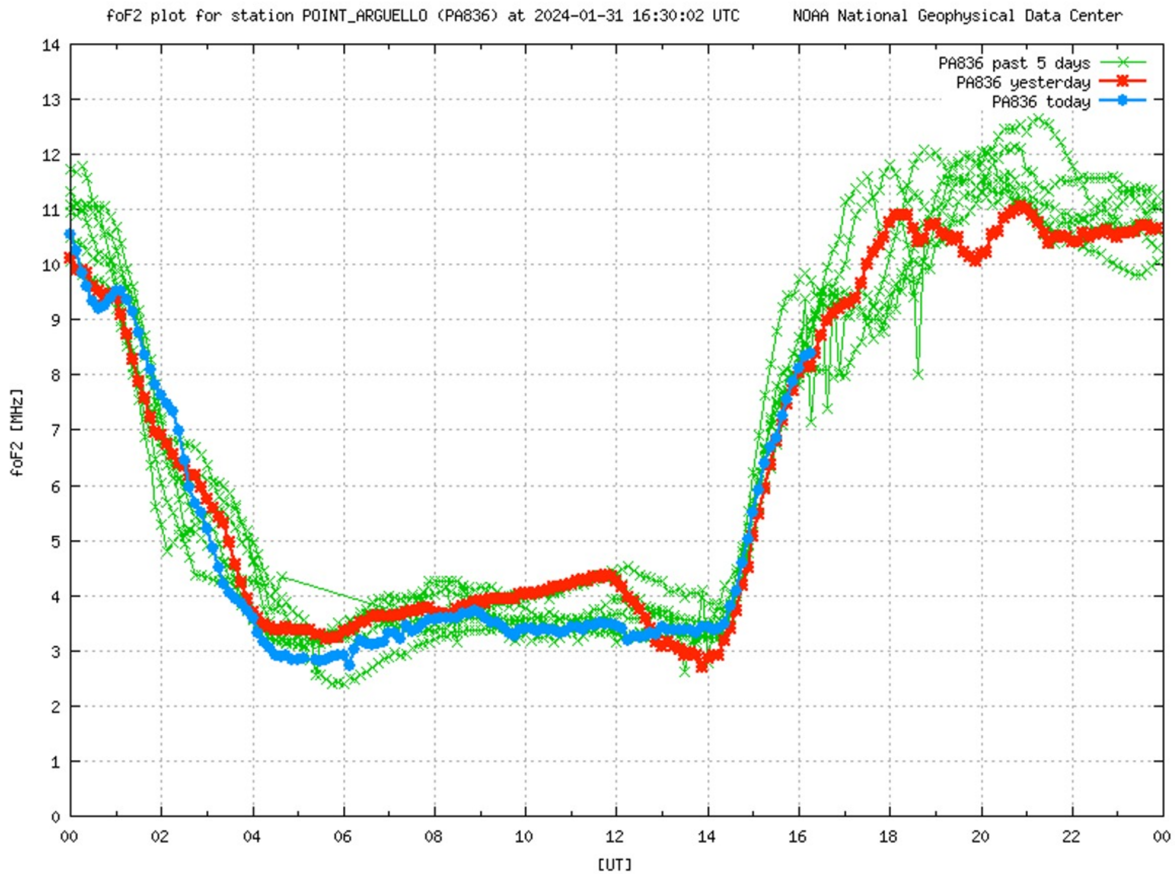
$$MUF = \frac{f_c}{\sin E}$$

Determining Current F2 Critical Frequency



- 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

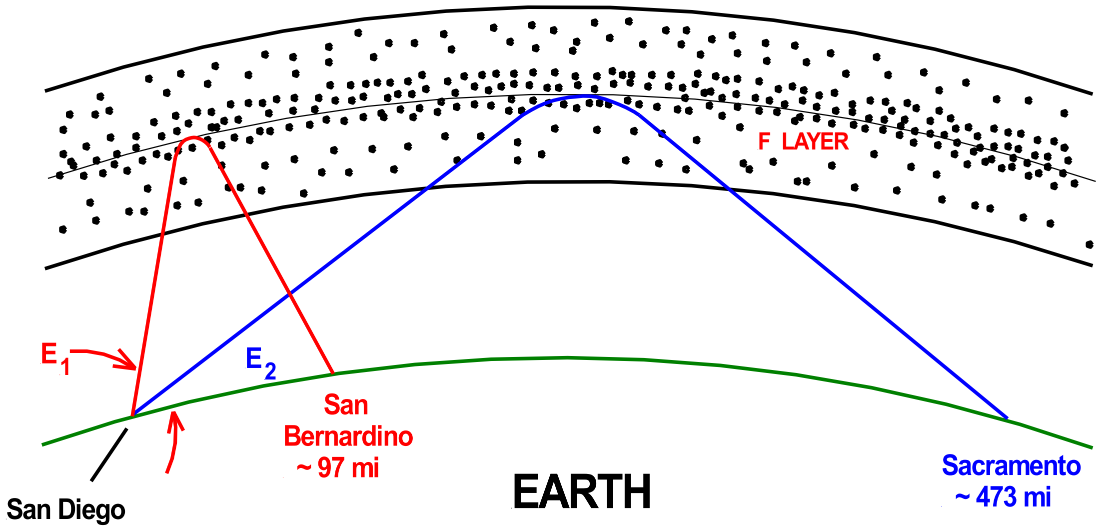


- Detailed regional critical frequency data is also available on the www.skywave-radio.org website by clicking on Ionosonde under the Current Conditions tab
- For California the regional critical frequency data is obtained by clicking on Point Arguello, CA FoF2

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



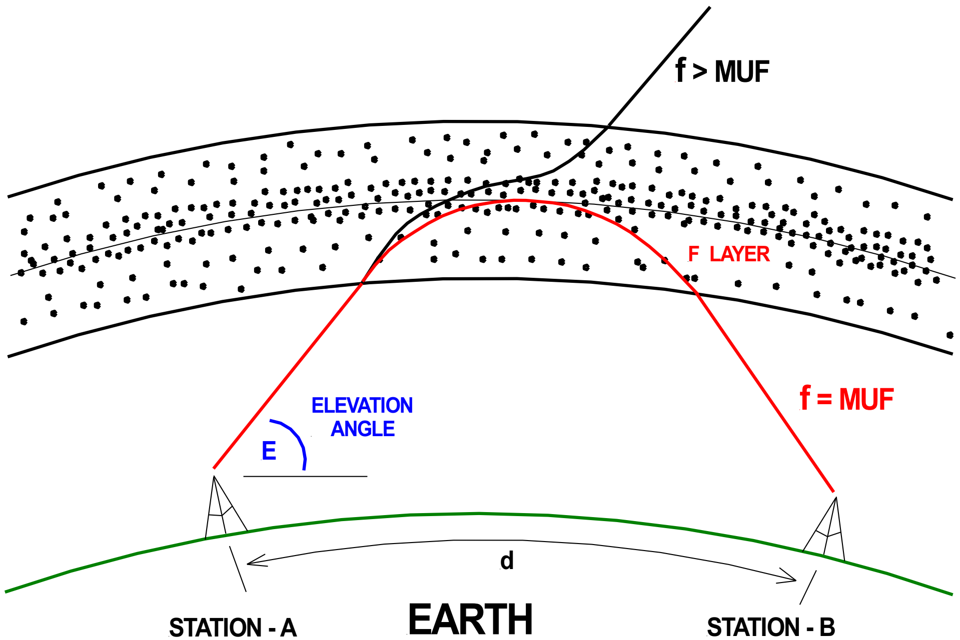
Net Operating Freq = 7.230 MHz

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

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

- 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 operation 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

Frequency of Optimum Transmission (FOT)



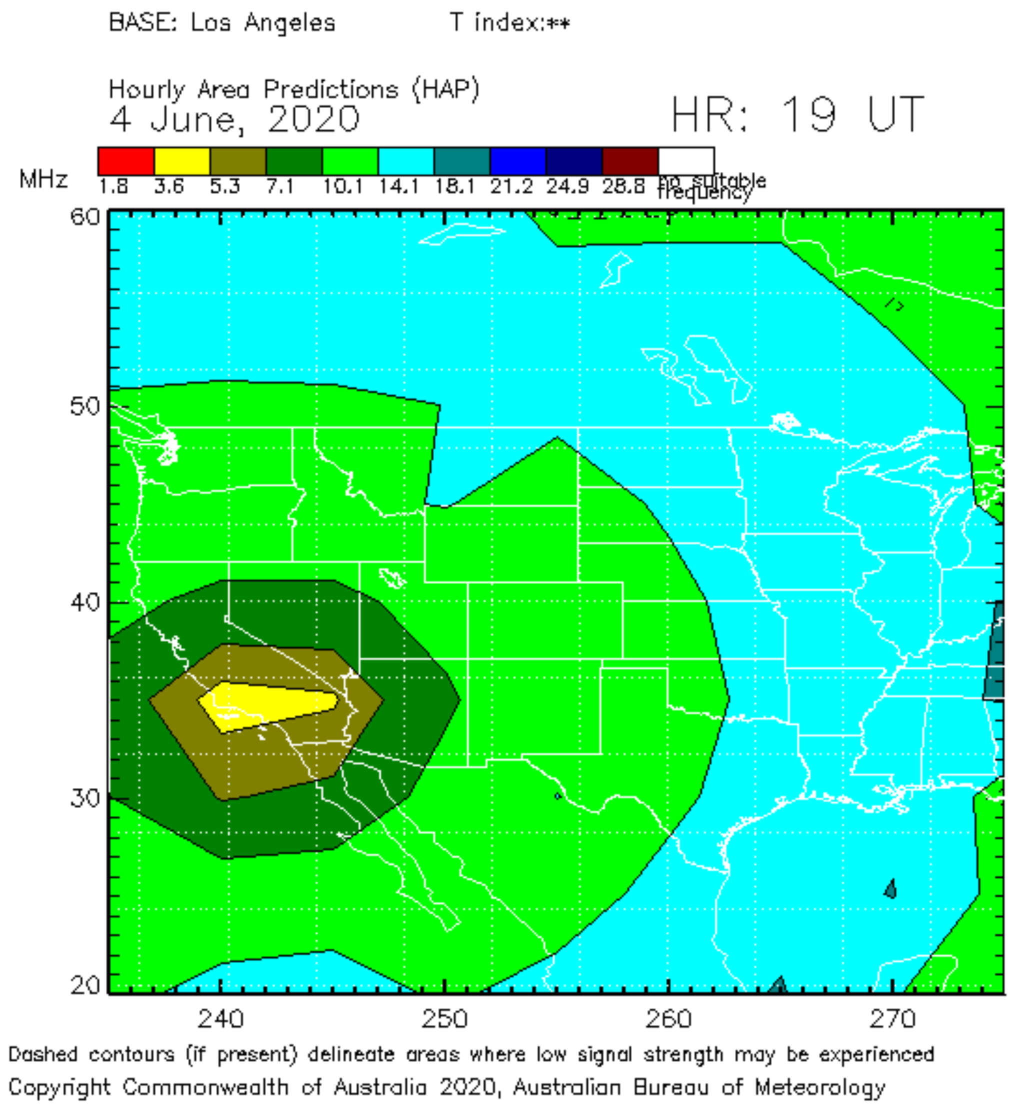
- Working at the Maximum Usable Frequency is literally "living on the edge"
- Small changes in critical frequency and other ionospheric parameters cause the MUF to be in a continuous state of change
- Signals transmitted at the MUF often fade in and out
- It is generally accepted that FOT is 80 to 85%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

HAP Charts

- FOT can be directly read from Hourly Area Prediction (HAP) charts produced by the Australian Government

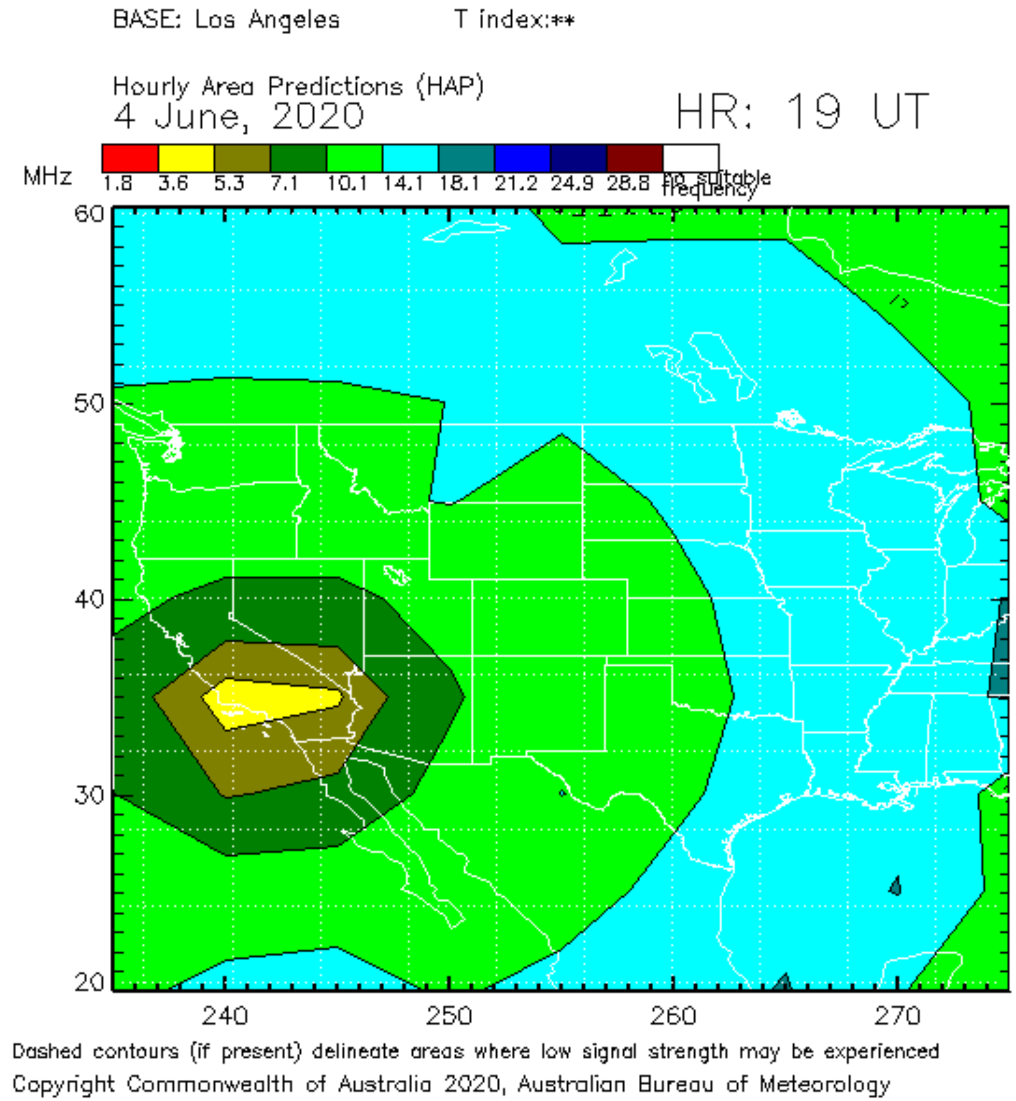
- HAP Charts are designed for predicting the optimum freq for communications between a specified city (the Base City) and a selected distant station

- Los Angeles, CA is the base city for this map



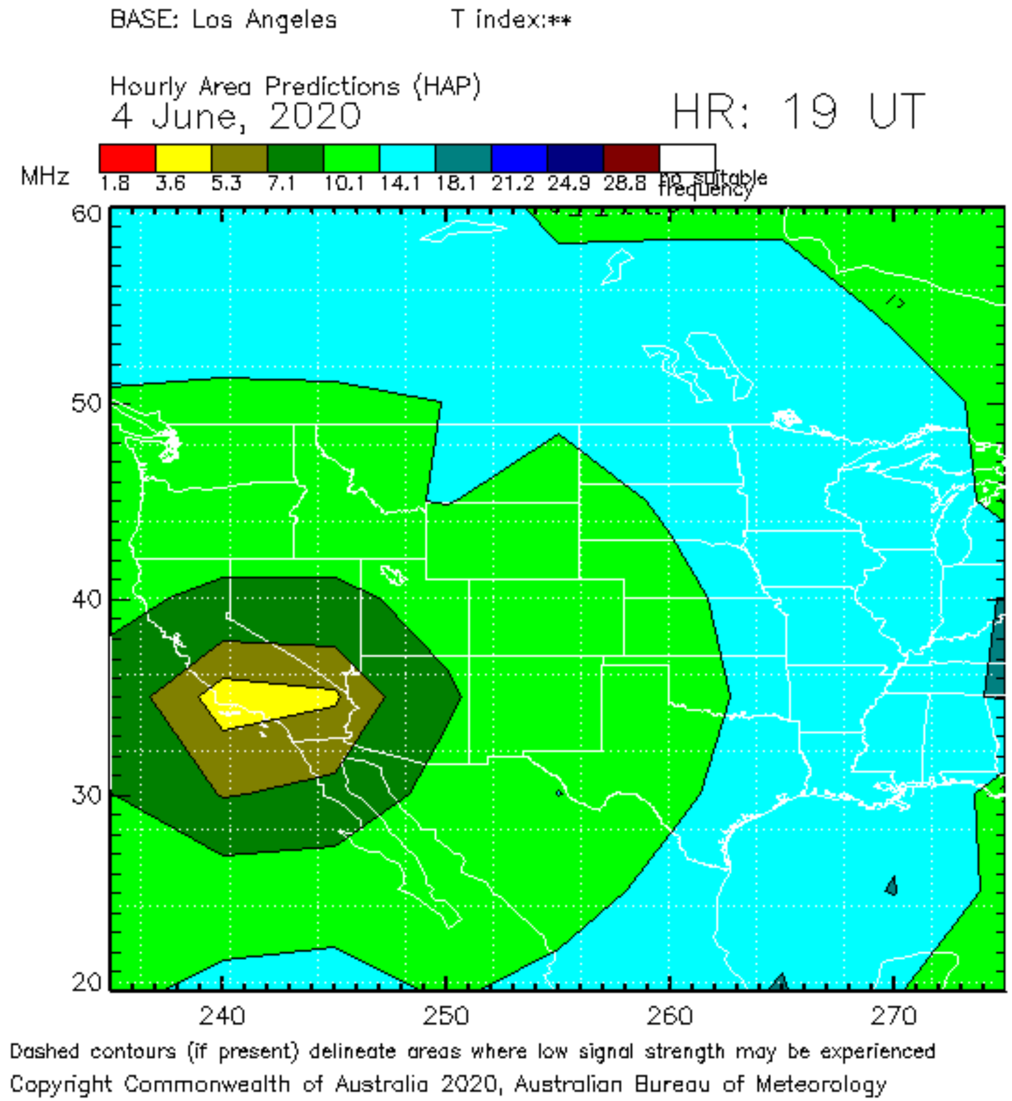
HAP Chart Coordinates

- The vertical axis of the chart is degrees Latitude
- The horizontal axis is degrees East Longitude (measured eastward from the Prime Meridian around the Earth)
- The color band at the location of the base city (yellow in this example) is by definition the critical frequency f_c at the time the chart was produced
- f_c being the highest frequency signal that can be transmitted straight up at the base city location and be reflected back down to Earth



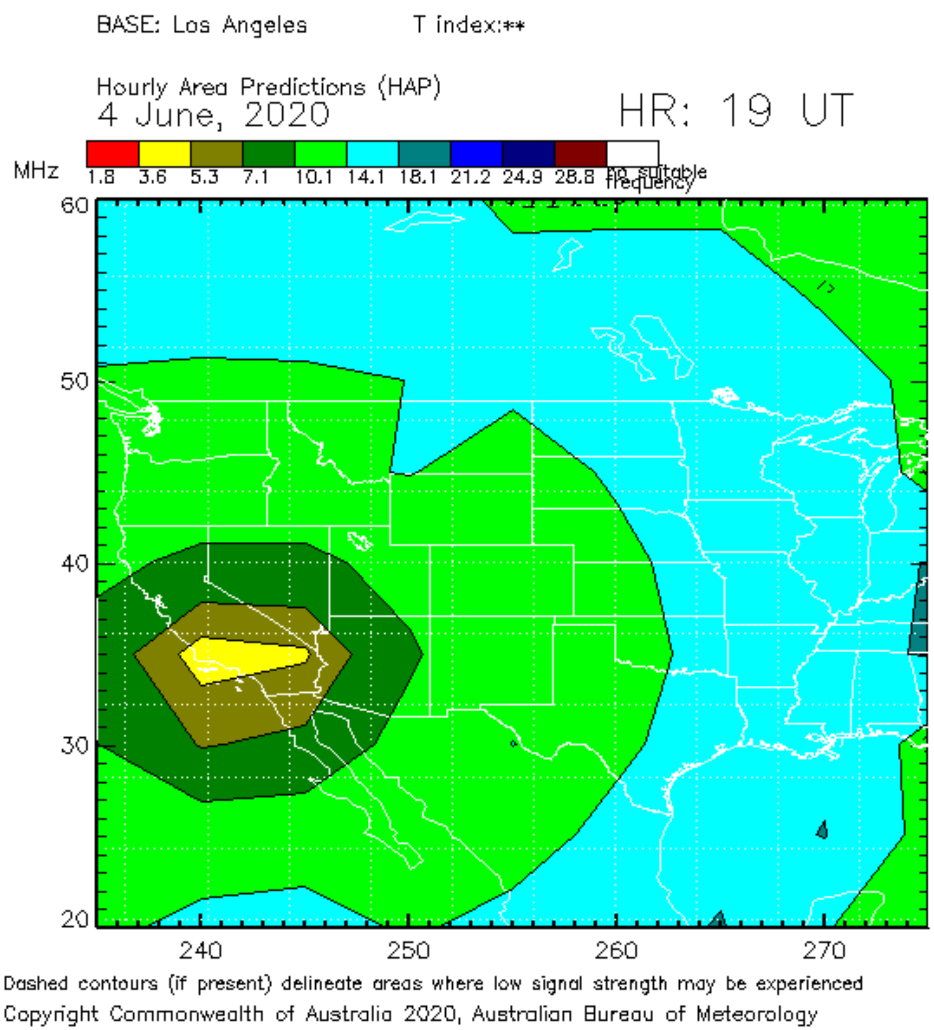
HAP Chart Color Bands

- Each HAP Chart color band represent the recommended HF frequency (FOT) for communications between the base city and a selected distant location for a given date and hour
- For this version of the HAP Chart the color bands represent different amateur radio frequency bands
- For example, 30 meters (10.1 MHz) is the FOT for communications between Los Angeles and Portland at 1900 UT (noon local time) on 6/4/2020



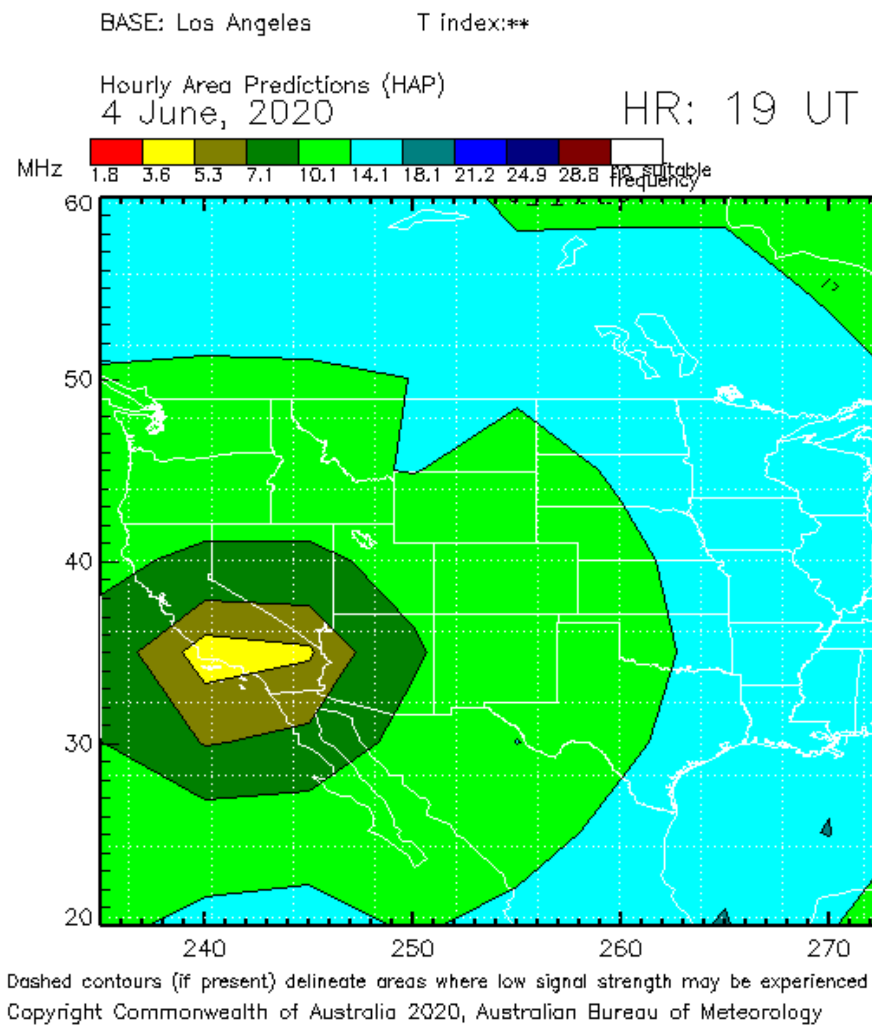
HAP Charts Provide An Estimate

- A HAP Chart is an estimate of the current FOT
- Remember that MUF > FOT
- So the MUF could actually be the next higher frequency band
- For example, the MUF for Los Angeles to Portland could be 20 m instead of the 30 m FOT shown on the HAP Chart
- However, it is unlikely that Portland could be reached on 17 meters
- A HAP Chart is a starting point in selecting a frequency band for communicating to a distance destination



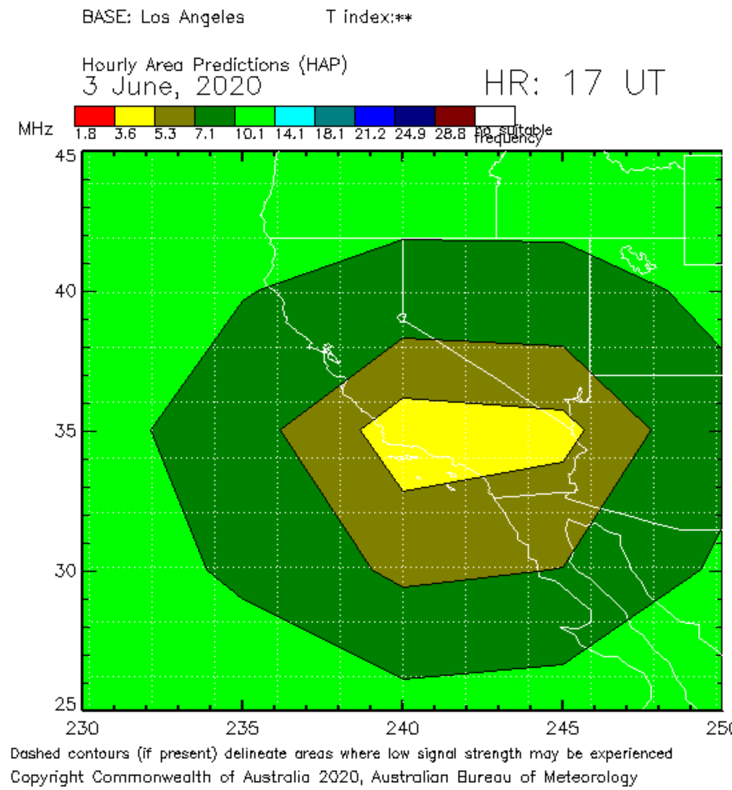
HAP Chart Displays Highest Freq

- The FOT shown on the HAP Chart for Los Angeles to Portland is 30 meters
- This is the highest frequency band for dependable comm from Los Angeles to Portland
- Any frequency band lower than the FOT could also be used
- For example, 40 meters could be used for communications between Los Angeles and Portland
- However, the 40 meter path could encounter multi-path interference & deep D Layer absorption not present at the 30 meter FOT frequency

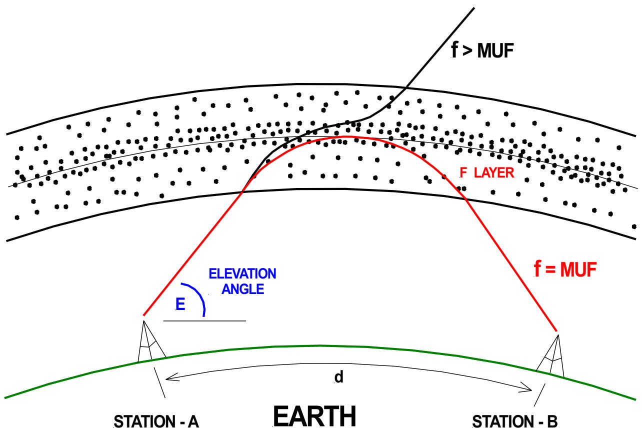


HAP Chart Regional Net Prediction

- The HAP Chart can be used to predict communications for a regional net including San Diego, Sacramento, & San Bernardino
- San Diego is not in the HAP Chart data base so the map is centered on the next closest large city (Los Angeles)
- The map must be visually shifted downward to be centered on San Diego
- When this is done, the FOT to Sacramento is 40 meters (dark green), thus San Diego can hear Sacramento during the net
- The FOT to San Bernardino is 80 m (yellow), thus on 40 meters San Diego can not hear San Bernardino
- San Bernardino net traffic must be relayed to San Diego thru Sacramento



In Summary



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

- Maximum Usable Frequency MUF is the highest frequency radio signal that can be transmitted through the ionosphere from one **specific** radio station to an other.
- MUF can be calculated knowing critical frequency f_c and elevation angle E
- f_c is determined from the Global Critical Frequency Map
- E is determined from the Distance vs Elevation chart
- Frequency of Optimum Transmission FOT = 0.85 MUF can be determined directly from the appropriate HAP chart

Knowing MUF Makes HF Radio a LOT of FUN !