Radio Wave Propagation

Things that affect and determine radio wave propagation

- There are many modes of radio wave radiation that are affected by phenomena such as reflection, refraction, diffraction, absorption, polarization, and scattering.

- How different radio wave frequencies are influenced by the various modes of propagation also come into play.

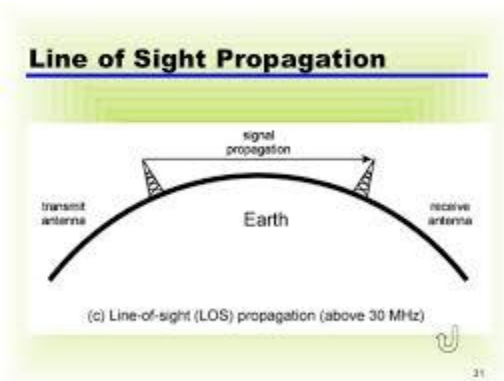
- The affects of space and atmospheric weather must also be considered in radio wave propagation.

Free Space Propagation.

- In outer space, there are none of the earthly phenomena that influence the propagation of electromagnetic waves which includes radio, light, X-rays, etc. The equation for radio propagation in free space is simple; it obeys the inverse-square law that states, the power density is proportional to the inverse of the square of the distance from the point source of the energy. If we double the distance away from the radio transmitting antenna, the signal is 1/4 as strong, and if we double the distance again, the signal is now only 1/16 as strong, etc. As a consequence, free space propagation gets quite weak quickly. Most short range propagation can be modelled based on free space loss.

Line-of-Sight Propagation

- **"Line-of-Sight" or "Direct**" propagation is best defined as propagation between radios with antennas that are visible to each other; this most often applies to signals at VHF and higher frequencies. Because radio signals travel through non-metallic objects, such propagation is also line-of-site through building walls in urban environments. **See Question B-007-001-001** Generally**, VHF Line-of -Sight propagation is not greatly affected by other propagation phenomena**. Line of sight propagation range is limited over the earth's surface by the curvature of the earth and other objects of the earth's natural topography such as mountains and valleys. **See Question B-007-001-004**



Ground Wave Propagation

- For a good full explanation goto: http://en.wikipedia.org/wiki/Ground_wave_propagation

- Ground waves can propagate a considerable distance beyond the earth's horizon in the low and medium frequency range portion of the radio spectrum. This includes the AM broadcast band and the 160 metre amateur band.

- Ground wave is made up a number of constituent modes of propagation that includes direct waves within the earth's horizon, reflections from hills and mountains and the diffracted surface wave that bends over the earth's curvature.

- As the surface wave front travels over the earth's surface, it is attenuated; this attenuation increases considerably as the frequency goes up so that, what works well over a distance at 500 kHz may be attenuated 20 to 60 dB at 3000 kHz and above. Surface wave propagation is enhanced over good surface terrain conductivity and sea water is optimum. **See Questions B-007-001-006, -007, and -008.**

- Low and Medium frequency Ground Wave propagation favours vertical polarization as vertical polarization as far less attenuation from the earth absorbing the surface wave signal by a factor of several 10's of dB. This is why all AM broadcast stations radiate vertical polarization.

- An HF amateur station may only be able to communicate a few Kms across town via ground wave especially if horizontally polarized.

- For HF propagation, in general, using ionospheric skip, both vertical and horizontal can be interchanged as signal reflections off the ionosphere can change the polarization from moment to moment by an affect known as “Faraday rotation”: **See Question B-007-004-007**

- At night, more distant ground wave reception may suffer interference from sky wave reception of the same station as the incident ground wave and reflected wave signals (from the ionosphere) may reinforce or cancel the overall signals causing **in and out fading** changes.

Sky-Wave Propagation.

- **Sky-Wave Propagation** may also be called **Ionospheric Wave Propagation**. **(See Question B-007-001-005)** Such propagation is a result of refraction (and reflection) of radio signals radiating out and upward and being returned to earth by ionized atoms and molecules in the earth's rarified upper atmosphere called the **ionosphere.**

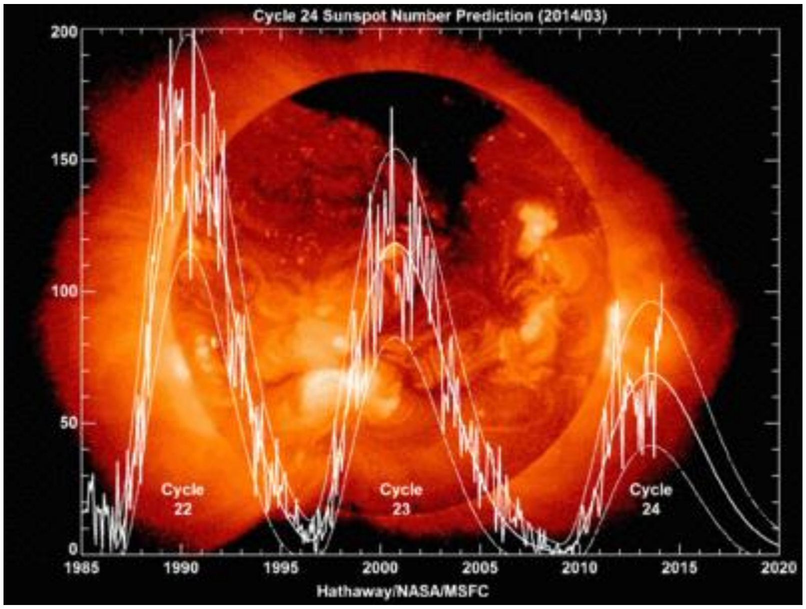
- **Ionospheric wave or Skywave propagation can**, under the right conditions, **extend radio communications range up to distances worldwide**. **See Questions B-007-001-002 and -010.**

- In the ionosphere, solar radiation primarily in the form of **Ultraviolet light,** dislodges free electrons in the very thin density of gas molecules. And because of the thin density of the ionosphere, natural recombination of electrons is slow compared to lower altitudes where recombination prevails, thus leaving the ionospheric gas atoms and molecules in a more or less state of ionization. **See Questions B-007-002-001 and -002**

- Ionization depends primarily on the **Sun** and its activity. The amount of ionization in the ionosphere varies greatly with the amount of radiation received from the Sun.

- There is, of course, **a time of day effect and a seasonal effect to Solar Radiation** and therefore ionospheric propagation

- There is also an effect based on the sunspot activity that follows an **11 year solar cycle** with more solar radiation occurring with more sunspots. **See Questions B-007-005-001, 002 and -009 .** The following illustrates the rise and fall of the Sun Spot numbers over the last few decades. We have now entered Solar Cycle 25 and there is now an uptick in the number of Sun Spots.



- To best measure the solar radiation intensity, there is the **Solar Flux Index.** It is measured by detecting the level of **radio noise emitted by the sun at a frequency of 2800 MHz, or 10.7 cm wavelength** and is quoted in terms of **Solar Flux Units**. Although this radiation varies around the globe, it is standardized for the world by readings taken from the **Penticton Radio Observatory in BC, Canada**. The Solar Flux Index correlates well to the daily **Smoothed Sun Spot number**. The Solar Flux typically varies from a low of about 50 during sunspot minima to a rise of about 300 during at times of sunspot maximum in the 11 year solar cycle. The Solar Flux Index is a good indicator of the intensity F layer iononization and the resulting good HF radio propagation. **See Questions B-007-005-003 and -004** .

- Indeed, when the sunspot numbers are very high (and the solar flux index) it may be possible to communicate into the low VHF range (just greater than 30 MHz by ionospheric propagation) Under such conditions, even 50 MHz amateur radio contacts have been known to take place between North America and Australia. **See Question B-007-005-007**

- At the <u>low end of the Solar Cycle</u> when the sunspot numbers few and far between, the higher HF bands usually do not support worldwide communications even during daylight hours. The highest frequency band usually <u>open well</u> during daytime hours is the 20 metre (14 MHz) band. **See Question B-007-006-007**

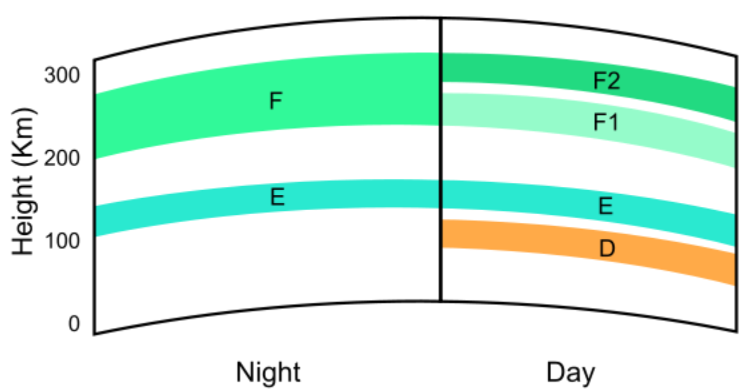
- There are extraordinary **<u>solar disturbances called Solar Flares</u>** that increase the ionospheric electron density to a great degree caused by **high solar X-Ray emissions** that strongly ionize the lower layers of the ionosphere **absorbing lower HF radio frequencies** that would normally get through and be reflected by the higher layers. **This can cause <u>Radio Blackouts</u>.** Sometimes the X-Ray emissions are so intense, even 30 MHz (meaning all of the HF spectrum) is totally absorbed. In other instances, the Black Out only goes up to a lesser frequency. **If for instance, the Black Out includes the 14 MHz (20 metre) band, communications may still be possible on the 21 MHz (15 Metre) band**. **See Question B-007-006-004**

- Besides the ionizing UV radiation, the **Sun emits a Solar Wind of charged proton and electron particles.** These emissions vary in intensity. The Earth is largely protected from these particle emissions by the Earth's magnetic field which deflects the Solar Wind. By exerting more pressure on the Earth's **"Magnetosphere"** it's shape can be more compressed and more of the charged particles can get in and influence the ionosphere affecting its ionization, especially in the higher latitudes planet.

- **<u>The measure</u>** of the effect of the solar wind on shaping the earth's magnetosphere are the **Earth's A and K geomagnetic indices**. These indices indicate the health of the earth geomagnetic activity from **Quiet to Unsettled to Minor Storm to Major Geomagnetic Storm. The ideal conditions for ionospheric propagation is to have the Solar index high and the Earth's geomagnetic A and K indices low or Quiet.**

- There are times of particularly intense solar activity called geomagnetic storms; these occur when a **<u>Coronal Mass Ejection</u>** (CME) erupts above the Sun and can send a shock wave towards the Earth in the form of extraordinary proton emissions that affect the lower ionosphere causing heavy absorption of HF radio. **Often associated with the resulting Geomagnetic Storms, there will be displays of the <u>Aurora Borealis</u> even at relatively lower latitudes caused by a heavily ionized "E" layer** of the ionosphere causing a visual luminescence. **See Question B-007-007-008** .
- One benefit of the **Aurora Borealis** is the Amateur Radio sport of **bouncing VHF signals off** this unique reflective medium **by pointing beam antennas north. See Question B-007-007-007 .** Unfortunately, **Auroral propagation causes a doppler frequency spreading** of the signal resulting in **highly distorted voices modes**. **Therefore, most auroral contacts are made using CW where distortion of the signal can be tolerated. See Question B-007-007-009.**

<u>Ionospheric Layers</u>



- At night, the F layer (the highest layer) is the only layer of significant ionization present while the E and D lose much of their ionization. The ionosphere is least ionized just shortly before dawn. **See Question B-007-002-007** .

- During the **midday**, the D and E layers become much more ionization as does the **F layer that splits into be two layers known as the F1 and F2 layer**; the F2 being stronger than the F1 layer below. The **F2 layer** is mainly responsible for the refraction of HF radio waves back to earth both day and night and **because it is the highest layer provides longest distance of radio wave propagation**. **See Questions B-007-002-006, -008 and -010.**

- **<u>The lowest layer is the D layer</u>**; this layer has very low ionization at night but during the day, hydrogen radiation from the sun ionizes the nitric oxide molecules which cause an **absorption of the HF radio waves particularly at 10 MHz and below in frequency** with progressively smaller absorption as radio frequencies of operation go higher.

- **The absorption of the D layer is small at night and is greatest midday.**

- The **D layer absorption** accounts for **relatively poor distance propagation on the 160, 80, 60 and even the 40 metre bands during the midday hours** but these bands come alive after sun set. **See Questions B-007-002-009 and B-007-004-001**

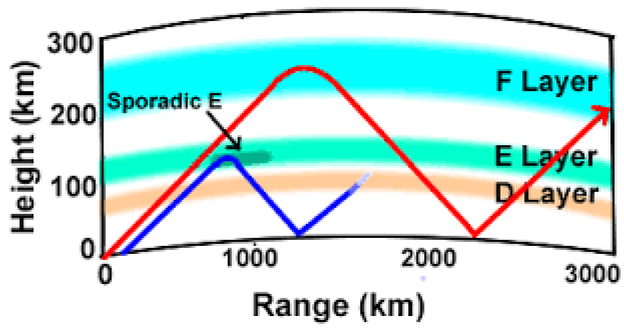
- Also, listening to the **AM broadcast band** and the **160 metre ham band,** absorption by the D layer also accounts for **only local stations being heard during the day** where Ground Wave is the mode of propagation but **at night, distant stations come in loud and clear** as their signals penetrate through the thin D layer and are refracted on the upper F layers. **See Question: B-007-004-002 .**

- **The E layer is the middle layer (below the F layer)** caused by solar Ultra Violet radiation on the oxygen O_2 molecule. Generally, this layer can reflect signals below 10 MHz during the day light hours along with some absorption of signals above 10 MHz. At night, the E layer all but disappears leaving most of the long distance skywave propagation to the F_2 layer. **See Question B-007-002-011.**

- Since the D **layer is responsible for day-time absorption of lower frequency radio waves** and does not reflect them, **it is the least useful for long distance propagation**. See **Question B-007-002-004.**

- There is a **special type of E layer propagation** called **Sporadic E** which is characterized by small intensely ionized **clouds** that can support reflection of radio waves **well into the VHF spectrum including the 50 MHz and occasionally the 144 MHz bands**. Sporadic E events may last a few minutes to several hours. This propagation phenomena occurs mainly during summer months. Skip distances for Sporadic E propagation are generally around 1500 km to a maximum of 2000 km for single hops and twice that is possible for rare double hop situations. **See Questions B-007-003-003 and B-007-007-001, -005 and -006**

The following illustrates an Sporadic E layer cloud.



Critical Frequency and Maximum Usable Frequency (MUF)

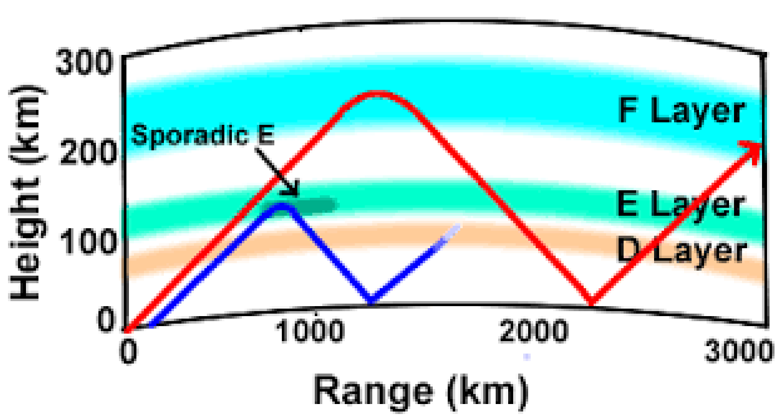
- When dealing with the condition of the Ionosphere, the **Critical Frequency** is a measure of its health for HF propagation.

- Sounding measurements of the ionosphere are carried out many times a day (by scientific agencies such as NOAA in the US) by sending HF radio signals straight up to the ionosphere over a sweep of increasing radio frequency. There will be a point in frequency increase that the signal is no longer reflected back to earth but passes straight through the ionosphere into space; this is known as the **Critical Frequency** of the ionosphere. **See Question B-007-006-001** Sounding of the ionosphere can also measure the distance to the reflecting layer and determine which layer is responsible for the reflection.

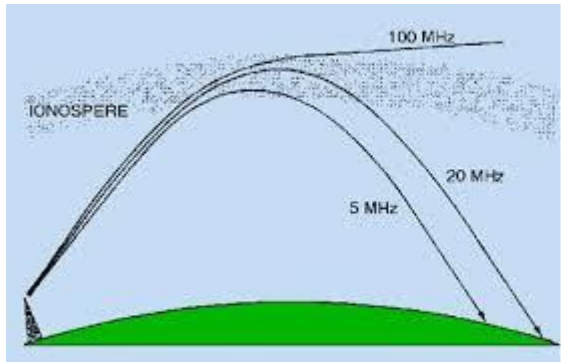
- Similar but different from the Critical Frequency is **<u>The Maximum Usable Frequency (MUF)</u>** which is **the highest radio frequency for communications <u>between two points on Earth</u> via diagonal reflection from the ionosphere**. Since the refractive index of the ionosphere decreases with increasing frequency, there is an upper limit to the frequency which can be used. This is the MUF. Above the MUF, the radio waves are not reflected by the ionosphere but pass through into space. **See Questions B-007-006-005, -006, -008, and -010**

<u>Ionospheric Skip Distance and what influences it:</u>

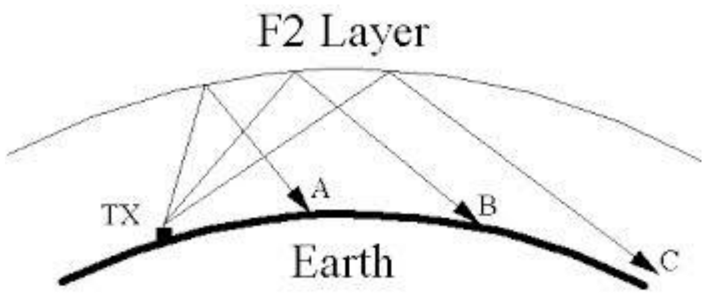
- **The higher the reflecting (or refracting) layer, the greater the skip distance.** F layers propagation should therefore provide greater distance that E layer propagation. **See Questions B-007-003-006 and -011 . The maximum distance of one F2 layer skip hop may be as much as 4000 km for the high HF bands but much less for the lower HF bands**. **See Question B-007-003-002**



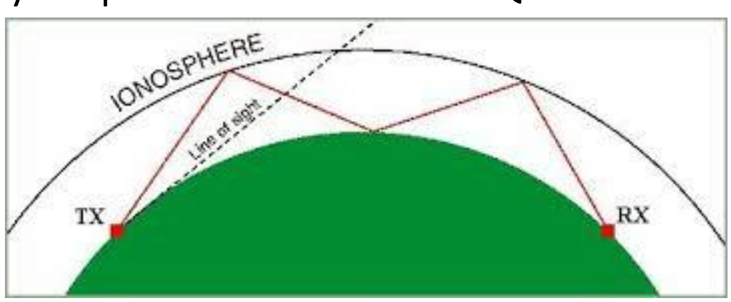
- **The higher the HF frequency, the greater the angle of refraction to a further point on the earth; however, too high a frequency will result in no signal at all returned to earth.**



- The lower angle of radiation from the station's antenna should result in greater skip distance by the laws of geometry. **See Question B-007-003-010 and part of right answer to Question B-007-003-006 .**



- For a longer skip range, **multi hops** of the signal may be necessary to span the distance. **See Question B-007-003-005**

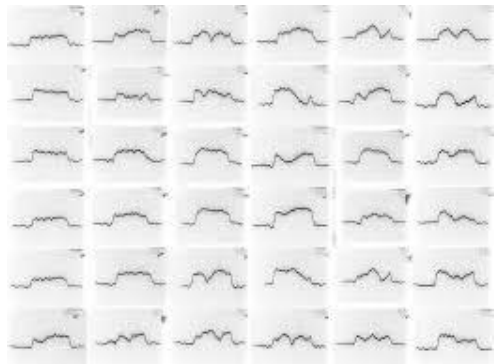


Skywave Signal Strength Variations called Fading <u>(QSB)</u>

- **<u>Fading</u>** (flat fading). Skywave propagated signals are often subject to multi-paths when bounced off of the ionosphere resulting in reflected signals that may be in and out of phase thus increasing and reducing the signal reception level over a short period of time. Indeed, the signal may fade away completely only to return to full strength moments later. This is sometimes the nature of HF skywave propagation. **See Questions B-007-004-003, -004, and -005 .**

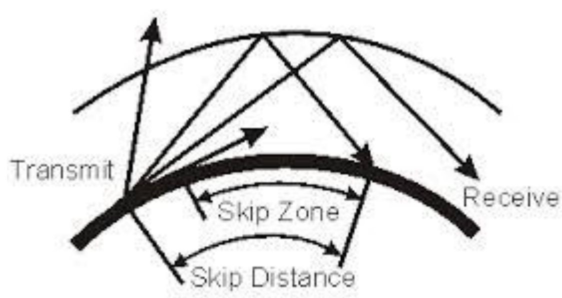
- **<u>Selective Fading</u>** Sometimes multipath ionospheric propagation reception manifests itself that the strength and phase of the same radio signal varies differently over the very small frequency range of the emission bandwidth (even less than 6 KHz at times)**. This causes distortion to wider bandwidth modulation emissions such as AM and wider data modes as opposed to the narrower bandwidth emissions such as SSB or CW.** When this happens, it's called **Selective (frequency) Fading. See Questions B-007-004-008 and -009 and -011**

Tracings showing Selective Fading over the Channel Bandwidth over time:



<u>Skip Distance and Skip Distance</u>

- When receiving other stations on HF, we often hear one station of the conversation, but not the other. The one we hear is within the **<u>Skip Distance</u>** and the one we don't hear is in the **<u>Skip Zone</u>** (or dead zone). <u>"Skip Zone" </u>can be defined as an area which is too far away for ground wave propagation, but too close for sky-wave propagation. **See Questions B-007-003-001, -003 and -007**. The following illustrates:



<u>HF Ionospheric Scatter.</u>

On HF, from to time to time, we will hear two stations communicating with each other, one at the **Skip Distance** will be distinct and while the other should be in the **Skip (dead) Zone** yet we hear the other station **<u>with a weak distorted sounding signal that has a hollow flutter quality</u>**; this is a characteristic of a propagation phenomena called **<u>HF scatter propagation</u>**. The mechanisms for HF scatter propagation may involve "forward" scattering along the path of the signal to the reception location, "side" scattering from reflection anomalies to the side of the path of the signal or "back" scatter reception backwards along the signal path to a reception location. Also, scatter usually involves several simultaneous paths of more or less localized reflection. **See Questions B-007-008-001, -002, -003, -004, -005, -006, -007, -008 and -010**

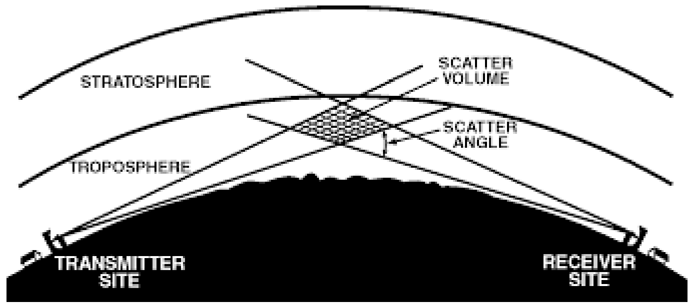
<u>Meteor Scatter Propagation</u>

- Meteor Scatter is a unique propagation technique that uses the <u>very short term densely ionized trail from a burning meteor</u> entering the earth's atmosphere. Low VHF spectrum signals can be reflected off these ionized trails and is a great sport for radio amateurs well setup and coordinated to take advantage of this propagation phenomena. The 6 metre band (50 MHz) is often used for amateur meteor scatter contacts during regular major meteor shower events such as the Perseid’s shower in August and Leonid shower in November each year. There is a digital mode of operation called MSK144 as part of the WSJT-X data modes application that is well suited for the sport of making amateur contacts using Meteor Scatter Propagation. **See Questions B-007-008-008, -009 and -011 .**

Tropospheric Scatter (Troposcatter) Propagation

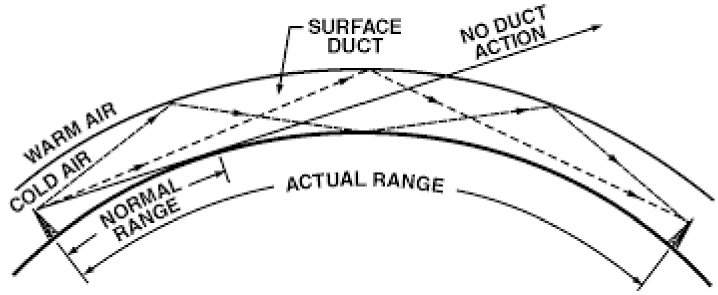
- Normally, VHF, UHF, and SHF propagation is restricted to line-of-sight paths. This will often extend beyond the optical horizon because of diffraction and refraction (bending of the radio waves) to some extent. Even so, the maximum distance is limited to, for a 2 metre path, 60 to 100 km maximum using a repeater with a 250 foot tower. That said, having a good beam 15 dBi Yagi antenna and a 50 foot tower and using narrow bandwidth modes, often 300 to 500 kms paths can be achieved with a station similarly equipped, albeit with marginal signal strength. The means of the this propagation is **Troposcatter**.

- The Troposphere is the atmosphere below a height of approximately 10 km. Most of the day to day weather occurs in the troposphere. It is because of these irregularities in this portion of the atmosphere that VHF and UHF and even higher frequency signals can be scattered and thus reflected back to earth by the variables of air density in troposphere thus resulting in the **troposcatter** propagation phenomenon.



Tropospheric Ducting Propagation.

- This is a type of **VHF enhanced propagation is caused by a <u>temperature inversion</u> in the troposphere**. Normally within the troposphere, an increase in elevation will result in the atmospheric temperature decreasing. However, with certain weather conditions, the opposite happens and the temperature rises with altitude causing a significant change in the refractive index of the air to radio waves. This will bend the VHF radio waves back to earth extending the range of communicating considerably. This propagation phenomena has been known to take a normal range of communicating with an FM repeater that may be 60 miles to 1000 miles or more. Over more shorter range enhancements, Tropo Ducting due to a troposphere temperature inversion is often experienced during morning summer times when the air is still and stable. **See Questions B-007-007-002, -003 and -004**



EME Propagation.

- An exclusive bunch of radio amateurs do Earth-Moon-Earth propagation using the Moon as a big reflector in the sky; this is no trivial endeavor.

- The moon is approximately 384,400 km from earth and the radio path loss is enormous as the signal has to make a 2 way journey. The propagation loss can amount to more than 250 dB.

- And the moon is only 7% efficient as a reflector.

- All things have to be perfect to even hear your own signal reflected off the moon 2.5 seconds later.

- Usually, EME communications is attempted when the moon is at Perigee (closest to the earth).

- Normally, an Azimuth and Elevation antenna pointing mechanism under computer control is used that tracks the movement of the moon.

- Using conventional modes such as CW or SSB, over one million watts of Effective Radiated Power is necessary. It can be achieved with the legal limit of transmitter power (1500 watts) and a 30 dBd antenna system.

- Now, however, it is possible to make a VHF contact off the moon using the digital mode JT-65, a 15 dBi Yagi antenna and about 200 watts of power. The JT-65 narrow band digital mode has the ability to resolve signals 25 dB into the noise. Still, all things have to be perfect. JT-65 uses a transmission duration of 110 seconds and is one of data modes as part of the WSJT-X software application.

- This is W5UN's EME Yagi antenna array below on his QSL card. The system has 48 Yagi beam antennas coupled together to provide over 30 dBd gain. Two truck chassis' with electric motors are used to rotate the array around a circular track for azimuth orientation.