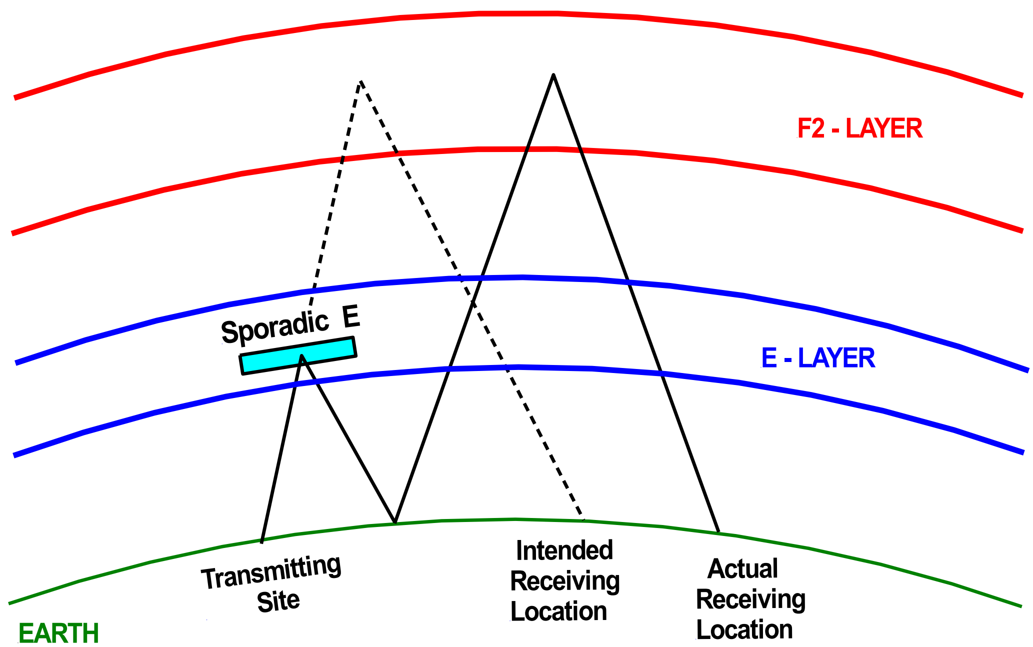
Chapter 18

Propagation Modes



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18 Propagation Modes

Propagation modes describe the single and multi-hop paths through the ionosphere that radio signals traverse in route from the transmitting to the receiving radio station. The various propagation modes include:

- F mode propagation,
- E mode propagation,
- Sporadic E propagation,
- Multi-path propagation,
- Backscatter,
- Great Circle propagation,
- Gray Line propagation,
- Equatorial Sporadic E propagation,
- Transequatorial Propagation (TEP), and
- Ionospheric Ducting

18.1 F Mode Propagation

Long distance communication consists of multiple hops through the ionosphere as illustrated in Figure 1.

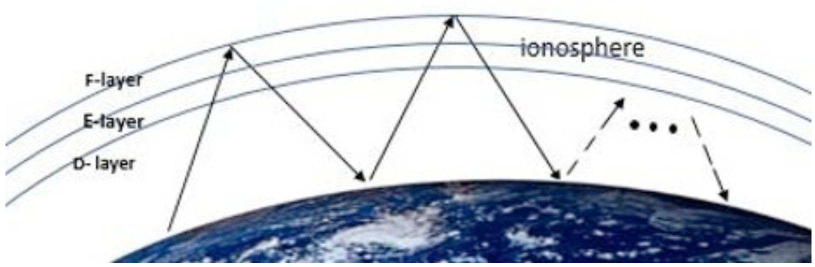

Figure 1 Multiple hop propagation through the ionosphere (source: ResearchGate)

However, the strength of a signal decreases with each hop limiting the distance that a radio signal can travel. Losses are due to:

- The energy absorbed in each pass through the D region, and
- Ground losses with each reflection from the Earth's surface

Reflections from the ocean's surface are typically attenuated 0.5 db while a signal reflecting from poorly conducting arid soil can be attenuated 3 db or more. Absorption in the D region coupled with ground losses limit most long distance skywave communications to 3 or 4 hops. 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. Consequently, long distance communication depends on each hop being as long as possible, enhanced by using high transmitting power and high gain directional antennas.

The distance traveled on each hop depends on:

- The operating frequency: signals transmitted at the maximum usable frequency (MUF) travel the furthest,
- The ionosphere's critical frequency: a high critical frequency increases the maximum usable frequency,
- The elevation angle at which signals are transmitted: low angles result in long hops,
- Height of the ionosphere's F2 region: longer hops are achieved with a high F2 region.

Signals penetrate progressively higher into the ionosphere as the transmitting frequency increases, i.e. as its wavelength decreases. Operating at the Maximum Usable Frequency (MUF) produces the longest hops. In Figure 2 the maximum usable frequency is 20 meters (14.0 – 14.35 MHz). Operating at a lower frequency, for example 40 meters, results in shorter hops. However, operating at a frequency higher than the maximum usable frequency results in signals being lost to outer spaces, as is the case for the 15 meter signals in Figure 2. Operating at the MUF is important for achieving long hop distances.

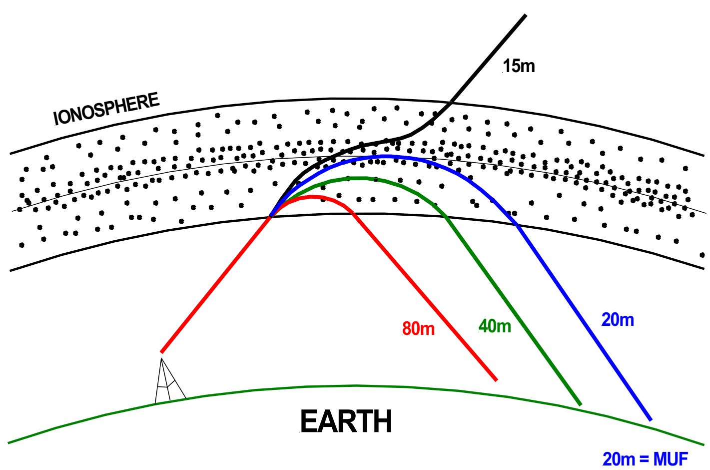

Figure 2 Hop distance verses operating frequency (source: author)

Maximum usable frequency is determined by the ionosphere's critical frequency f_c and the elevation angle E at which a signal is transmitted according to the equation

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

A high MUF depends upon on a high critical frequency f_c and transmitting at a low elevation angle E as illustrated by Figure 3. For example, at a critical frequency of 9 MHz, the MUF is approximately 35 MHz when transmitting at an elevation angle of 15^o (red trace).

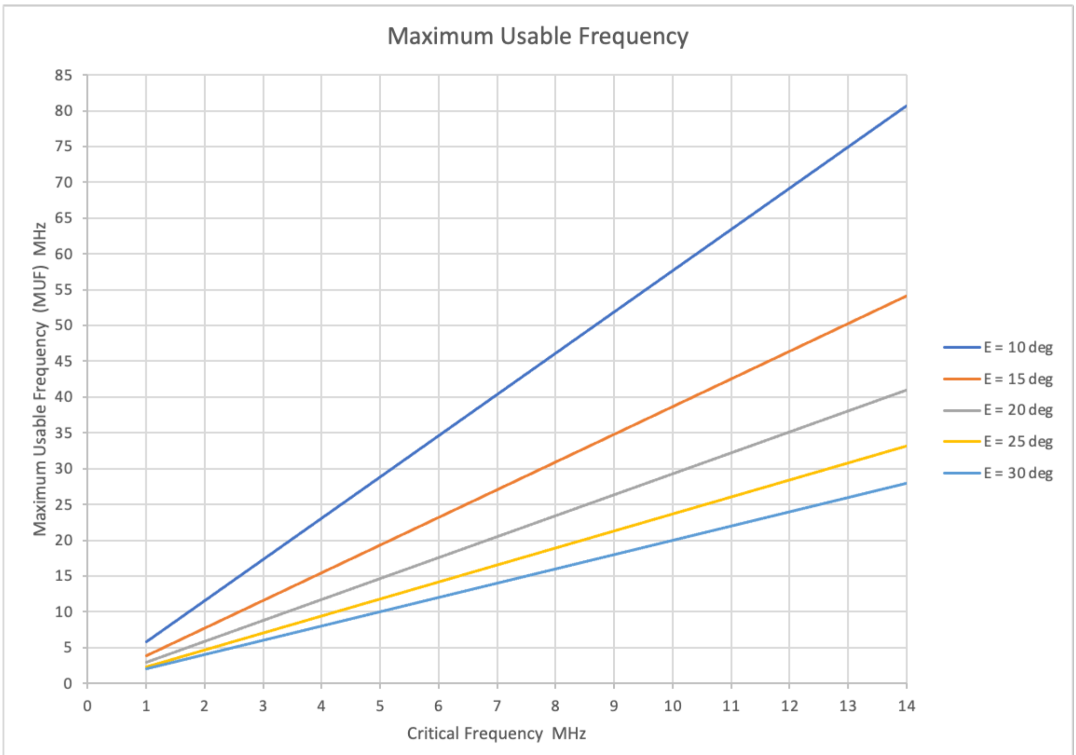

Figure 3 Maximum Usable Frequency chart (source: author)

The ionosphere's current critical frequency is obtained by clicking on Critical Frequency under the Current Conditions tab of the www.skywave-radio.org web site. For example, in Figure 4 the critical frequency over California was approximately 9 MHz (dark blue) at 19:30 UT on April 29, 2024.

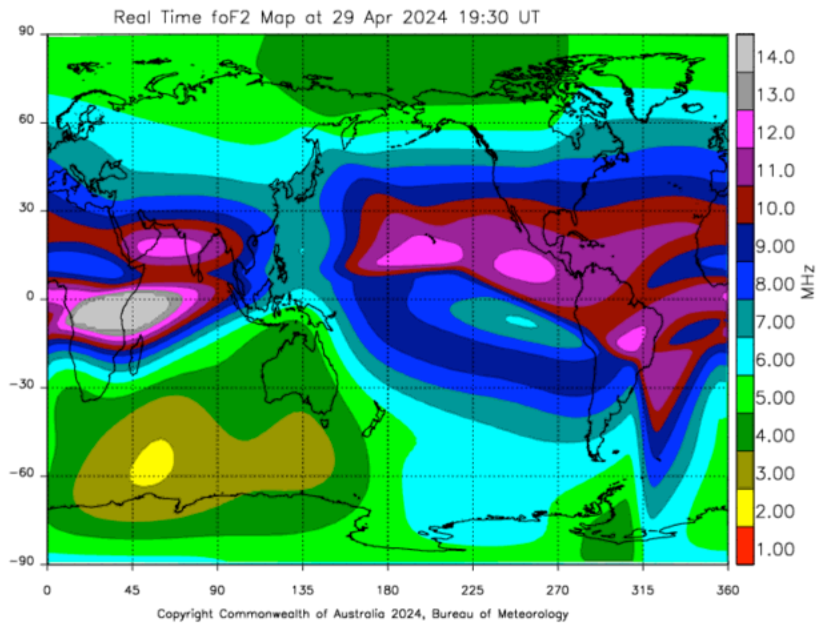

Figure 4 Critical frequency at 19:30 UT on April 29, 2024. (source: Australian Dept Meteorology)

The characteristics of the transmitting antenna determine the lowest angle at which a signal can be transmitted. The radiation pattern for a typical 20 meter Inverted-V antenna $\frac{1}{2}\lambda$ above ground is shown in Figure 5. In this figure the lowest angle at which this antenna can effectively radiate a signal is approximately 10°. This is the antenna's Lowest Radiated Angle or LRA. LRA is defined as the angle at which the antenna's radiated power is 6 db below its maximum level. The power radiated by the antenna drops off very quickly below its 10° LRA with nearly all of the antenna's energy radiated at higher angles. For example, the power radiated at an elevation angle of 15° is 3 db higher, twice that radiated at its LRA. Similarly, Highest Radiated Angle (HRA) is the high angle at which the antenna's radiated power is 6 db below its maximum level.

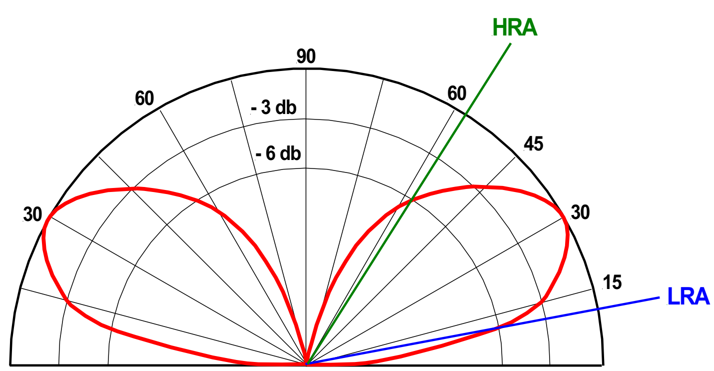

Figure 5 Radiation pattern for a typical 20 meter Inverted-V antenna (source: author)

Using Figure 3, the maximum usable frequency MUF = 35 MHz at an ionosphere critical frequency f_c = 9 MHz and an antenna radiation elevation angle of E = 15º. Under these conditions, communications on the 20 through 10 meter frequency bands should be good.

An antenna's LRA directly affects the maximum hop distance that the antenna can achieve, as shown in Figure 6. To use this chart the current height of the ionosphere's F region must be known. This information is obtained by clicking on Ionograms under the Current Conditions tab of the www.skywave-radio.org website. The h_mF2 chart for April 29, 2024 is shown in Figure 7. This chart shows h_mF2 for the past 5 days (green trace), yesterday (red trace), and today (blue trace) in Universal Time (UT) time. The ionosphere's F2 height at 19:30 UT on April 29, 2024 was approximately 275 km. This height is close to the 250 km red trace in Figure 6. Using this information the maximum hop distance for the antenna shown above, at an elevation angle of 10º, is 1,200 miles. At an elevation angle of 15º the hop distance is 900 miles. Transmitting at the lowest possible angle is important.

The height of the ionosphere's F2 region is also important in determining hop distance as can be seen in Figure 6. At a height of 350 km the hop distance is approximately 1250 miles for a signal transmitted at an elevation angle of 15º.

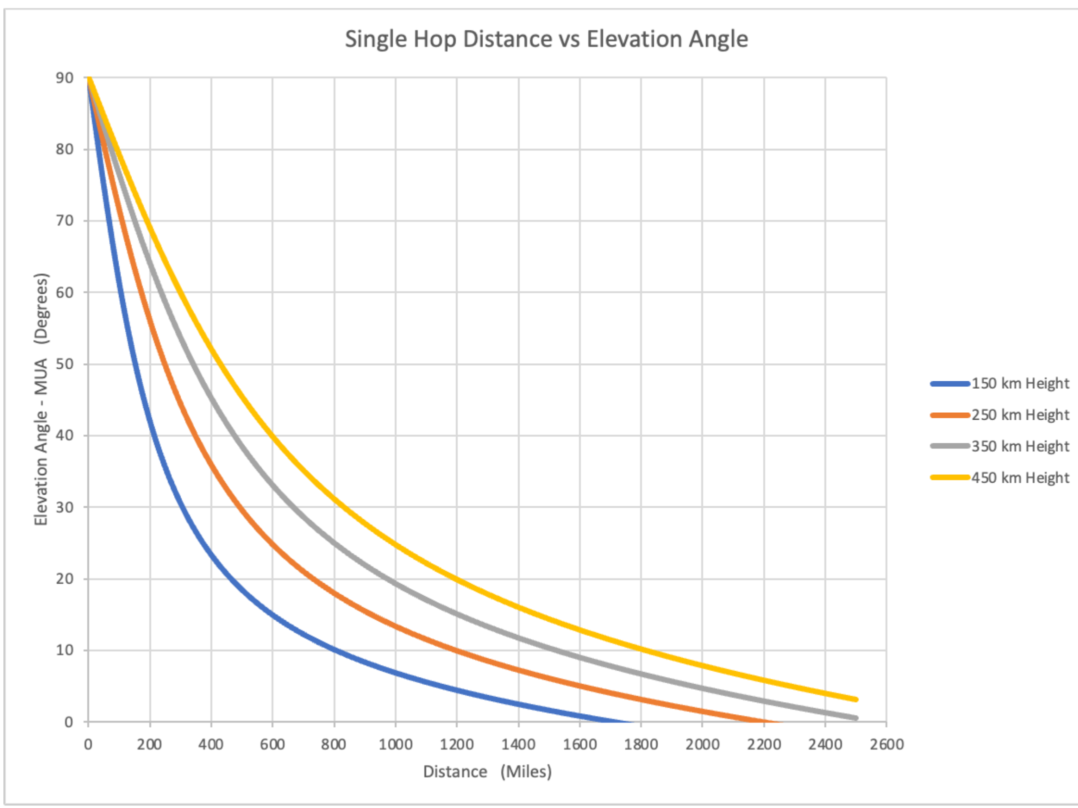

Figure 6 Hop distance verses elevation angle (source: author)

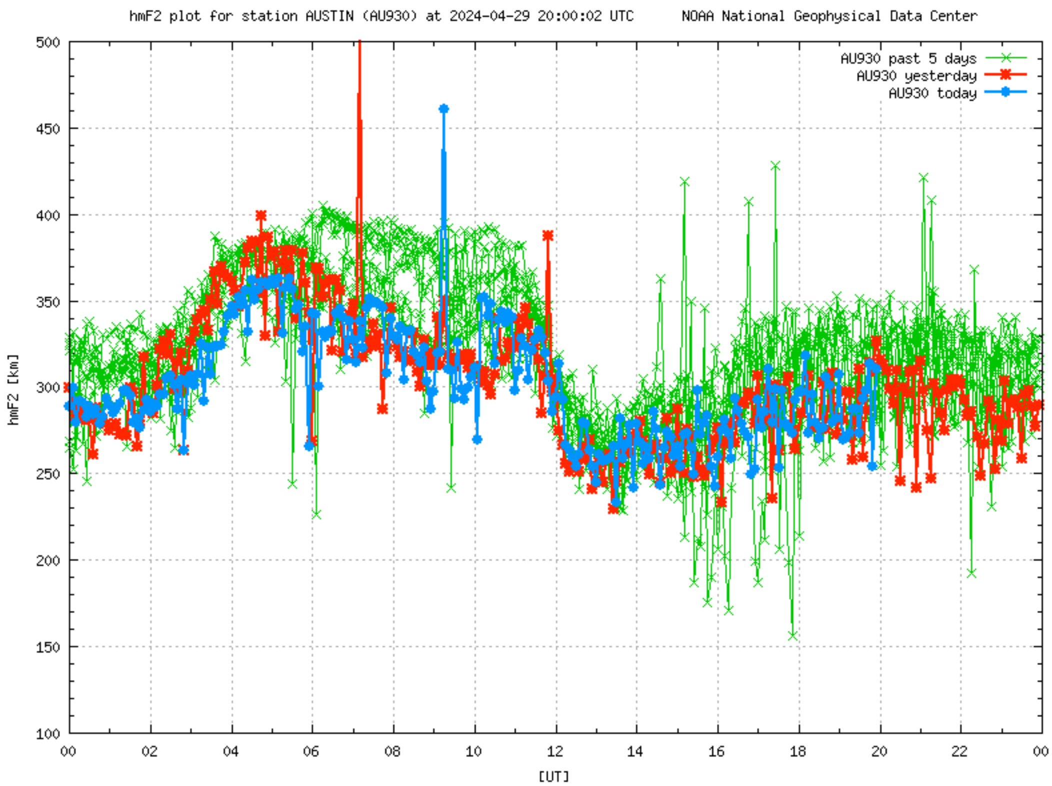

Figure 7 Height of the ionosphere's F2 region on April 29, 2024 (source: NOAA)

18.2 E Mode Propagation

Radio waves refract back to Earth from both the ionosphere's E and F regions as illustrated in Figure 8. E region hops are shorter than hops through the F layer requiring more hops to reach a particular destination. This means more passes through the signal absorbing D region and more ground reflection losses. Consequently, E mode propagation generally results in the received signal strength being less than that for propagation through the F layer.

A transmitted signal will bend back to Earth in the E region of the ionosphere if the signal's elevation angle is below the E region Maximum Usable Angle (MUA_E)

$$MUA_E = \sin^{-1}\left[\frac{f_{cE}}{f_o}\right] \quad :: \quad f_{cE} = E\ region\ critical\ frequency, \quad f_o = \text{operating frequency}$$

When that occurs the E region acts like a shield preventing low angle signals from reaching the F region. As a result, the hop distances for low angle signals are dramatically shortened compared to their normal long hops through the F layer.

E region shielding adversely affects long distance (DX) communications. This typically occurs around noon time when the E region critical frequency is the highest. The E region's noon time critical frequency f_{cE} during solar maximum is 3 to 4 MHz. During solar minimum the noon time critical frequency is 2 to 3 MHz as shown in Figure 9.

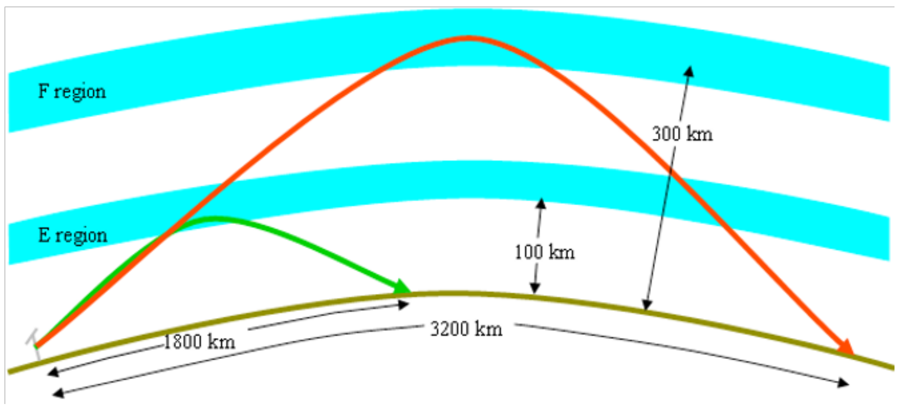

Figure 8 E and F mode propagation (source: Space Weather Service)

In Figure 10, at an F region height of 300 km (gray trace), 40m hop distance increases as the transmitted signal's elevation angle drops, reaching a distance of 1,400 miles at an elevation angle of 10^o. However, the E region mid-day critical frequency of fcE = 3 to 4 MHz causes 40-meter signals transmitted at angles below the E region MUA_E of 29^o to refract in the E region instead of reaching the F2 layer. For completeness:

$$MUA_E = \sin^{-1}\left[\frac{f_{cE}}{f_o}\right] = \sin^{-1}\left[\frac{3.5\ MHz}{7.1\ MHz}\right] = \sin^{-1}[0.49] = 29°$$

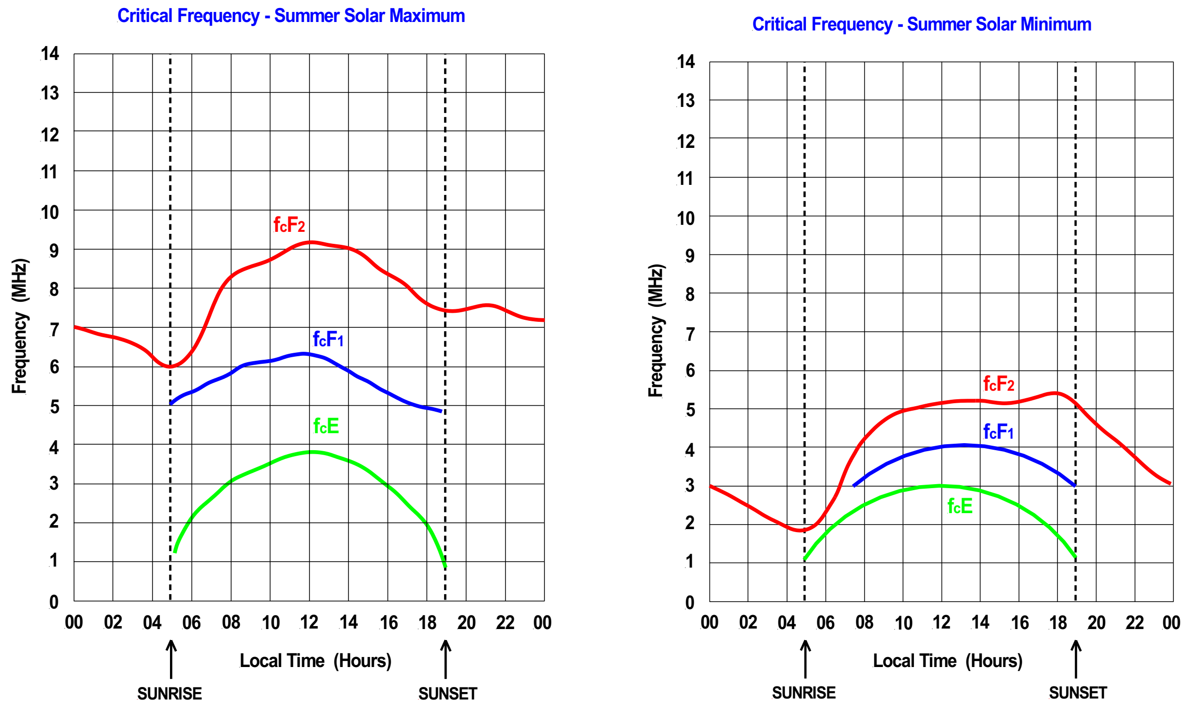

Figure 9 Critical frequencies during solar maximum (source: author)

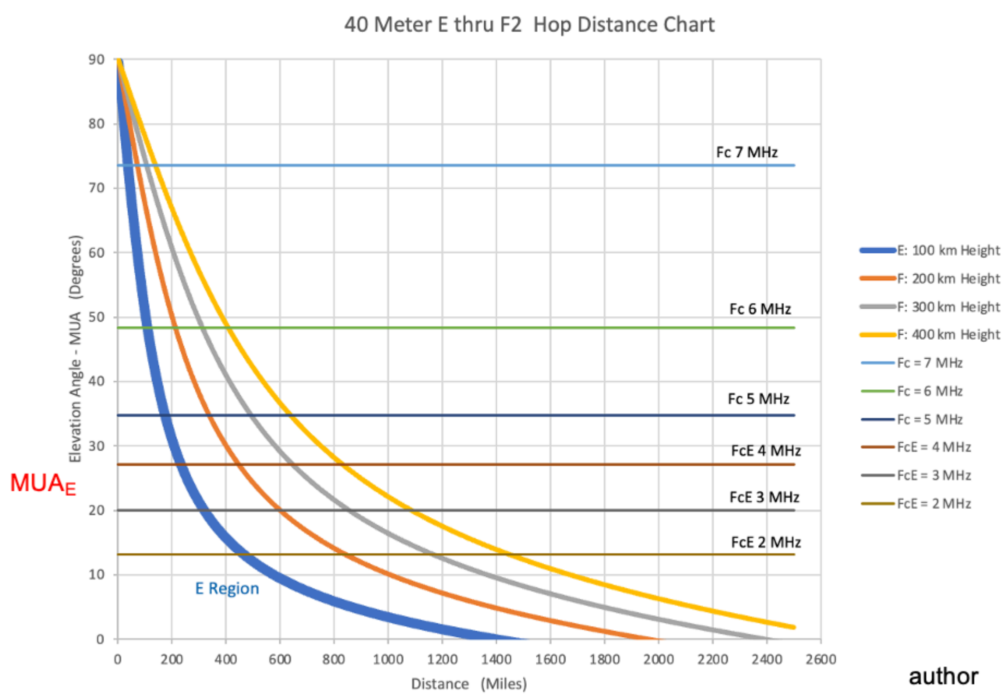

Figure 10 E through F2 40 meter hop distances

Signals refracting in the E region are blocked from reaching the F layer. The affect of E region screening is illustrated in Figure 10. At an F region height of 300 km (gray trace) the hop distance for a 40 meter signal transmitted at an angle of 30° is about 600 miles. At elevation angles of 29° and below, E mode propagation occurs represented by the thick blue trace in Figure 10. At 29° hop distance suddenly drops from the F2 hop distance of 600 miles to the E mode hop distance of only 200 miles. In essence, long distance communications through the ionosphere's F region stops at elevation angles equal to and below MUA_E. E region screening has a more detrimental effect on 40, 30, and 20 meter mid-day DX than D layer absorption. D layer absorption is often blamed for poor mid-day DX while E region screening is the culprit.

18.3 Sporadic E Propagation

Sporadic E (E_s) formations of abnormally high ionization within the E region (Figure 11) are important because they can reflect HF radio signals at frequencies up to about 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 zones often have electron densities far greater than normal E region levels and at times even greater than in the F region. Sporadic E patches can appear opaque to radio waves, reflecting waves that normally would have been refracted high in the F2 layer. This can seriously impact HF radio circuits. Instead of a single hop through the ionosphere multiple hops, with more ground reflections and more passes through the attenuating D region, may be required to reach a destination as illustrated on the left in Figure 12. This can seriously degrade signal levels at the receiving site. Worse yet, the intended receiving location could be missed altogether as occurs on the right in Figure 12. At times sporadic E patches are partially transparent or patchy permitting radio waves to penetrate through the gaps. However, a partially transparent sporadic E patch often leads to weak or fading signals as the sporadic E zone evolves.

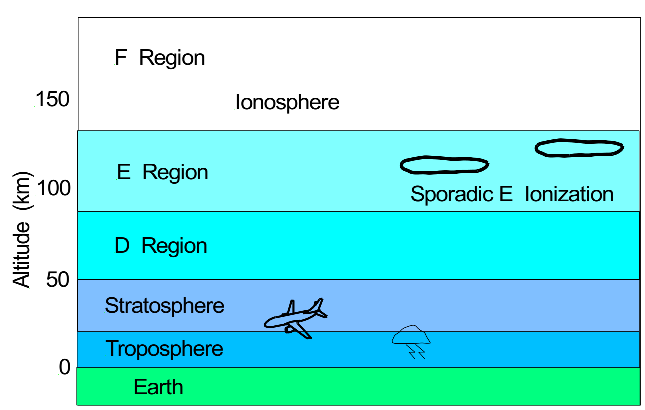

Figure 11 Sporadic E ionization (source: author)

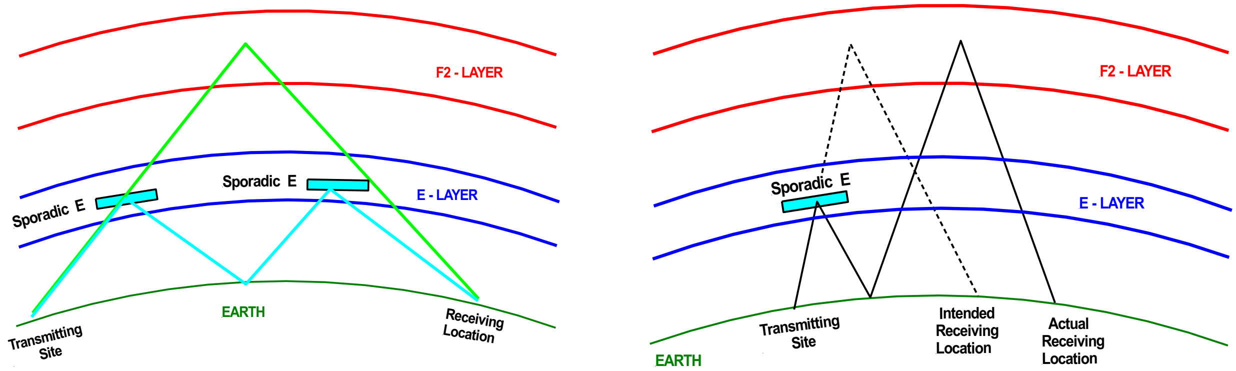

Figure 12 Disruptions in propagations paths due to sporadic E (source: author)

Figure 13 illustrates the important fact that sporadic E reflections can occur on the top side of the E region as well as on the bottom side shown in Figure 12.

Sporadic E zones are particularly strong in the low latitude equatorial region where they are essentially a daytime phenomenon with little seasonal variation. It is believed that they are formed in this part of the world by instabilities in the equatorial electrojet illustrated in Figure 14.

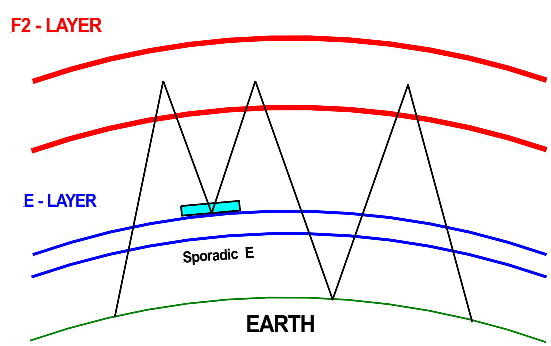

Figure 13 Topside Sporadic E reflection (source: author)

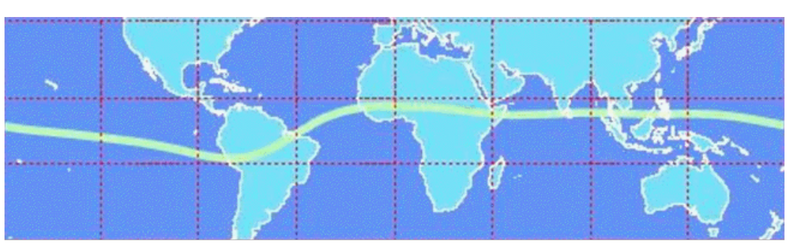

Figure 14 Equatorial electrojet (source: gfz-potsdam.de)

At mid latitudes sporadic E zones tend to be weaker than elsewhere. Their occurrence is subject to diurnal and seasonal variations. They tend to be more prevalent during the summer than in winter and during the day than at night, occurring particularly in mid-morning and near sunset. 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 (Figure 15). The meteoric debris is largely monatomic metallic ions consisting of iron, sodium, magnesium, and other similar elements. These monatomic ions are relatively small compared to the much larger molecular ions which comprise the E region. Because of their small size, the rate of electron-ion recombination is lower than for molecular ions.

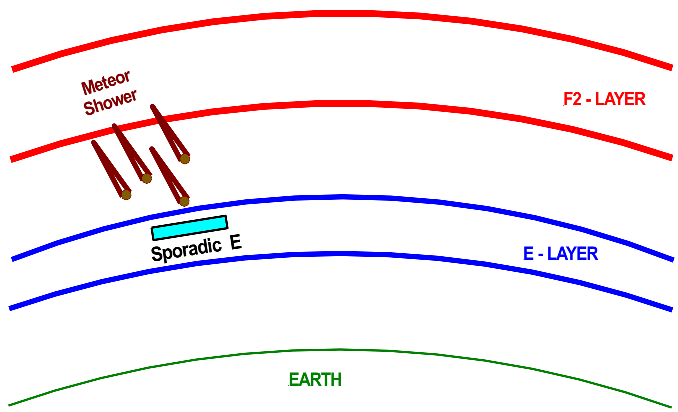

Figure 15 Meteor showers creating sporadic E patches (source: author)

Atmospheric gravity waves, associated with traveling ionospheric disturbances (TIDs), create upper atmosphere high velocity winds that travel in opposite directions at slightly different altitudes (Figure 16). This set of conditions produce what is known as vertical wind shear. Meteoric debris becomes trapped between the wind reversals at locations where the wind velocity tends to be low. Within the pockets of trapped debris, the rate of electron-ion recombination (the rate of electron loss) is lower than elsewhere in the E region. Consequently, relatively high electron concentrations develop in these pockets producing sporadic E patches.

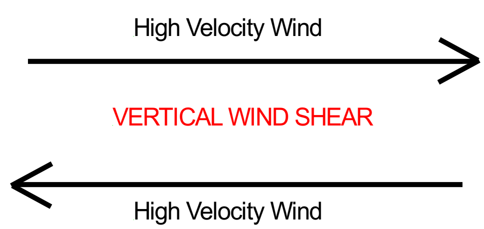

Figure 16 Vertical wind shear (source: author)

At high latitudes sporadic E zones occur mainly at night with little seasonal variance. They are attributed to ionization by incoming high energy charged particles entering the auroral region from the magnetosphere. Clouds of auroral E_s drift westward in the evening and eastward in the early morning at speeds between 200 and 3,000 meters per second, much like the auroral itself. Sporadic E zones within the polar caps have a different characteristic. They are weaker and extend across the polar caps in the form of ribbons in a roughly sunward direction.

18.4 Multi-path Propagation

Communications between Los Angeles and Denver, a distance of 800 miles, can occur on 40 meters in either one hop or in two hops of 400 miles each as illustrated in Figure 17.

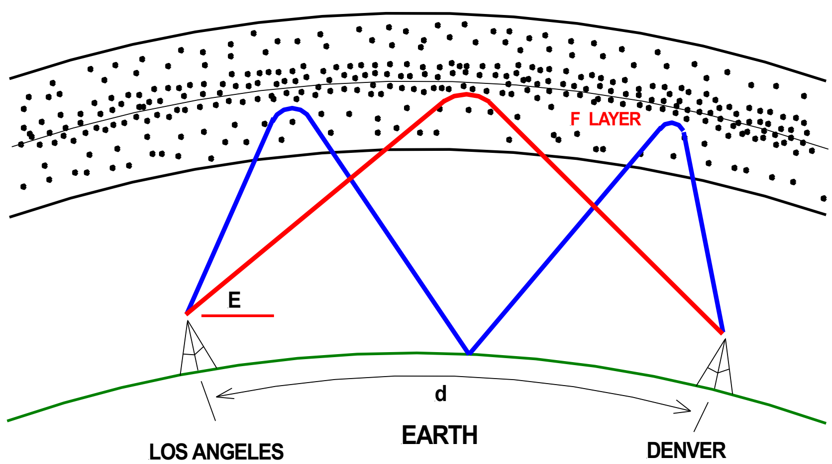

Figure 17 Communications between Los Angeles and Denver (source: author)

The 40-meter skip distance chart in Figure 18 shows that at a F2 region height of 350 km (gray trace) an elevation angle of roughly 25^{o} is needed to reach Denver in one hop while an angle of 45^{o} is required for the double hop path. A critical frequency of 6.0 MHz supports both paths.

In general, we have relatively little control over the elevation angle at which our antenna radiates. The 40-meter half wavelength dipole shown in Figure 19 radiates at all angles from 20 to 90^{o}. Radiation from this antenna will reach Denver following both the single and double hop propagation paths. There is nothing that we can do about this!

The single and double hop signals will be out of phase when they arrive in Denver since the double hop signal has to travel a longer distance to reach Denver. Consequently, the two signals will interfere with each other reducing the strength of the received signal, in addition to producing distortion and fading.

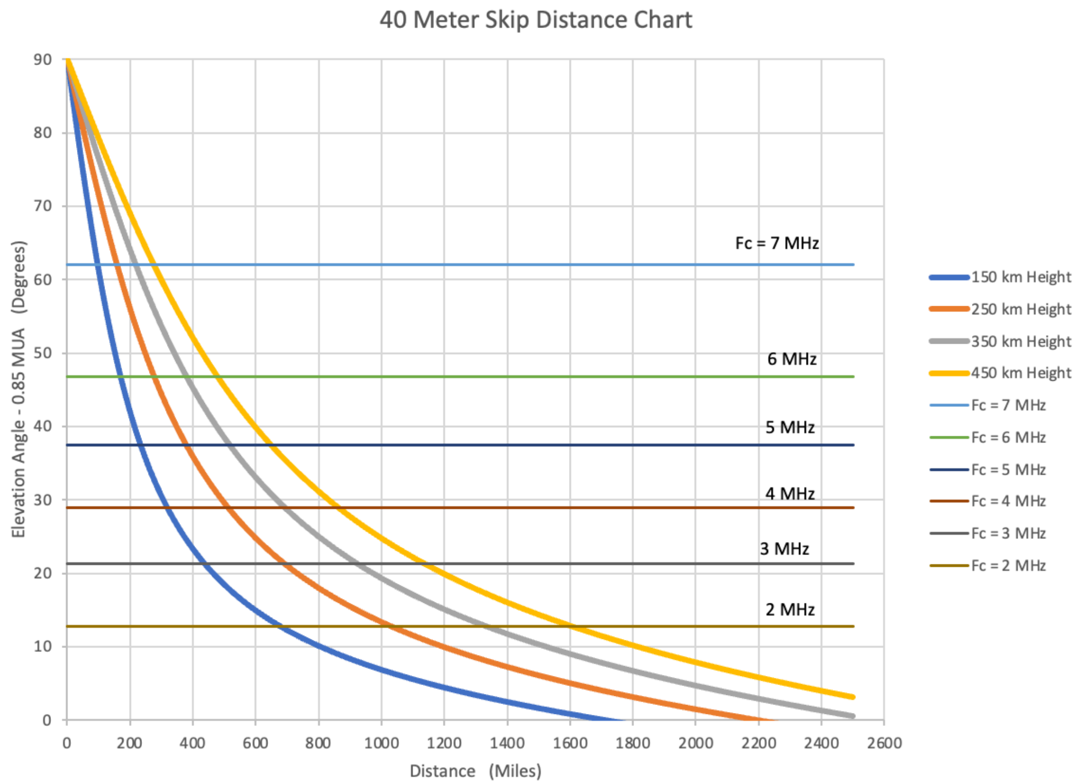

Figure 18 Skip distance chart - 40 meters. (source: author)

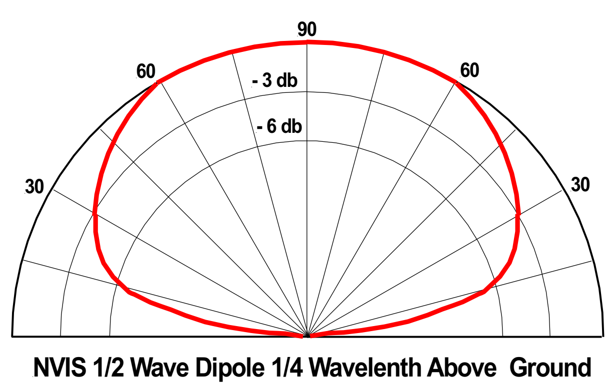

Figure 19 Elevation pattern for an NVIS 40 meter antenna (source: author)

The maximum usable frequency at a critical frequency of 6.0 MHz and an elevation angle of 25° is

$$[MUF]_{25^\circ} = \frac{f_{cF2}}{\sin E} = \frac{6.0\ MHz}{\sin 25} = 14.2\ MHz$$

At an elevation angle of 45° the maximum usable frequency is

$$[MUF]_{45^\circ} = \frac{f_{cF2}}{\sin E} = \frac{6.0\ MHz}{\sin 45} = 8.5\ MHz$$

Consequently, the double and single hop propagation modes are supported since the 40-meter operating frequency of 7.2 MHz is below the MUF for both the 25° and 45° elevation angles.

The 25° elevation angle MUF of 14.2 MHz supports communications with Denver on 30 meters (10.1 MHz), but the 45° elevation angle (MUF = 8.5 MHz) does not. This is illustrated by the 30-meter skip distance chart in Figure 20. In this chart an elevation angle of 45° is above the 31° elevation angles permitted by the 6.0 MHz critical frequency. Transmitting at an elevation angle of 45° on 30 meters will result in the transmitted signal penetrating the ionosphere and being lost to outer space. However, Denver is easily reached by transmitting on 30 meters at an elevation angle of 25°. In fact, this is the only possible path to Denver on 30 meters. Moving from the 40 meter to the 30 meter frequency band eliminates the Los Angeles to Denver multi-path interference problem.

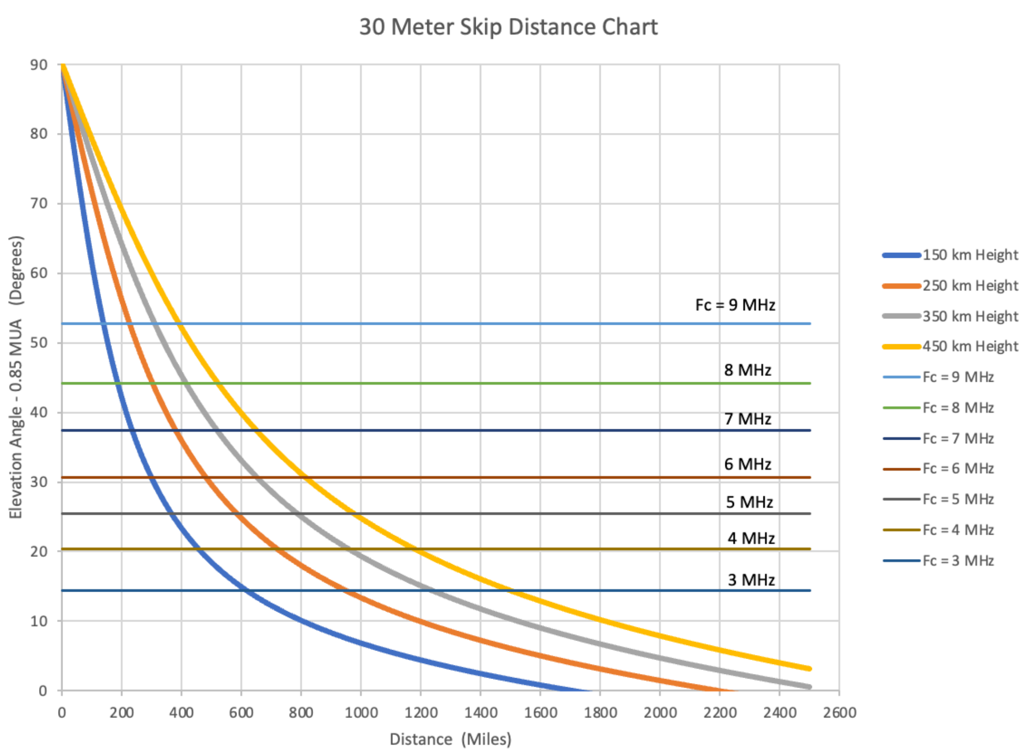

Figure 20 Skip distance chart - 30 meters (source: author)

This brings us back to a common theme. Optimum communications through the ionosphere is achieved by operating at the highest possible frequency.

18.5 Ground Scattering of Radio Waves and Backscatter

We assume in our simple Figure 21 propagation diagram that our radio waves reflect back and forth between the ionosphere and a smooth flat Earth in route to the receiving station. This over simplification is usually not the case.

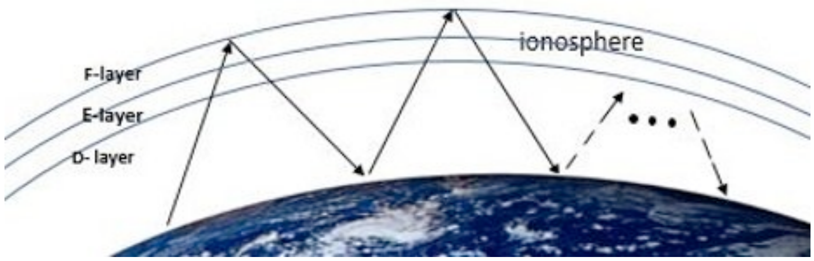

Figure 21 Multiple hop propagation through the ionosphere (source: ResearchGate)

Our assumption of a smooth flat Earth is analogous in many ways to scenery perfectly reflecting from the surface of the very smooth lake shown in Figure 22. In terms of reflection, the average depth of surface irregularities must be substantially less than the wavelength of the incident light, or radio wave, to be a perfectly smooth surface. Radio waves do at times perfectly reflect from a smooth flat Earth according to our simplistic propagation model. But again, this is usually not the situation.

Figure 22 Reflections from a perfectly smooth lake

If the surface of a lake is not perfectly smooth, reflected light will be scattered in all directions producing the blurry image shown in Figure 23. The same is true of radio waves. The depth of surface irregularities in hilly terrane is considerably larger than the wavelength of incident radio waves, scattering the radio waves in multiple directions. Some of the scattered radio waves will be reflected in the desired propagation direction. Radio waves scattered in other directions will be lost resulting in ground scatter attenuation.

Figure 23 Blurry reflections from a rough lake (source: olympus-lifescience.com)

Some of the scattered signal may travel back through the ionosphere toward the transmitting site as illustrated in Figure 24. 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.

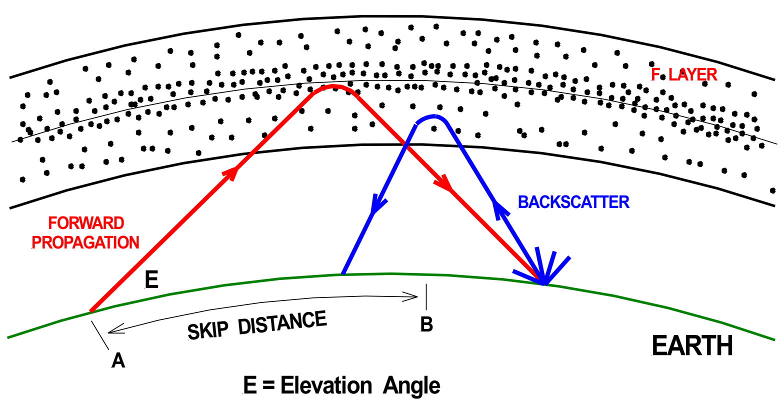

Figure 24 Backscatter propagation (source: author)

18.6 Great Circle Propagation

A great circle path is the shortest distance between any two locations on Earth’s surface. A great circle is formed by a plane passing through the two points of interest and the center of the Earth as shown in Figure 25. A great circle always divides the Earth in half. Thus, the equator and lines of longitude are great circles. However, lines of latitude are not great circles since they do not cut the Earth in equal halves.

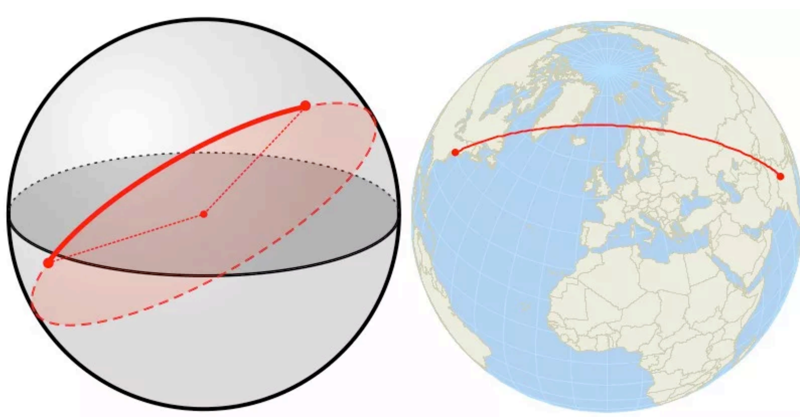

Figure 25 Great Circle path (source: Caliper Corporation)

Normally, radio waves follow great circle paths since a great circle is the shortest distance between the transmitting and receiving stations. However, high latitude ionospheric irregularities including

- Ionospheric troughs,
- High latitude spread F,
- Patches,
- Blobs, and
- Traveling Ionospheric Disturbances,

can seriously alter signal propagation paths. (See the “High Latitude Ionosphere” chapter for an in-depth discussion of these irregularities.) In addition, diverging ordinary and extra ordinary waves in the polar regions complicate the problem further. For example, a signal intended to travel along the great circle path over the polar region from eastern United States to India (Figure 25) could instead end up in Egypt or perhaps Korea. In general, great circle paths become less meaningful for signals propagating through Earth's polar zones.

18.7 Gray Line Propagation

In Figure 26 the line dividing night and day is called the terminator. It is also referred to as the gray line and twilight zone. It is actually a fuzzy line due to the bending of sunlight in Earth's atmosphere. Thus, a more appropriate term would be gray zone.

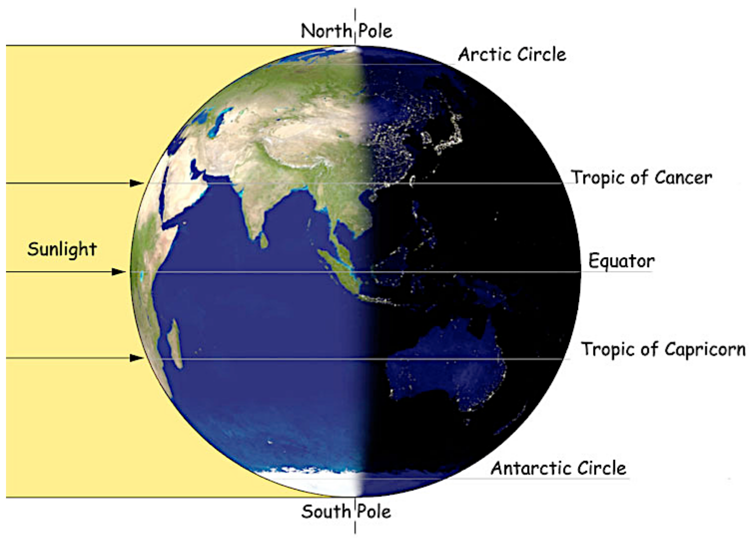

Figure 26 Earth's terminator (source: cseligman.com)

The position of the gray line is constantly changing as the Earth rotates throughout the day and orbits around the Sun during the year. As illustrated in Figure 27, the Earth's axis is always tilted 23.5^o with respect to its orbit. In Figure 27, the gray line runs north and south passing through the Earth's geographic poles during the March 21 and September 21 solar equinoxes. During the December and June solstices (December 21 and June 21), the gray line is tilted 23.5^o with respect to Earth's axis, as shown in Figures 27. During the course of a year, the gray line traverses a 47^o sector of the Earth north and south of the equator as the Earth orbits the Sun. The width of the gray zone also varies. The transition between night and day occurs quickly near the equator while in the polar zones it occurs more slowly. Consequently, the gray zone is wider at high latitudes than at the equator.

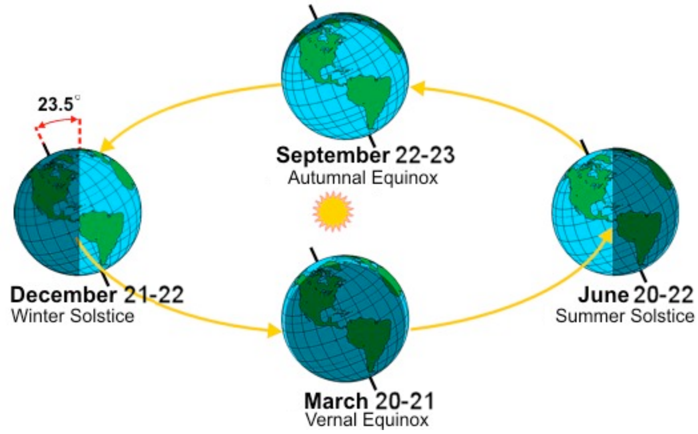

Figure 27 Earth's orbit around the Sun (source: NOAA National Weather Service)

The ionosphere changes significantly during sunrise and sunset. At sunrise the F region builds rapidly as solar ionization resumes. The D layer also reappears but more slowly. The reverse occurs in the evening. The D layer disappears soon after sunset while the F region slowly declines throughout the night. The delay between the appearance and disappearance of the D region relative to the F layer, illustrated in Figure 28, provides a period of enhanced communications.

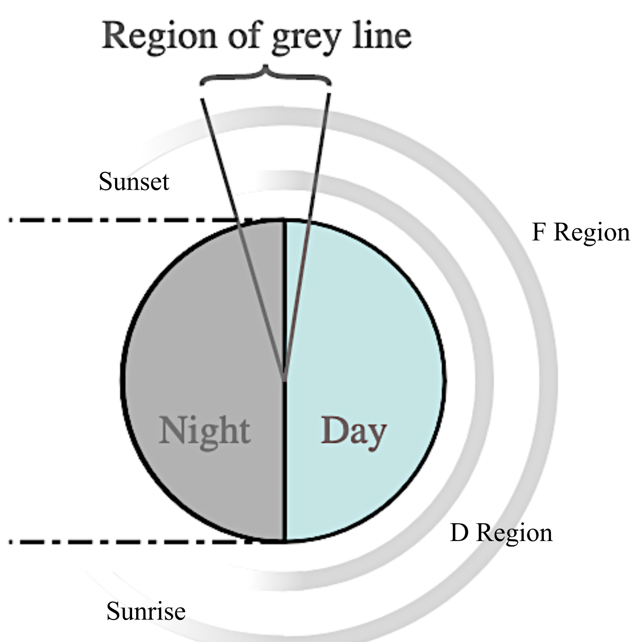

Figure 28 Gray line formation (source: Electronics Notes)

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.

In Figure 29 excellent communications from northern Europe to eastern Africa occurs at sunrise. In western Canada good communications into the south Pacific occurs at sunset. Seasonal variations in gray line orientation provide optimum paths to slightly different parts of the world each day. These periods of enhanced communications last for about 45 minutes to an hour.

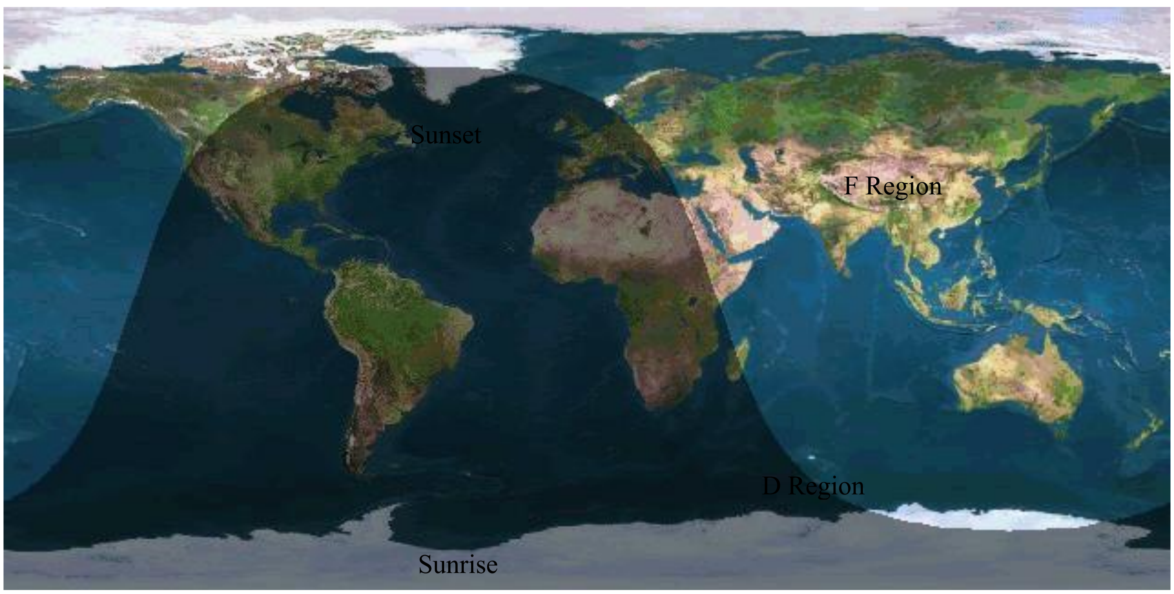

Figure 29 Gray line propagation

Since D level absorption is inversely proportional to frequency squared, gray line propagation is very important for 80 meter and 40 meter DX, less so for 20 meters, and usually not relevant for 15 meters.

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

18.8 Equatorial Sporadic E Propagation

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° either side of the magnetic equator.

A low elevation angle signal can travel a considerable distance by reflecting from an equatorial sporadic E patch followed by a subsequent F layer refraction, as illustrated in Figure 30.

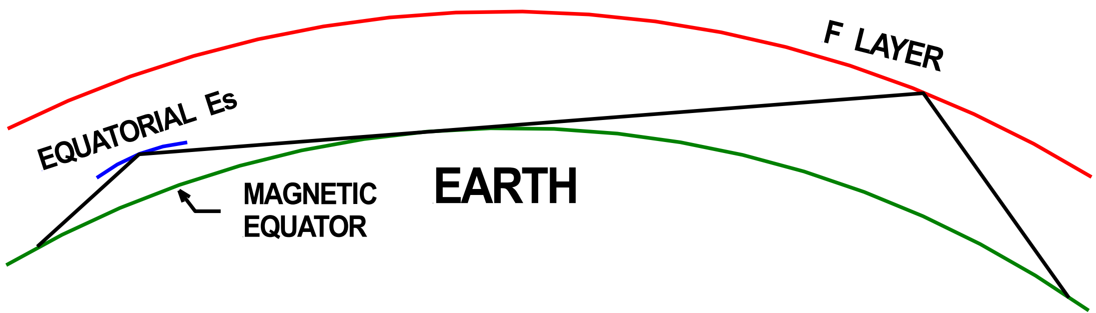

Figure 30 Equatorial Sporadic E propagation (source: author)

18.9 Transequatorial Propagation (TEP)

Transequatorial propagation is primarily a long distance 6 meter propagation mode between:

- Central America and South America,
- Japan and northern Australia,
- The Mediterranean and South Africa

as illustrated in Figure 31.

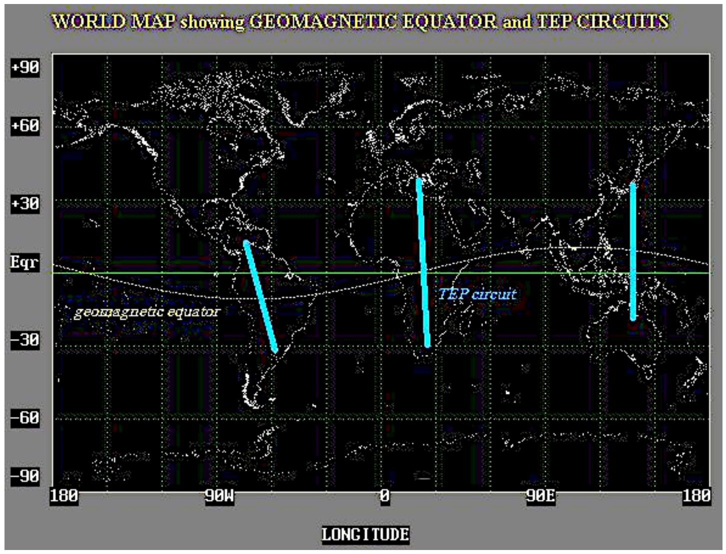

Figure 31 Transequatorial propagation paths (source: Australian Space Weather Services)

Transequatorial propagation is caused by the equatorial fountain effect illustrated in Figure 32. During the day ions and electrons drift upward in the ionosphere due to the force exerted by perpendicular electric and magnetic fields along the geomagnetic equator. The electric field gradually weakens and finally disappears at an altitude of around 800 km. With the electric field no longer present, charged particles (ions and electrons) travel under the influence of gravity and pressure gradients along magnetic field lines that curve back to Earth as illustrated in Figure 32. The charged particles combine with those already in the region creating a peak or crest in electron concentrations 15 to 20° north and south of the equator while a trough, or deficiency of electrons, develops over the equator.

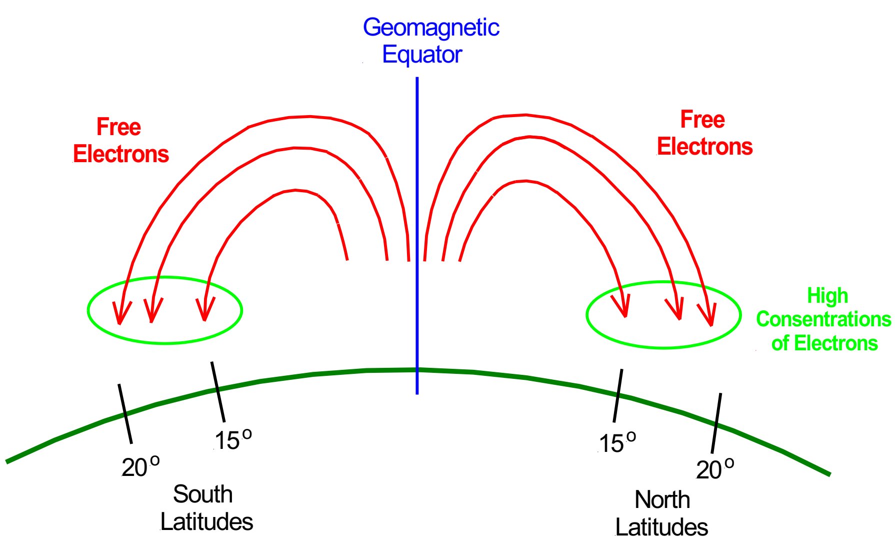

Figure 32 Equatorial plasma fountain (source: author)

Initially, before the fountain effect was understood, the high concentration of electrons appearing at latitudes between 15 to 20 degrees was known as the equatorial or Appleton anomaly. It was believed to be an anomaly since the highest electron concentrations were expected to occur over the equator.

The fountain effect is clearly visible in the winter (December) ionospheric map shown in Figure 33. The black line sloping through South America is the magnetic dip equator. The crests in electron concentrations are the bright pink zones on both sides of the magnetic equator.

The crests usually form in the late afternoon and early evening. While the crests vary from day-to-day and seasonally, they are most pronounced during solar maximum. Notice in Figure 33 that the largest electron peaks (two of them) occur in the winter hemisphere.

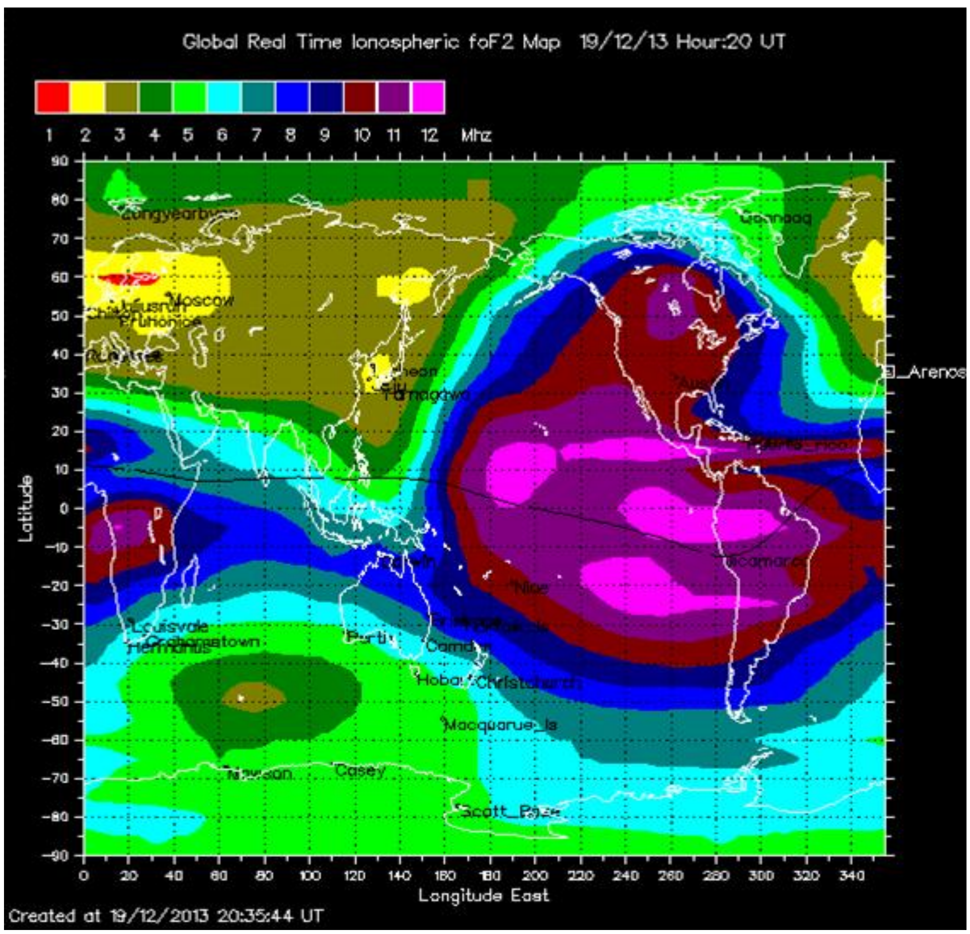

Figure 33 Ionospheric map showing fountain crests (source: Australian Space Weather Services)

F2 critical frequencies within the crests can often reach 18 MHz or higher during solar maximum. The maximum usable frequency at f_{cF2} = 18 MHz and an elevation angle E = 17^{o} is

$$[MUF]_{17^\circ} = \frac{f_{cF2}}{\sin E} = \frac{18\ MHz}{\sin 17} = 61\ MHz$$

with the frequency of optimum transmission

$$FOT = 0.85\ MUF = 0.85(61\ MHz) = 52.3\ MHz$$

occurring in the 6 meter frequency band. Because of the fountain effect and associated equatorial trough, critical frequencies along the magnetic equator are typically several MHz less than in the crests.

The fountain effect distorts the general form of the ionosphere throughout the low latitude equatorial region leading to the Transequatorial 6 meter propagation phenomena, as illustrated in Figure 34. 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. Instead, a radio signal experiencing Transequatorial propagation reflects off one fountain crest, travels across the equator to the second crest, and then reflects back to Earth. Transequatorial propagation allows a radio signal to traverse long distances from the transmitter to receiver in one hop, greatly minimizing signal loss.

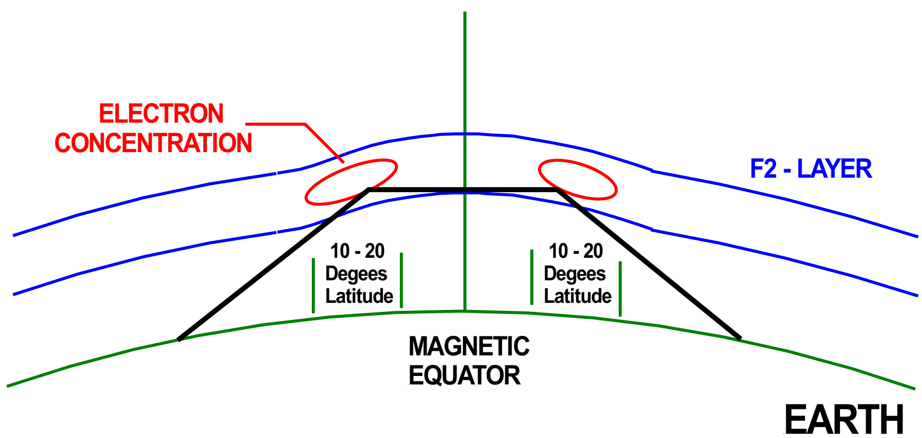

Figure 34 Transequatorial Propagation (source: author)

18.10 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, as illustrated in Figure 35. 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. Experiencing ionospheric ducting is weird. 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.

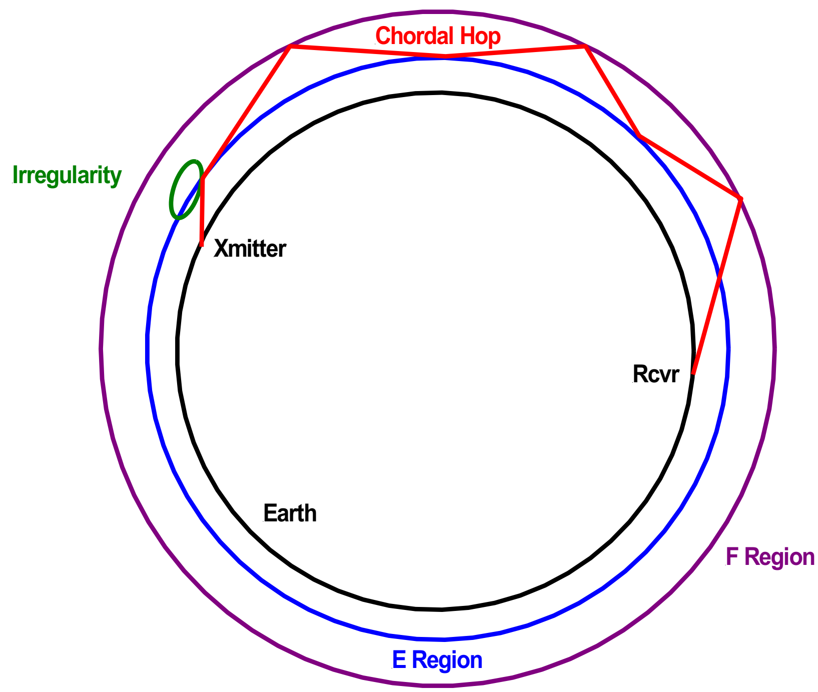

Figure 35 Ionospheric ducting (source: author)

18.11 HF Non-Skywave Propagation

In concluding this chapter, it is important to point out that there are two non-skywave HF propagation modes, specifically:

- Line of sight, and
- Ground wave propagation.

Historically these two propagation modes were very important.

Prior to the mid 1960's the primary amateur radio bands were 160 through 10 meters. While the VHF/UHF 2 meter, 220 MHz, and 440 MHz bands were assigned for amateur radio use, they were in general used only by experimenters (technicians, engineers, and scientists). The reason for this was that the vacuum tube transmitters and receivers of the day were physically too large to support communications at these VHF and UHF frequencies. Figure 36 shows the author's 1962 amateur radio rig. The wiring in these big radios was sufficiently long that it radiated at VHF frequencies making the technology impractical for VHF/UHF work. For comparison, the small radio on the far left in Figure 28 is the author's 1990 Kenwood TS-440 transceiver. The TS-440 was a 100 watt semiconductor HF radio that far out performed the 100 watt vacuum tube rig.

Figure 36 Author's 1962 ham radio station (source: author)

Opening up the VHF and UHF bands for general amateur radio use had to wait for development of semiconductor technology and the subsequent tiny hand held and desk top VHF/UHF transceivers. Today 2 meters is the most popular amateur radio band, being used primarily for local communications.

The question is, what frequency band was used for local communications prior to the introduction of semiconductor technology? The answer is 80 meters, which was used both day and night. How can that be? During the day 80 meters is dead due to intense D layer absorption. Yes, 80-meter skywave communications is dead during the day, but not 80-meter line of sight and ground wave propagation.

The distance covered by line of sight on 80 meters is essentially the same as line of sight 2-meter coverage. The range of ground wave propagation increases as the electrical conductivity of the ground increases. It is greatest over sea water and smooth flat fertile ground. The range of ground wave propagation is also proportional to signal wavelength as illustrated in the following table. Long wavelength signals travel further along the ground than short wavelength signals.

Frequency Band	Typical Ground Wave Distance
80 meters	68 miles
40 meters	50 miles
20 meters	30 miles

Consequently, the range of 80-meter ground wave is similar to that of 2-meter non-link repeaters. 80 meters is a good local communications band with one exception, the long 80-meter antennas. Because of the long antennas, 80 meters has largely been abandoned with local communications switching to the highly desirable VHF and UHF bands. However, the physics has not changed. 80 meters is a good back up option should VHF and UHF repeaters fail during a large-scale disaster.

One could ask why 40 meters, with its shorter antennas, was not use for location communications? The answer is relatively simple. The amateur radio bands were fairly congested, particularly with wide bandwidth (6 KHz) AM phone traffic. While invented, single side band (SSB) had not yet come to the amateur radio bands. At the time, amateur radio operators wanted to relieve 40-meter congestion and so moved all location communications to 80 meters.

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