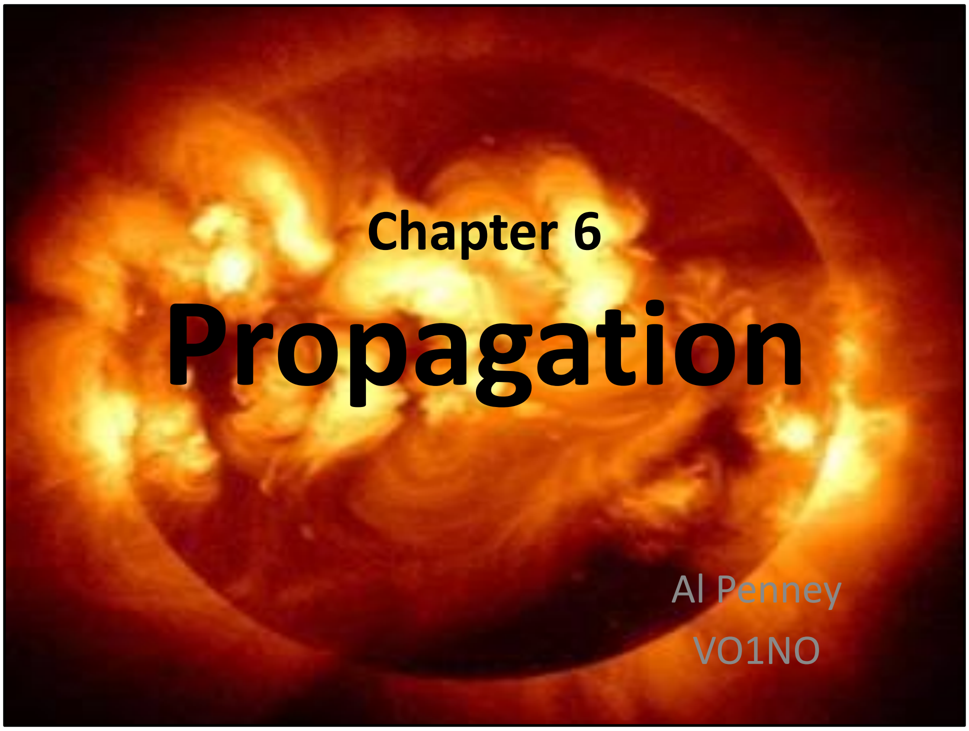


Chapter 6

Propagation

Al Penney
VO1NO

Objectives

To become familiar with:

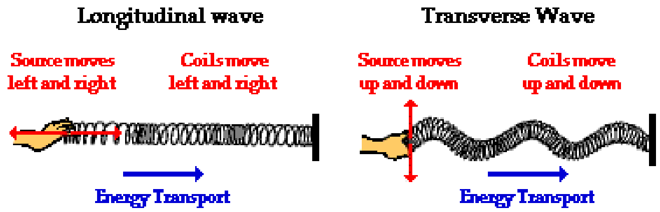
- Classification of waves wrt propagation;
- Factors that affect radio wave propagation; and
- Propagation characteristics of Amateur bands.

Propagation

- How signals get from Point A to Point B.

Waves

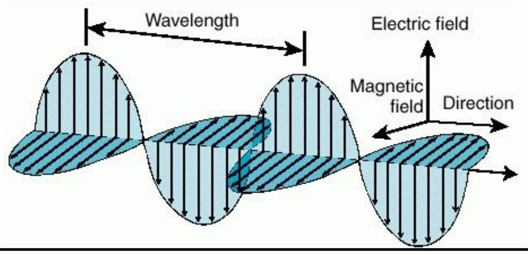
- Transverse
  - – Vibration is at right angles to direction of propagation, e.g.: guitar string
- Longitudinal
  - – Vibration is parallel to direction of propagation, e.g.: sound waves



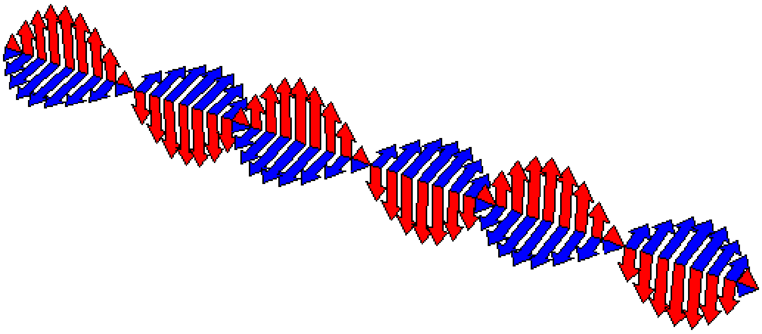
Al Penney
VO1NO

Electromagnetic (EM) Waves

- Transverse waves
- Consist of Electric and Magnetic components:
  - – In phase with each other; and
  - – At right angles to each other.
- Orientation of Electric field determines Polarization.

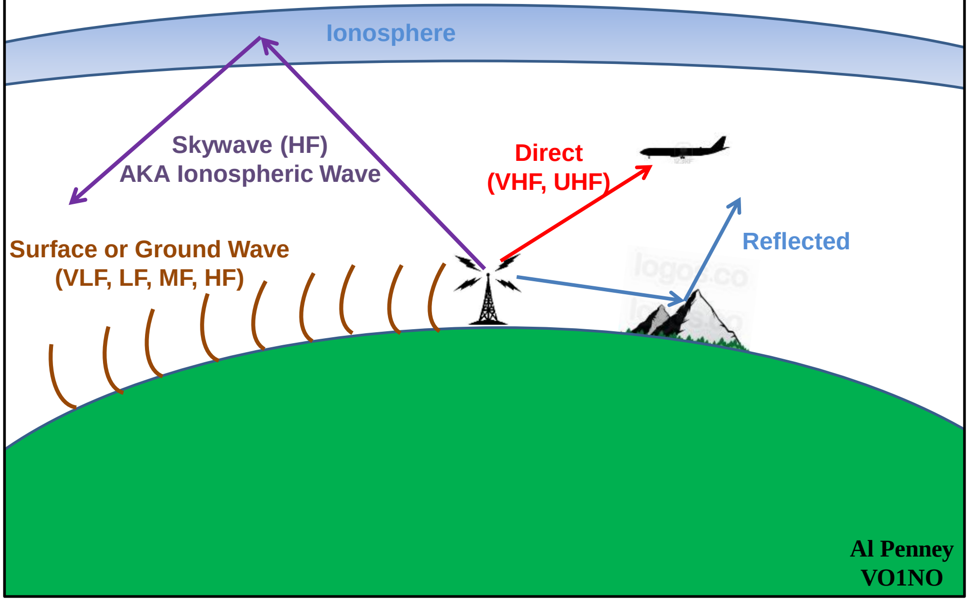


Al Penney
VO1NO



Al Penney
VO1NO

Classification of Waves



Ionosphere

Skywave (HF)
AKA Ionospheric Wave

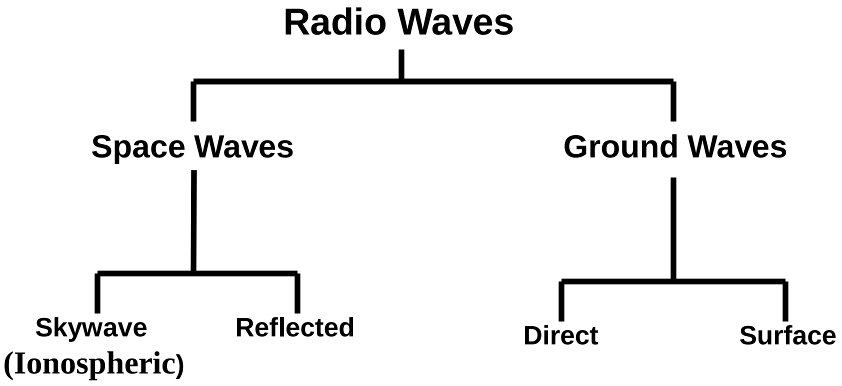
Direct
(VHF, UHF)

Reflected

Surface or Ground Wave
(VLF, LF, MF, HF)

Al Penney
VO1NO

Classification of Waves



Radio Waves

Space Waves

Ground Waves

Skywave
(Ionospheric)

Reflected

Direct

Surface

Al Penney
VO1NO

space waves are the radio **waves** of very high frequency (i.e. between 30 MHz to 300 MHz or more). The **space waves** can travel through atmosphere from transmitter antenna to receiver antenna either directly or after reflection from ground in the earth's stratosphere region.

In radio communication, **skywave** or **skip** refers to the propagation of radio waves reflected or refracted back toward Earth from the ionosphere, an electrically charged layer of the upper atmosphere. Since it is not limited by the curvature of the Earth, skywave propagation can be used to communicate beyond the horizon, at intercontinental distances. It is mostly used in the shortwave frequency bands.

As a result of skywave propagation, a signal from a distant AM broadcasting station, a shortwave station, or – during sporadic E propagation conditions (principally during the summer months in both hemispheres) a distant VHF FM or TV station – can sometimes be received as clearly as local stations. Most long-distance shortwave (high frequency) radio communication – between 3 and 30 MHz – is a result of skywave propagation. Since the early 1920s amateur radio operators (or "hams"), limited to lower transmitter power than broadcast stations, have taken advantage of skywave for long-distance (or "DX") communication.

Skywaves also called Ionospheric Waves.

Reflected waves are those reflected off terrain.

The term *ground wave* has had several meanings in antenna literature, but it has come to be applied to any wave that stays close to the Earth, reaching the receiving point without leaving the Earth's lower atmosphere. This distinguishes the ground wave from a *sky wave*, which utilizes the ionosphere for propagation between the transmitting and receiving antennas. The ground wave could be traveling in actual contact with the ground, as in Fig 1, where it is called the *surface wave*. Or it could travel directly between the transmitting and receiving antennas, when they are high enough so they can "see" each other—this is commonly called the *direct wave*. The ground wave also travels between the transmitting and receiving antennas by reflections or diffractions off intervening terrain between them. The ground-influenced wave may interact with the direct wave to create a vector-summed resultant at the receiver antenna.

THE SURFACE WAVE

The surface wave travels in contact with the Earth's surface. It can provide coverage up to about 100 miles in the standard AM broadcast band during the daytime, but attenuation is high. The attenuation increases with frequency.

The surface wave is of little value in amateur communication, except possibly at 1.8 MHz and the 630 Meter Band. Vertically polarized antennas must be used, which tends to limit amateur surface-wave communication to where large vertical systems can be erected.

Ground wave refers to the propagation of radio waves parallel to and adjacent to the surface of the Earth.

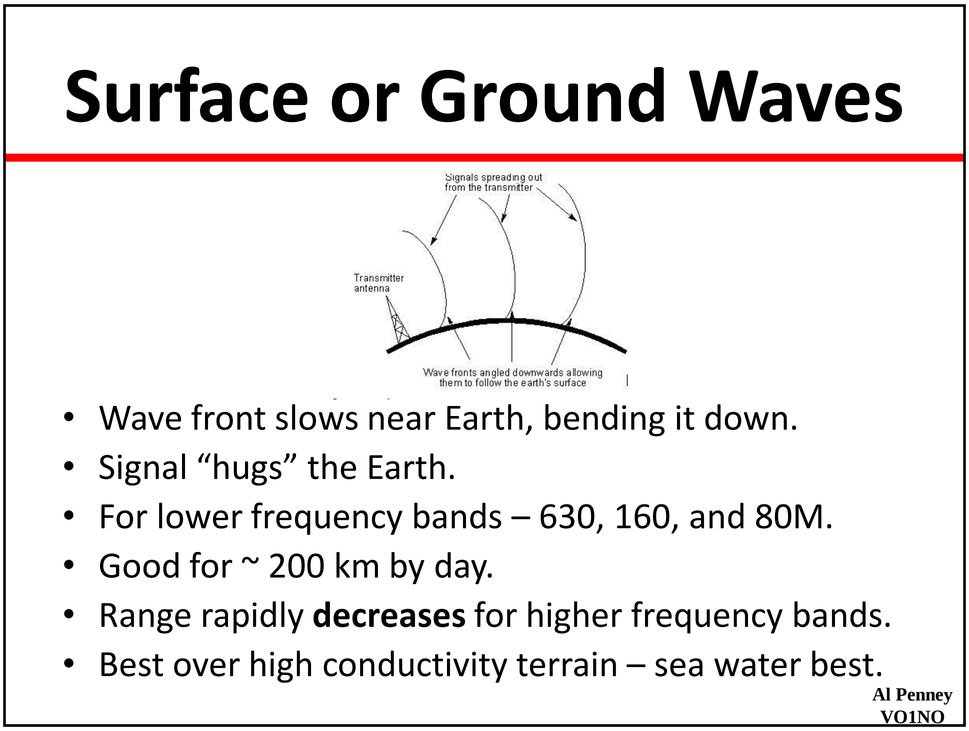
Surface Wave propagation works because lower-frequency waves are more strongly diffracted around obstacles due to their long wavelengths, allowing them to follow the Earth's curvature. Ground waves propagate in vertical polarization, with their magnetic field horizontal and electric field (close to) vertical. With VLF waves, the ionosphere and earth's surface act as a waveguide.

Conductivity of the surface affects the propagation of surface waves, with more conductive surfaces such as sea water providing better propagation. Increasing the conductivity in a surface results in less dissipation. The refractive indices are subject to spatial and temporal changes. Since the ground is not a perfect electrical conductor, ground waves are attenuated as they follow the earth's surface. The wavefronts initially are vertical, but the ground, acting as a lossy dielectric, causes the wave to tilt forward as it travels. This directs some of the energy into the earth where it is dissipated,[15] so that the signal decreases exponentially.

Most long-distance LF "longwave" radio communication (between 30 kHz and 300 kHz) is a result of groundwave propagation. Mediumwave radio transmissions (frequencies between 300 kHz and 3000 kHz), including AM broadcast band, travel both as groundwaves and, for longer distances at night, as skywaves. Ground losses become lower at lower frequencies, greatly increasing the coverage of AM stations using the lower end of the band. The VLF and LF frequencies are mostly used for military communications, especially with ships and submarines. The lower the frequency the better the waves penetrate sea water. ELF waves (below 3 kHz) have even been used to communicate with deeply submerged submarines.

Ground waves have been used in over-the-horizon radar, which operates mainly at frequencies between 2–20 MHz over the sea, which has a sufficiently high conductivity to convey them to and from a reasonable distance (up to 100 km or more; over-horizon radar also uses skywave propagation at much greater distances). In the development of radio, ground waves were used extensively. Early commercial and professional radio services relied exclusively on long wave, low frequencies and ground-wave propagation. To prevent interference with these services, amateur and experimental transmitters were restricted to the high frequencies (HF), felt to be useless since their ground-wave range was limited. Upon discovery of the other propagation modes possible at medium wave and short wave frequencies, the advantages of HF for commercial and military purposes became apparent. Amateur experimentation was then confined only to authorized frequencies in the range.

Direct modes (line-of-sight)Line-of-sight refers to **radio waves** which travel **directly** in a line from the transmitting antenna to the receiving antenna. It does not necessarily require a cleared sight path; at lower frequencies **radio waves** can pass through buildings, foliage and other obstructions.



Surface or Ground Waves

- Wave front slows near Earth, bending it down.
- Signal “hugs” the Earth.
- For lower frequency bands – 630, 160, and 80M.
- Good for ~ 200 km by day.
- Range rapidly **decreases** for higher frequency bands.
- Best over high conductivity terrain – sea water best.

Al Penney
VO1NO

Ground wave propagation is particularly important on the LF and MF portion of the radio spectrum. Ground wave radio propagation is used to provide relatively local radio communications coverage, especially by radio broadcast stations that require to cover a particular locality.

Ground wave propagation of radio signal is ideal for relatively short distance propagation on these frequencies during the daytime. Sky-wave ionospheric propagation is not possible during the day because of the attenuation of the signals on these frequencies caused by the D region in the ionosphere. In view of this, radio communications stations need to rely on the ground-wave propagation to achieve their coverage.

The surface wave is also very dependent upon the nature of the ground over which the signal travels. Ground conductivity, terrain roughness and the dielectric constant all affect the signal attenuation. In addition to this the ground penetration varies, becoming greater at lower frequencies, and this means that it is not just the surface conductivity that is of interest. At the higher frequencies this is not of great importance, but at lower frequencies penetration means that ground strata down to 100 meters may have an effect.

Despite all these variables, it is found that terrain with good conductivity gives the best result. Thus soil type and the moisture content are of importance. Salty sea water is the best, and rich agricultural, or marshy land is also good. Dry sandy terrain and city centers are by far the worst. This means sea paths are optimum, although even these are subject to variations due to the roughness of the sea, resulting on path losses being slightly dependent upon the weather. It should also be noted that in view of the fact that signal penetration has an effect, the water table may have an effect dependent upon the frequency in use.

Al Penney
VO1NO

Marconi believed that radio waves would follow the earth's curvature, making communication to ships at sea feasible, and designed an experiment to prove his contention.

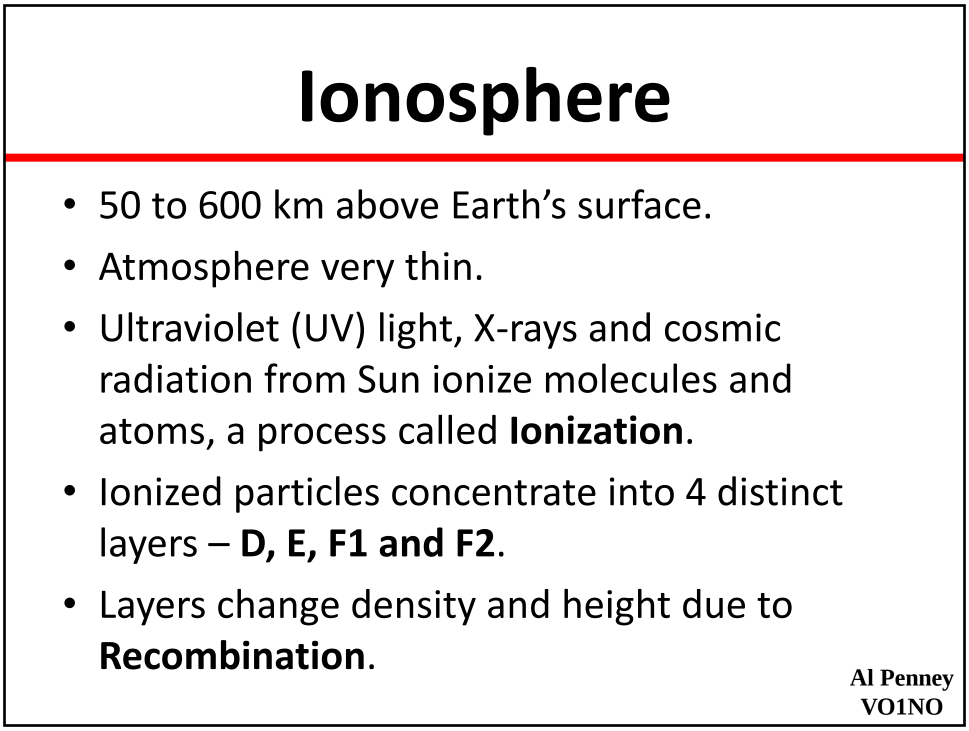
In December 1901 Marconi assembled his receiver at Signal Hill, St. John's, nearly the closest point to Europe in North America. He set up his receiving apparatus in an abandoned hospital that straddled the cliff facing Europe on the top of Signal Hill. After unsuccessful attempts to keep an antenna aloft with balloons and kites, because of the high winds, he eventually managed to raise an antenna with a kite for a short period of time for each of a few days. Accounts vary, but Marconi's notes indicate that the transatlantic message was received via this antenna.

At the appointed time each day his staff in Poldhu transmitted the Morse code letter "s" - three dots. This signal had been chosen as the most easily distinguished. On the 12 December Marconi pressed his ear to the telephone headset of his rudimentary receiver and successfully heard "pip, pip, pip" - slightly more than 2100 miles from the transmitter. This demonstrated that transatlantic wireless communication was possible. While "ground waves" followed the curvature of the earth for only a short distance over the horizon, "sky waves" also bounced off the ionosphere in the upper atmosphere and returned to earth, which although unknown at the time, had allowed Marconi to demonstrate that radio communication over great distances was possible.

Although Marconi had proved that radio transmissions could be received well beyond line of sight, he was not aware of the mechanism that permitted it – the Ionosphere.

The office door was always open to one member of Marconi's staff, namely George Stephen Kemp.

Born in Kent in 1857 he served as an electrician and instructor with the Royal Navy, before working for the Post Office where his boss was William Preece. When Preece realized Marconi's great potential he decided to help him and George Kemp was one of the first men he put to work alongside the young Bolognese. From that moment - July 1896 - Kemp devoted himself entirely to wireless telegraphy, thus becoming Marconi's inseparable assistant. In 1897 he moved from the Post Office to the fledgling Marconi Company, where he worked as «first assistant» for the next thirty six years. Kemp was at Marconi's side for his most memorable achievements, including the first wireless transmission across the Atlantic Ocean, from where in St. John's, Newfoundland they heard the letter 's' in Morse code sent from the Poldhu station in Cornwall.

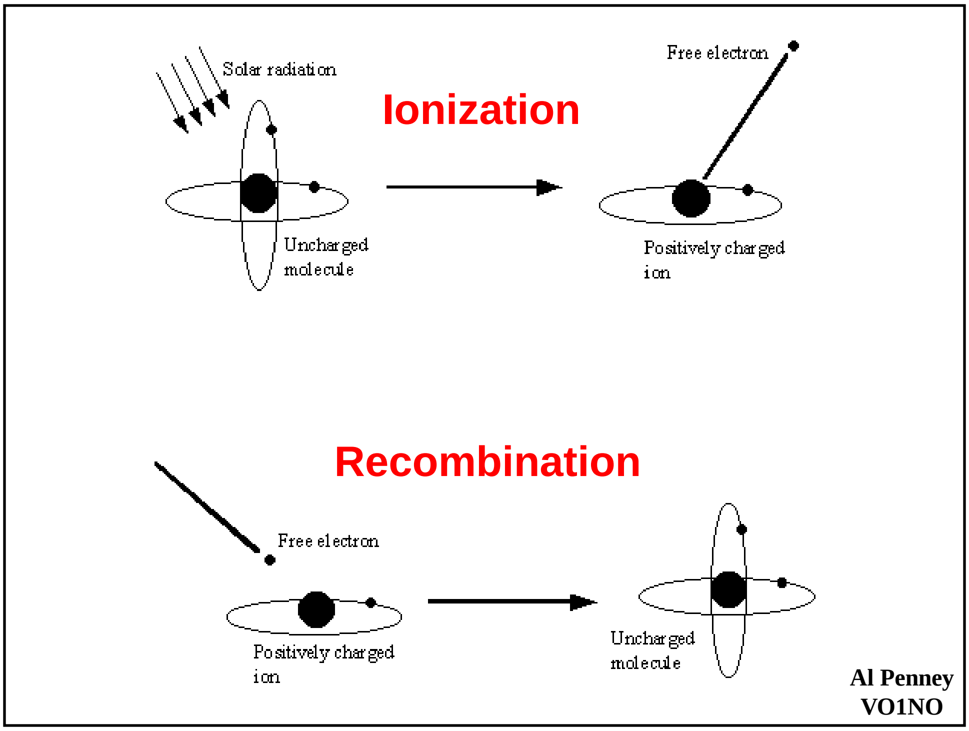


Ionosphere

- 50 to 600 km above Earth’s surface.
- Atmosphere very thin.
- Ultraviolet (UV) light, X-rays and cosmic radiation from Sun ionize molecules and atoms, a process called **Ionization**.
- Ionized particles concentrate into 4 distinct layers – **D, E, F1 and F2**.
- Layers change density and height due to **Recombination**.

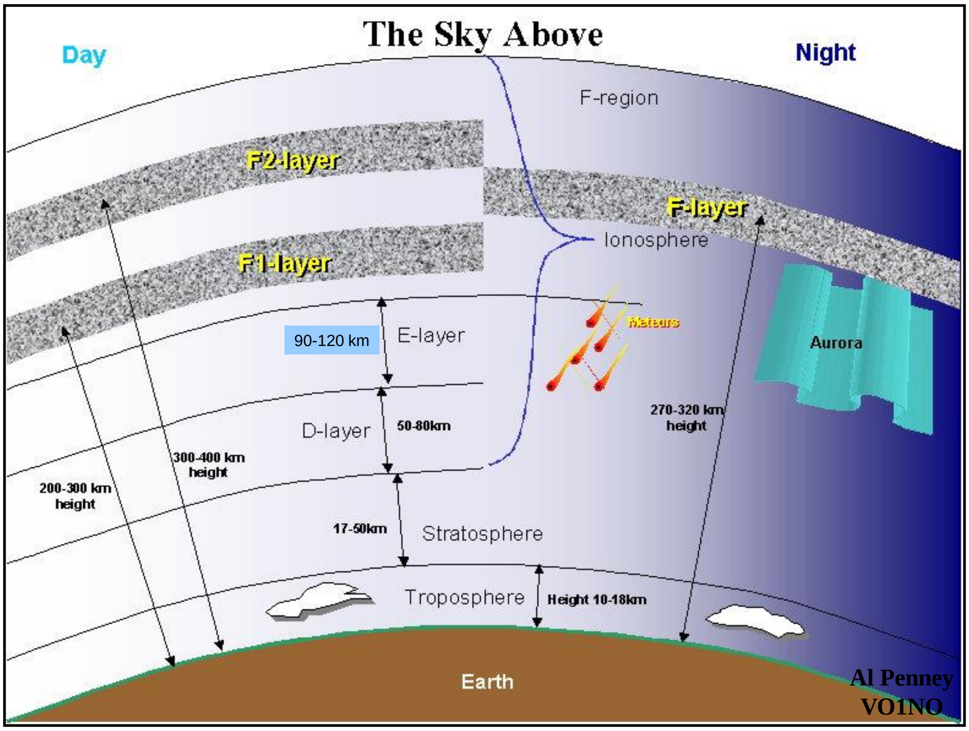
Al Penney
VO1NO

The **ionosphere** is the ionized part of Earth's upper atmosphere, from about 60 km (37 mi) to 1,000 km (620 mi) altitude, a region that includes the thermosphere and parts of the mesosphere and exosphere. The ionosphere is ionized by solar radiation. It plays an important role in atmospheric electricity and forms the inner edge of the magnetosphere. It has practical importance because, among other functions, it influences radio propagation to distant places on the Earth



Al Penney
VO1NO

Ionization or **ionisation**, is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons, often in conjunction with other chemical changes. The resulting electrically charged atom or molecule is called an ion. Ionization can result from the loss of an electron after collisions with subatomic particles, collisions with other atoms, molecules and ions, or through the interaction with electromagnetic radiation.



Due to the ability of ionized atmospheric gases to refract high frequency (HF, or shortwave) radio waves, the ionosphere can reflect radio waves directed into the sky back toward the Earth. Radio waves directed at an angle into the sky can return to Earth beyond the horizon. This technique, called "skip" or "skywave" propagation, has been used since the 1920s to communicate at international or intercontinental distances. The returning radio waves can reflect off the Earth's surface into the sky again, allowing greater ranges to be achieved with multiple hops. This communication method is variable and unreliable, with reception over a given path depending on time of day or night, the seasons, weather, and the 11-year sunspot cycle. During the first half of the 20th century it was widely used for transoceanic telephone and telegraph service, and business and diplomatic communication. Due to its relative unreliability, shortwave radio communication has been mostly abandoned by the telecommunications industry, though it remains important for high-latitude communication where satellite-based radio communication is not possible. Some broadcasting stations and automated services still use shortwave radio frequencies, as do radio amateur hobbyists for private recreational contacts.

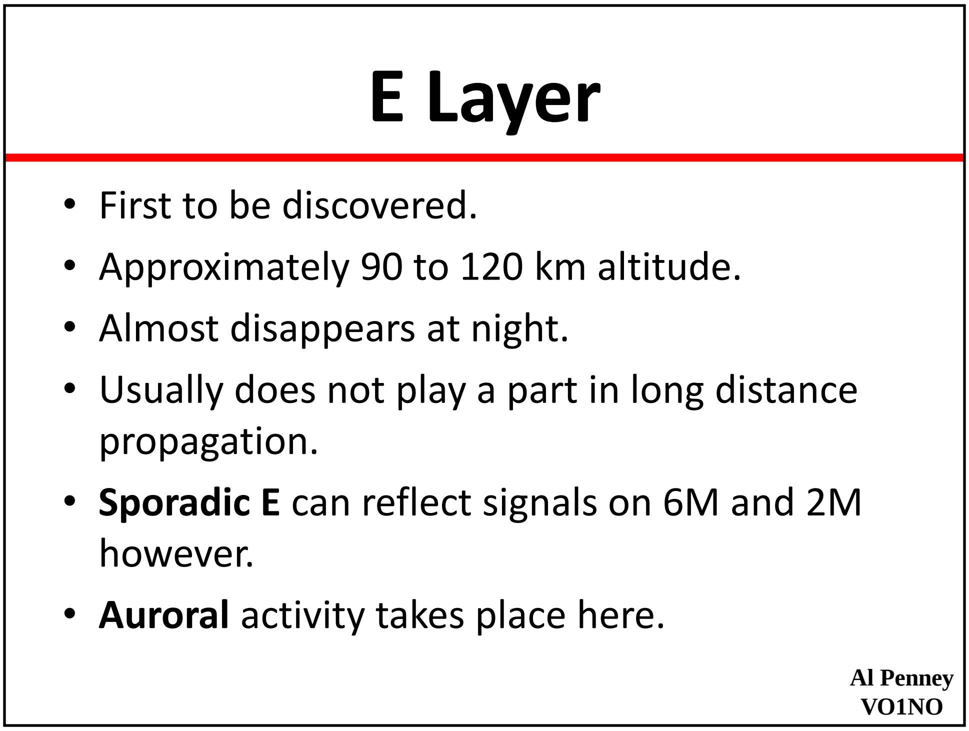
D Layer

- Innermost layer.
- Approximately 50 – 80km altitude.
- **Dense** in daylight, **disappears** at night.
- Not useful for long-distance propagation.
- **Absorbs signals** below approximately 10 MHz.

Al Penney
VO1NO

D layer
The D layer is the innermost layer, 60 km (37 mi) to 90 km (56 mi) above the surface of the Earth. Ionization here is due to Lyman series-alpha hydrogen radiation at a wavelength of 121.5 nanometre (nm) ionizing nitric oxide (NO). In addition, with high Solar activity hard X-rays (wavelength < 1 nm) may ionize (N_2, O_2). During the night cosmic rays produce a residual amount of ionization. Recombination is high in the D layer, the net ionization effect is low, but loss of wave energy is great due to frequent collisions of the electrons (about ten collisions every msec). As a result high-frequency (HF) radio waves are not reflected by the D layer but suffer loss of energy therein. This is the main reason for absorption of HF radio waves, particularly at 10 MHz and below, with progressively smaller absorption as the frequency gets higher. The absorption is small at night and greatest about midday. The layer reduces greatly after sunset; a small part remains due to galactic cosmic rays. A common example of the D layer in action is the disappearance of distant AM broadcast band stations in the daytime.

During solar proton events, ionization can reach unusually high levels in the D-region over high and polar latitudes. Such very rare events are known as Polar Cap Absorption (or PCA) events, because the increased ionization significantly enhances the absorption of radio signals passing through the region. In fact, absorption levels can increase by many tens of dB during intense events, which is enough to absorb most (if not all) transpolar HF radio signal transmissions. Such events typically last less than 24 to 48 hours.



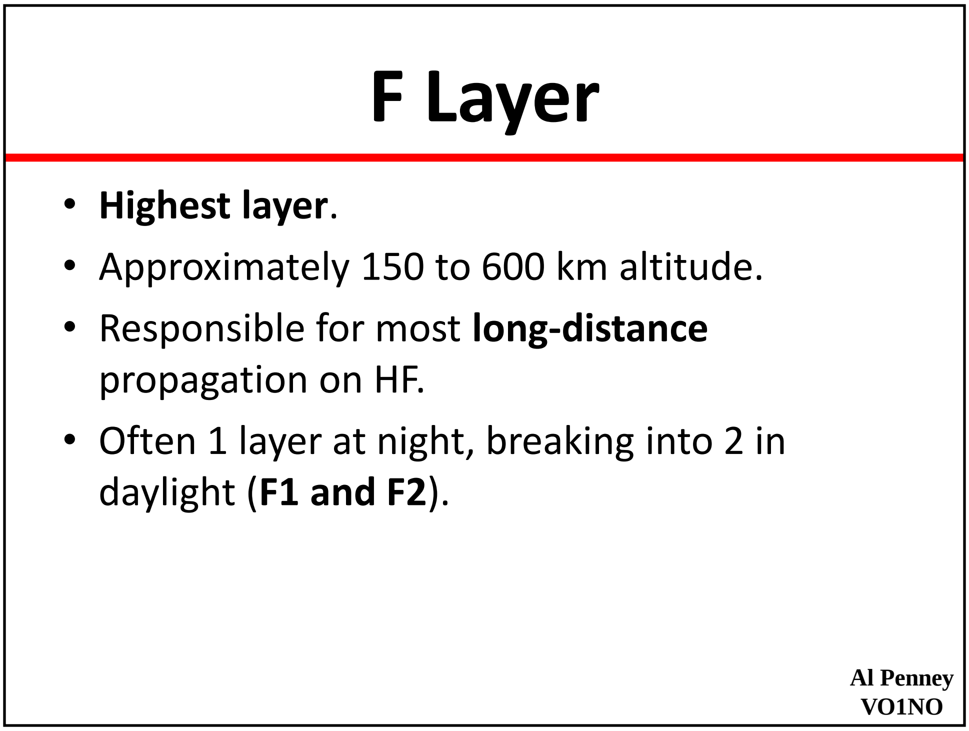
E Layer

- First to be discovered.
- Approximately 90 to 120 km altitude.
- Almost disappears at night.
- Usually does not play a part in long distance propagation.
- **Sporadic E** can reflect signals on 6M and 2M however.
- **Auroral** activity takes place here.

Al Penney
VO1NO

E layer
The E layer is the middle layer, 90 km (56 mi) to 120 km (75 mi) above the surface of the Earth. Ionization is due to soft X-ray (1-10 nm) and far ultraviolet (UV) solar radiation ionization of molecular oxygen (O_2). Normally, at oblique incidence, this layer can only reflect radio waves having frequencies lower than about 10 MHz and may contribute a bit to absorption on frequencies above. However, during intense Sporadic E events, the E_s layer can reflect frequencies up to 50 MHz and higher. The vertical structure of the E layer is primarily determined by the competing effects of ionization and recombination. At night the E layer rapidly disappears because the primary source of ionization is no longer present. After sunset an increase in the height of the E layer maximum increases the range to which radio waves can travel by reflection from the layer.

This region is also known as the Kennelly–Heaviside layer or simply the Heaviside layer. Its existence was predicted in 1902 independently and almost simultaneously by the American electrical engineer Arthur Edwin Kennelly (1861–1939) and the British physicist Oliver Heaviside (1850–1925). However, it was not until 1924 that its existence was detected by Edward V. Appleton.

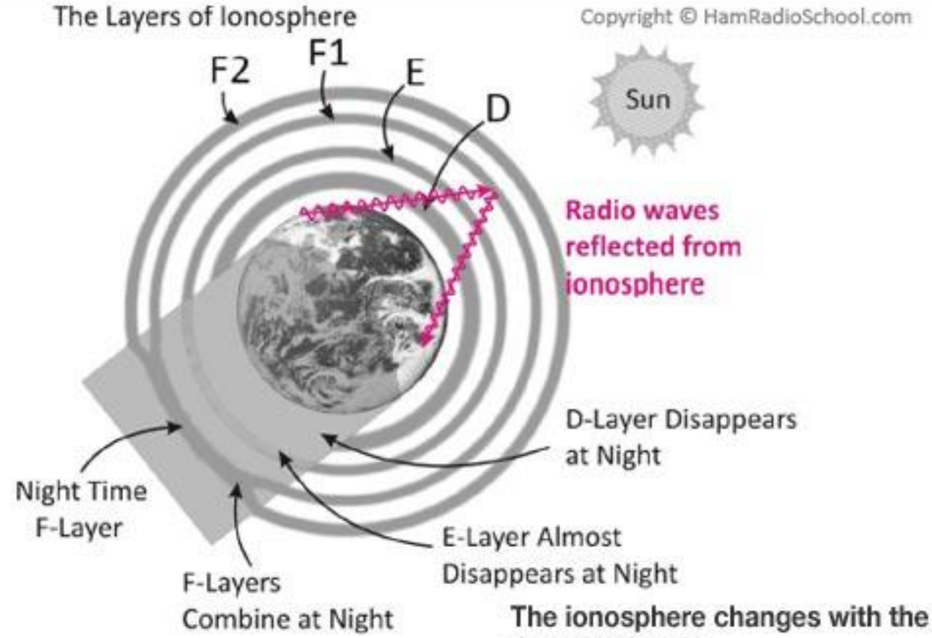


F Layer

- **Highest layer**.
- Approximately 150 to 600 km altitude.
- Responsible for most **long-distance** propagation on HF.
- Often 1 layer at night, breaking into 2 in daylight (**F1 and F2**).

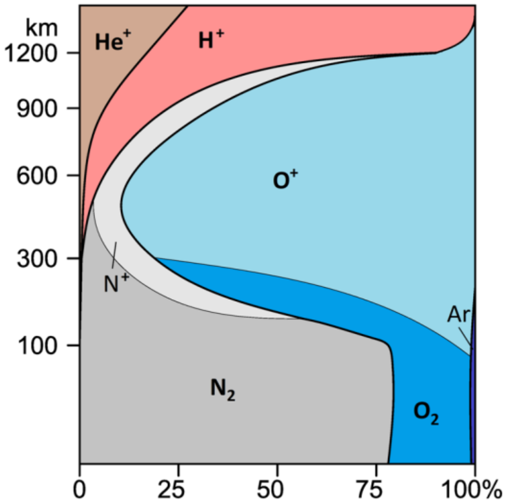
Al Penney
VO1NO

F layer
The F layer or region, also known as the Appleton layer, extends from about 200 km (120 mi) to more than 500 km (310 mi) above the surface of Earth. It is the densest point of the ionosphere, which implies signals penetrating this layer will escape into space. At higher altitudes, the number of oxygen ions decreases and lighter ions such as hydrogen and helium become dominant; this layer is the topside ionosphere. There, extreme ultraviolet (UV, 10–100 nm) solar radiation ionizes atomic oxygen. The F layer consists of one layer at night, but during the day, a deformation often forms in the profile that is labeled F_1. **The F_2 layer remains by day and night responsible for most skywave propagation of radio waves**, facilitating high frequency (HF, or shortwave) radio communications over long distances.
From 1972 to 1975 NASA launched the AEROS and AEROS B satellites to study the F region.



The ionosphere changes with the day-night cycle.

Why Different Layers?



- Composition of Earth’s atmosphere changes with altitude.
- Different gasses are ionized at different altitude’s because of the degree of penetration into the atmosphere by the Sun’s ionizing radiation.

Al Penney
VO1NO

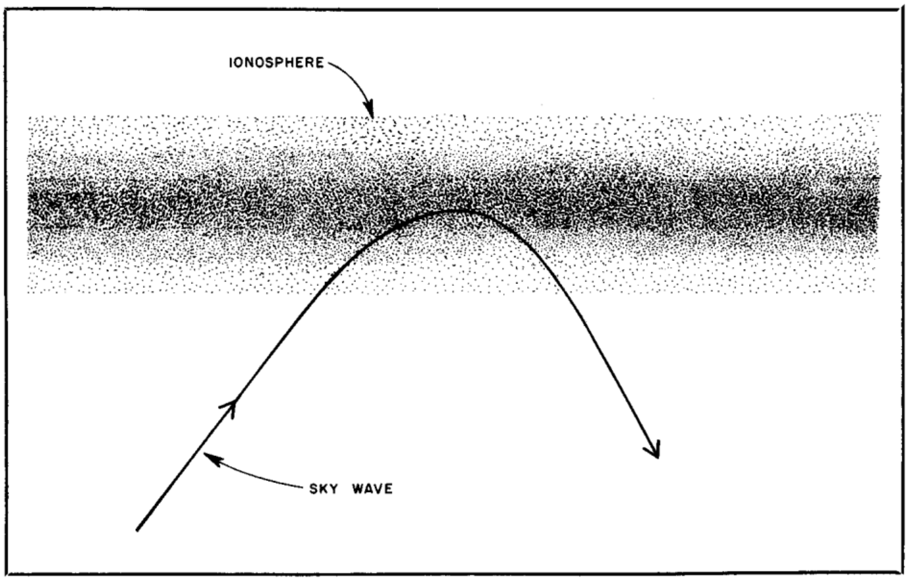


Fig. 2 — Under proper conditions, a radio wave entering the ionosphere will be refracted and follow a new course. This permits the signal to be heard on earth, perhaps thousands of miles from the transmitting antenna.

Al Penney
VO1NO

Refraction is the bending of a ray as it passes from one medium to another at an angle. The appearance of bending of a straight stick, where it enters water at an angle, is an example of light refraction known to us all.

Mechanism of refraction

When a radio wave reaches the ionosphere, the electric field in the wave forces the electrons in the ionosphere into oscillation at the same frequency as the radio wave. Some of the radio-frequency energy is given up to this resonant oscillation. The oscillating electrons will then either be lost to recombination or will re-radiate the original wave energy. Total refraction can occur when the collision frequency of the ionosphere is less than the radio frequency, and if the electron density in the ionosphere is great enough.

A qualitative understanding of how an electromagnetic wave propagates through the ionosphere can be obtained by recalling geometric optics. Since the ionosphere is a plasma, it can be shown that the refractive index is less than unity. Hence, the electromagnetic "ray" is bent away from the normal rather than toward the normal as would be indicated when the refractive index is greater than unity. It can also be shown that the refractive index of a plasma, and hence the ionosphere, is frequency-dependent,

What Causes Refraction?

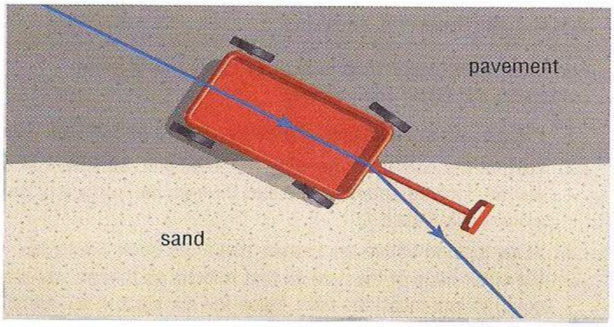


Figure 3 A wagon changes direction when travelling at an angle from pavement onto sand because one front wheel slows down while the other wheels continue moving at a higher speed.

Al Penney
VO1NO

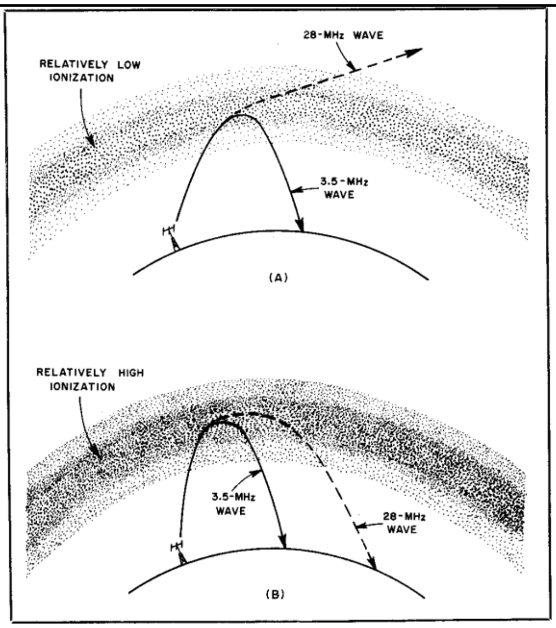
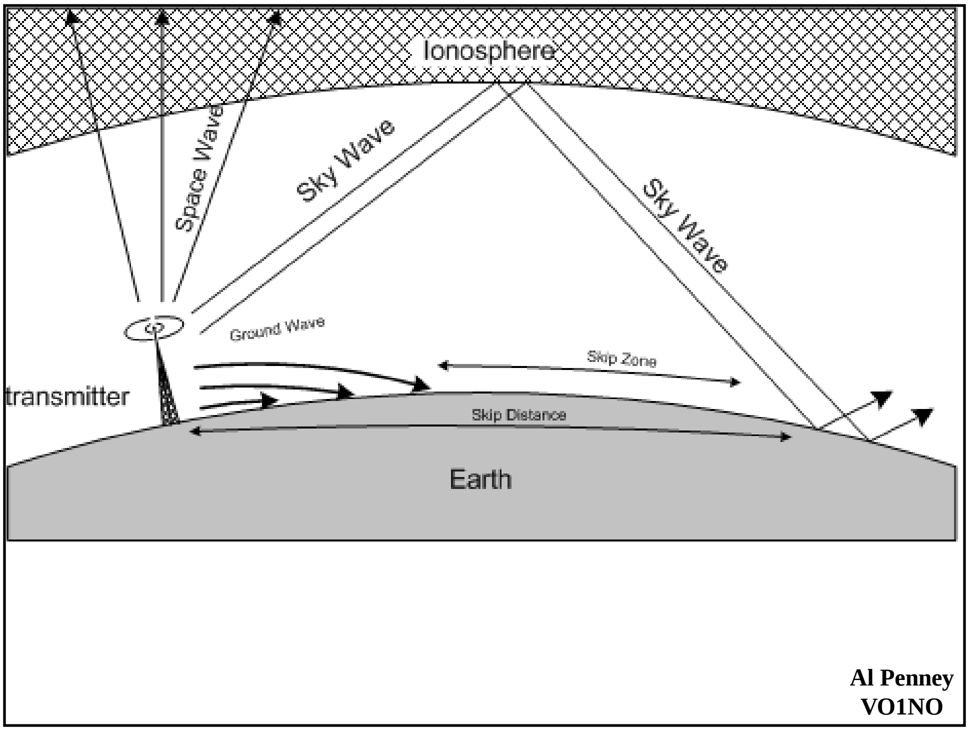


Fig. 5 — In A, the low-level ionization is insufficient to bend the 28-MHz wave back to earth; the level is high enough for 3.5-MHz propagation. Higher-level ionization in B is sufficient to refract the 28-MHz wave to earth.

Al Penney
VO1NO

The degree of bending of a wave path in an ionized layer depends on the density of the ionization and the frequency.

The bending at any given frequency or wavelength will increase with increased ionization density. For a given ionization density, bending will decreases with frequency. Two extremes are thus possible. If the intensity of the ionization is sufficient and the frequency low enough, even a wave entering the layer perpendicularly will be reflected back to Earth. Conversely, if the frequency is high enough or the ionization decreases to a low enough density, a condition is reached where the wave angle is not affected enough by the ionosphere to cause a useful portion of the wave energy to return to the Earth. This basic principle has been used for many years to “sound” the ionosphere to determine its communication potential at various wave angles and frequencies.

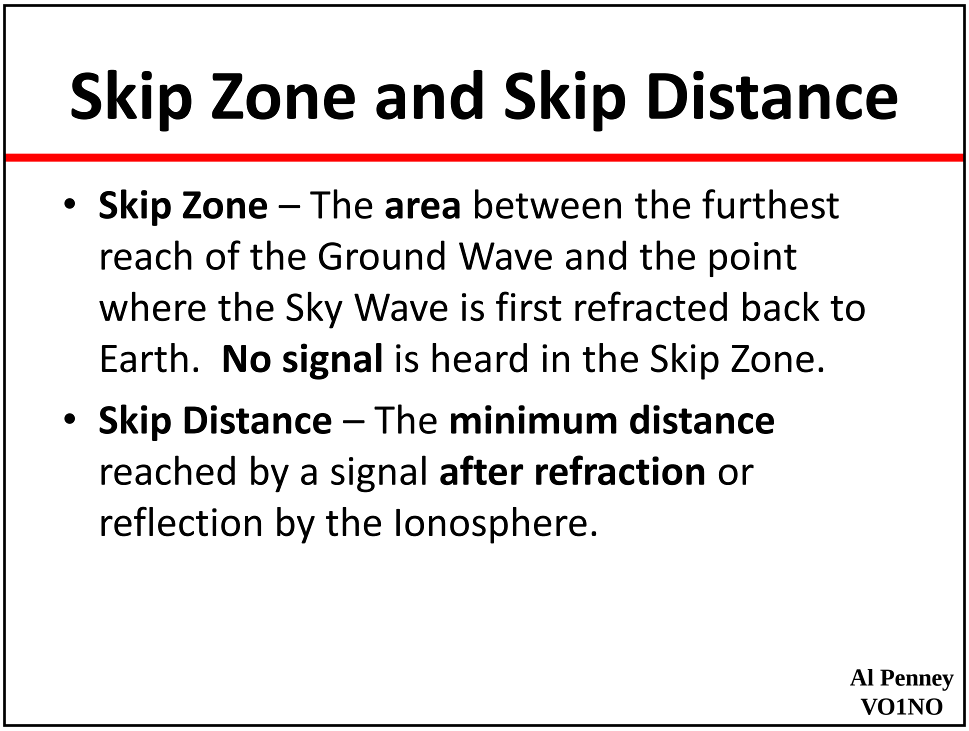


Al Penney
VO1NO

Because the skywave can be refracted back to Earth a long distance from the transmit antenna, the may be a region between the extent of the ground wave from the antenna to the point where the skywave is first refracted back to Earth where there is no signal.

Skip Zone – The **area** between the furthest reach of the Ground Wave and the point where the Sky Wave is first refracted back to Earth. **No signal** is heard in the Skip Zone.

Skip Distance – The **minimum distance** reached by a signal **after refraction** or reflection by the Ionosphere.



Skip Zone and Skip Distance

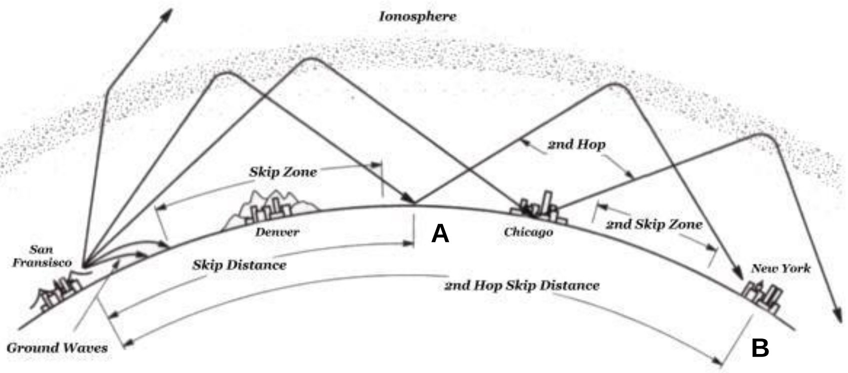
- **Skip Zone** – The **area** between the furthest reach of the Ground Wave and the point where the Sky Wave is first refracted back to Earth. **No signal** is heard in the Skip Zone.
- **Skip Distance** – The **minimum distance** reached by a signal **after refraction** or reflection by the Ionosphere.

Al Penney
VO1NO

Skip Distance

When the critical angle is less than 90° there will always be a region around the transmitting site where the ionospherically propagated signal cannot be heard, or is heard weakly. This area lies between the outer limit of the ground-wave range and the inner edge of energy return from the ionosphere. It is called the *skip zone*, and the distance between the originating site and the beginning of the ionospheric return is called the skip distance. This terminology should not to be confused with ham jargon such as “the skip is in,” referring to the fact that a band is open for sky-wave propagation.

The signal may often be heard to some extent within the skip zone, through various forms of scattering, but it will ordinarily be marginal in strength. When the skip distance is short, both groundwave and sky-wave signals may be received near the transmitter. In such instances the sky wave frequently is stronger than the ground wave, even as close as a few miles from the transmitter. The ionosphere is an efficient communication medium under favorable conditions. Comparatively, the ground wave is not.

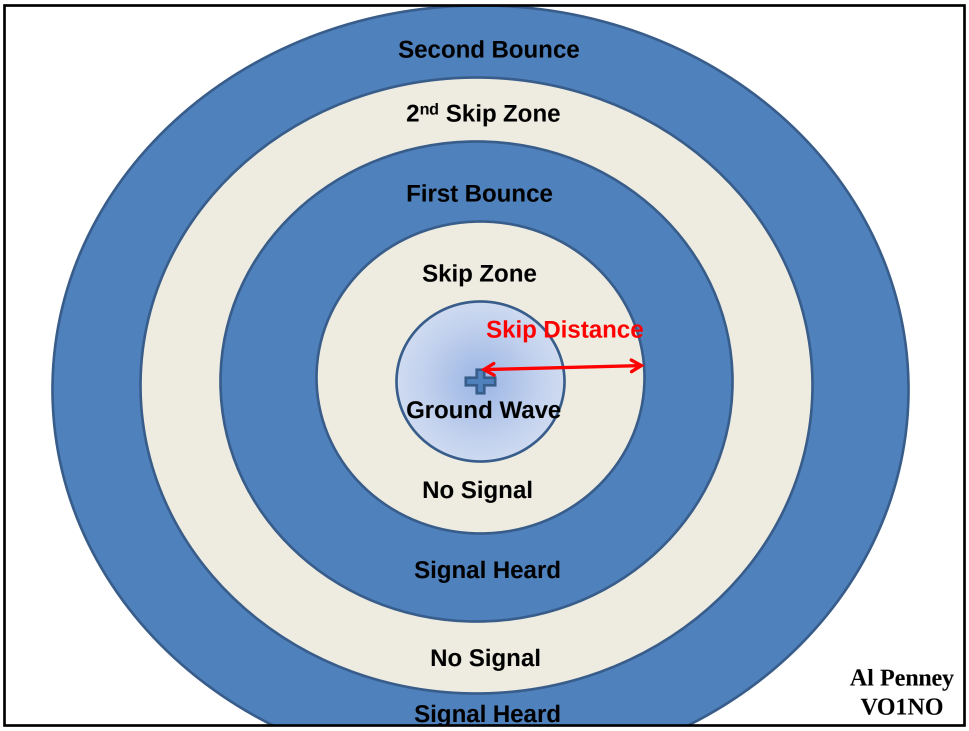


Al Penney
VO1NO

Signals that have been refracted back to Earth can also be reflected back up to the ionosphere and be refracted back to earth again. Under the right conditions, this can take place several times, permitting signals to travel completely around the globe.

A radio signal will often be reflected from the reception point on the Earth into the ionosphere again, reaching the Earth a second time at a still more distant point. As in the case of light waves, the angle of reflection is the same as the angle of incidence, so a wave striking the surface of the Earth at an angle of, say, 15° is reflected upward from the surface at approximately the same angle. Thus, the distance to the second point of reception will be about twice the distance of the first. Under some conditions it is possible for as many as four or five signal hops to occur over a radio path, but no more than two or three hops is the norm. In this way, HF communication can be conducted over thousands of miles.

An important point should be recognized with regard to signal hopping. A significant loss of signal occurs with each hop. The D and E layers of the ionosphere absorb energy from the signals as they pass through, and the ionosphere tends to scatter the radio energy in various directions, rather than confining it in a tight bundle. The roughness of the Earth’s surface also scatters the energy at a reflection point. at greater distances. It is because of these losses that no more than four or five propagation hops are useful; the received signal becomes too weak to be usable over more hops. Although modes other than signal hopping also account for the propagation of radio waves over thousands of miles, backscatter studies of actual radio propagation have displayed signals with as many as 5 hops. So the hopping mode is one distinct possibility for long-distance communication.



Perfect case – it never actually happens this way because the ionosphere is not uniform around a transmitter, and because of scatter propagation.

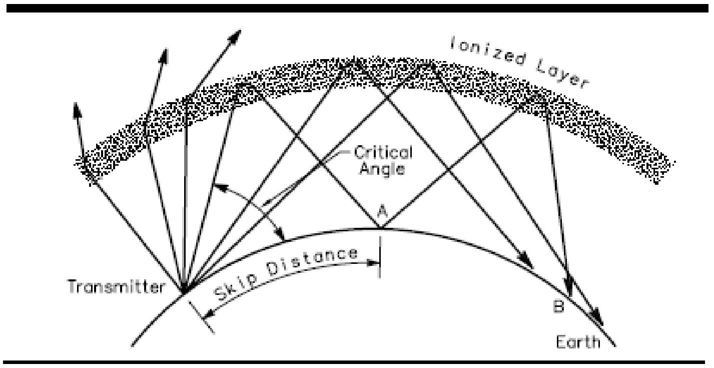
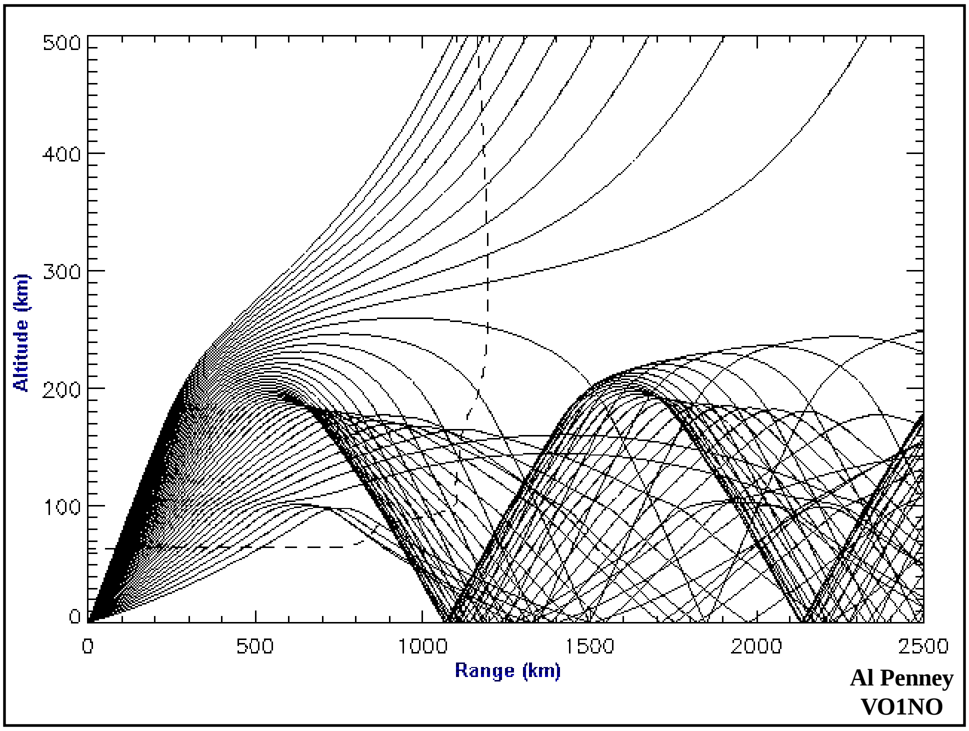


Fig 18—Behavior of waves encountering the ionosphere. Rays entering the ionized region at angles above the critical angle are not bent enough to be returned to Earth, and are lost to space. Waves entering at angles below the critical angle reach the Earth at increasingly greater distances as the launch angle approaches the horizontal. The maximum distance that may normally be covered in a single hop is 4000 km. Greater distances are covered with multiple hops.

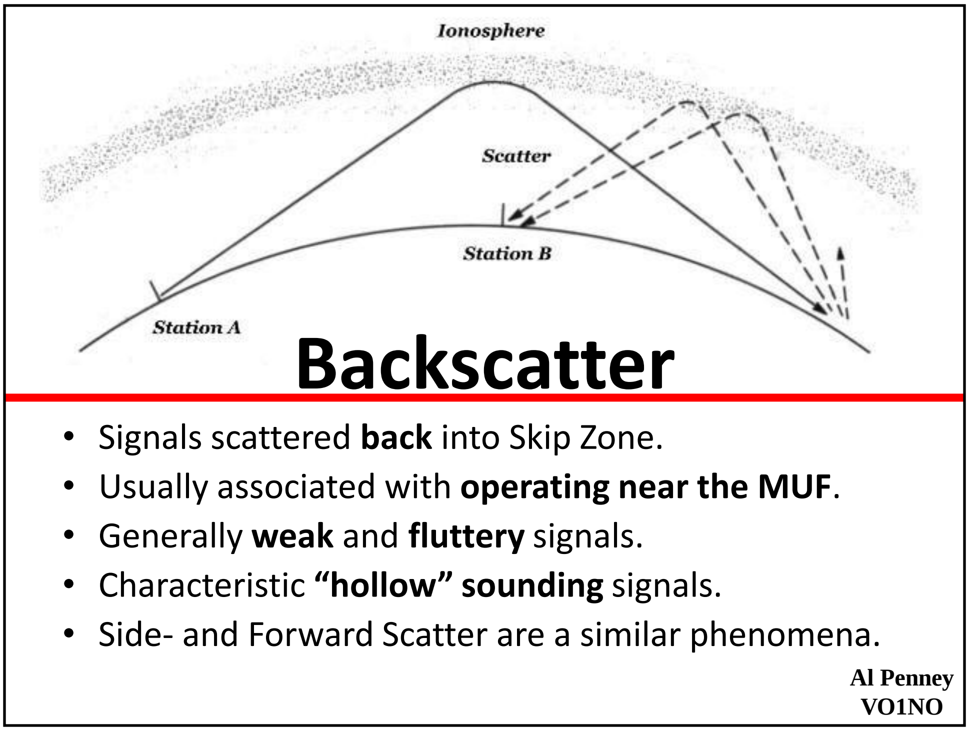
Al Penney
VO1NO

It is possible for a signal to take more than one route to get to the receiver. In the diagram above, lower angle signals will reach the receiver after only one refraction through the ionosphere. Higher angle signals (assuming they are less than the Critical angle – the angle above which signals are refracted into space and do not reach Earth) can be reflected back into the ionosphere and then refracted back to Earth again.

Assuming that both waves do reach point B in the figure above, the low-angle wave will contain more energy at point B. This wave passes through the lower layers just twice, compared to the higher-angle route, which must pass through these layers four times, plus encountering an Earth reflection. Measurements indicate that although there can be great variation in the relative strengths of the two signals— the one-hop signal will generally be from 7 to 10 dB stronger. The nature of the terrain at the mid-path reflection point for the two-hop wave, the angle at which the wave is reflected from the Earth, and the condition of the ionosphere in the vicinity of all the refraction points are the primary factors in determining the signal-strength ratio. The loss per hop becomes significant.



Actual example of propagation ray paths, between Hawaii and West coast. Note refraction from both the E and F layers. The first Skip Zone is distinct, but the next one is not as definite, with some level of signal present. Note also the Critical Angle, above which signals escape into space.



Backscatter

- Signals scattered **back** into Skip Zone.
- Usually associated with **operating near the MUF**.
- Generally **weak** and **fluttery** signals.
- Characteristic **“hollow” sounding** signals.
- Side- and Forward Scatter are a similar phenomena.

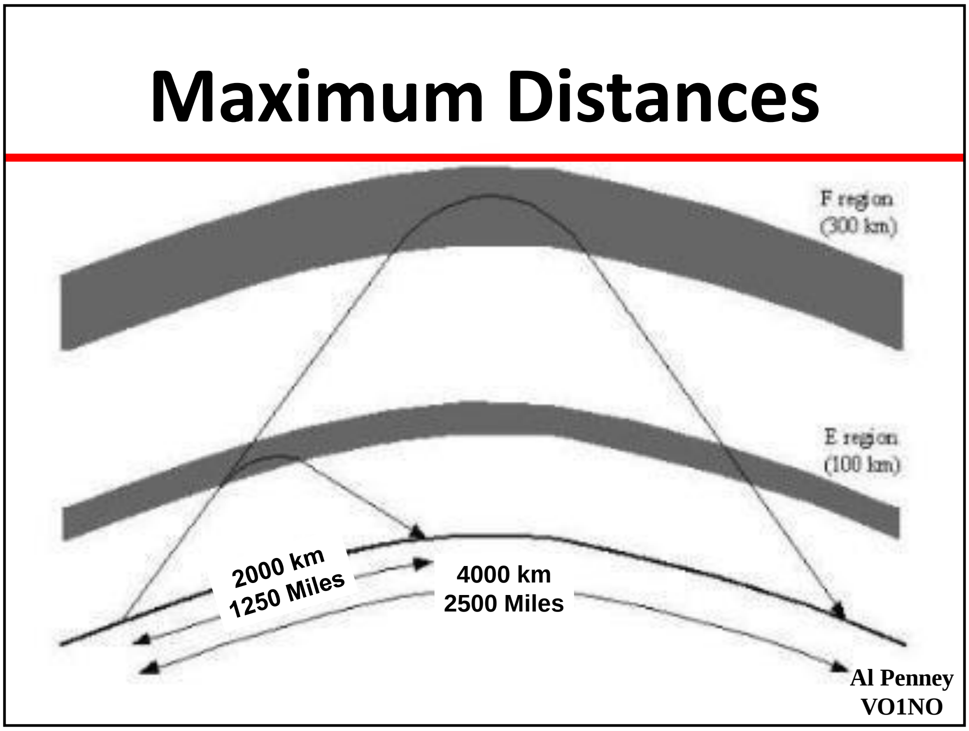
Al Penney
VO1NO

F-Layer Backscatter and Sidescatter

Special forms of F-layer scattering can create unusual paths within the skip zone. *Backscatter* and *sidescatter* signals are usually observed just below the MUF for the direct path and allow communications not normally possible by other means. Stations using backscatter point their antennas toward a common scattering region at the one-hop distance, rather than toward each other. Backscattered signals are generally weak and have a characteristic hollow sound. Useful communication distances range from 100 km (60 mi) to the normal one-hop distance of 4000 km (2500 mi).

Backscatter and sidescatter are closely related and the terminology does not precisely distinguish between the two. Backscatter usually refers to single-hop signals that have been scattered by the Earth or the ocean at some distant point back toward the transmitting station. Two stations spaced a few hundred km apart can often communicate via a backscatter path near the MUF.

Sidescatter usually refers to a circuit that is oblique to the normal great-circle path. Two stations can make use of a common side-scattering region well off the direct path, often toward the south. European and North American stations sometimes complete 28-MHz contacts via a scattering region over Africa. US and Finnish 50-MHz operators observed a similar effect early one morning in November 1989 when they made contact by beaming off the coast of West Africa.



Maximum Distances

Al Penney
VO1NO

Maximum 1-hop distance a signal can reach off **F2 layer** is **4000 km / 2500 miles** (For exam – in reality it can go to ~ 4800 km).

Maximum 1-hop distance a signal can reach off **E layer** is **2000 km / 1250 miles**.

The lower the angle of radiation of the EM wave from the transmit antenna, the further away the signal will travel (assuming it is refracted back to earth).

The higher the refracting layer, the further away the signal will travel (assuming it is refracted back to earth).

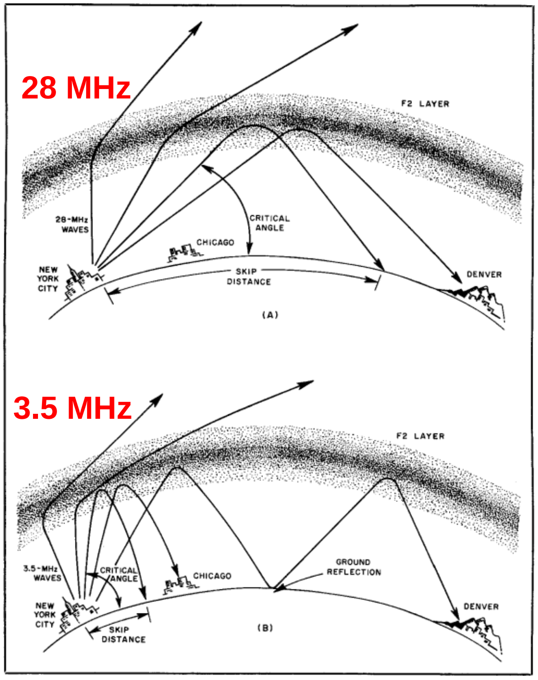
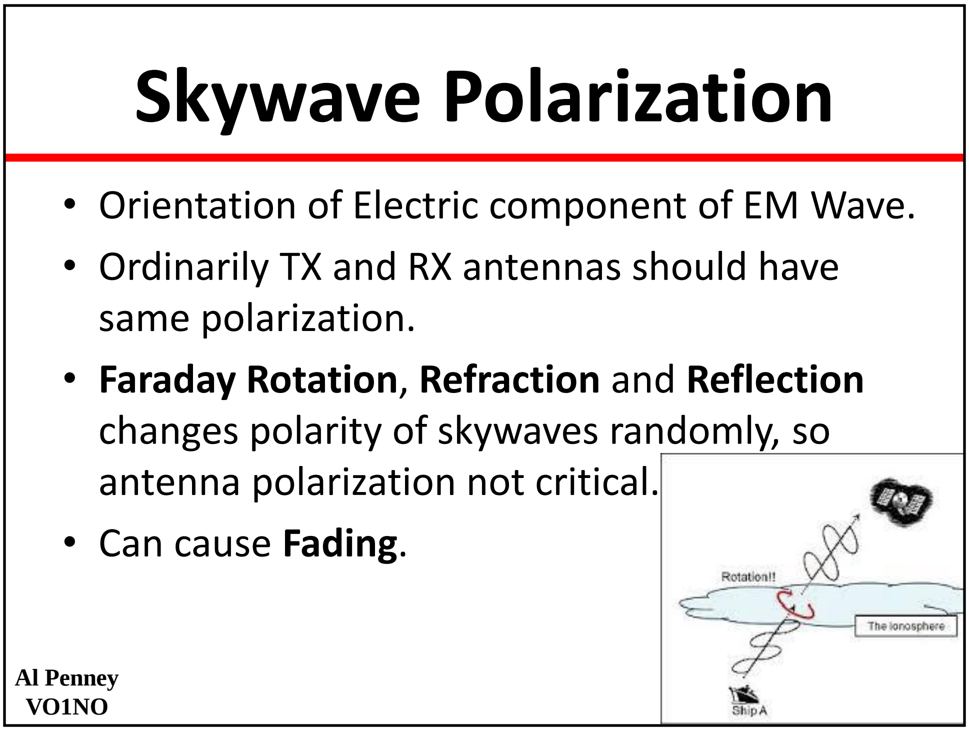


Fig. 6 — Illustration of how frequency, critical angle and skip distance are related. See text for explanation.

Al Penney
VO1NO

Lower frequency signals are refracted more for a given level of ionization, meaning the Critical Angle is greater for lower frequencies than higher frequencies. The lower frequency signals return to the ground at closer distances however, meaning **that multiple "hops" may be required to reach the target area. This results in weaker signal strength.**

Because the lower frequencies are refracted more, the skip distance is less, meaning communications can be established with stations closer to the transmitter than would be possible with higher frequencies.



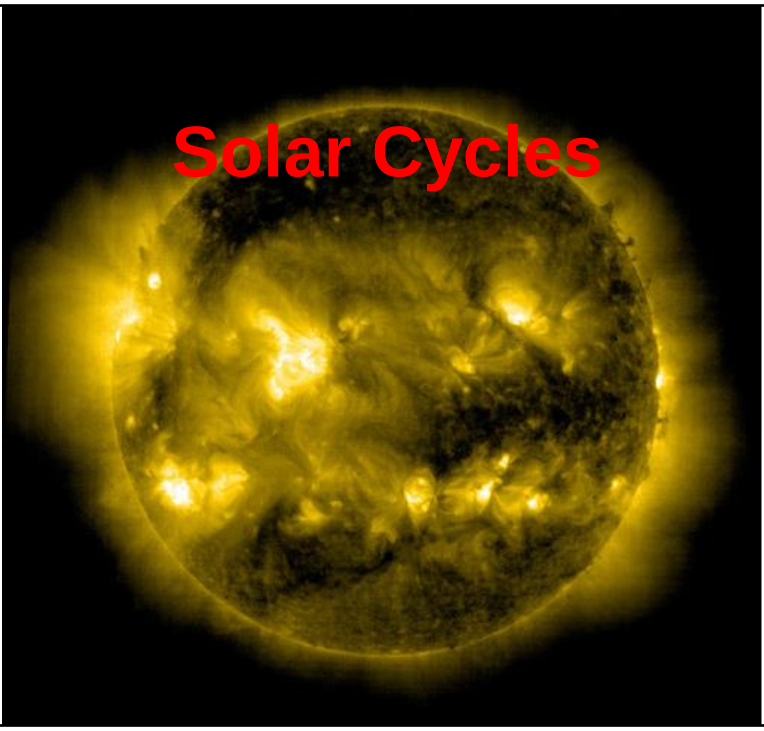
Skywave Polarization

- Orientation of Electric component of EM Wave.
- Ordinarily TX and RX antennas should have same polarization.
- **Faraday Rotation**, **Refraction** and **Reflection** changes polarity of skywaves randomly, so antenna polarization not critical.
- Can cause **Fading**.

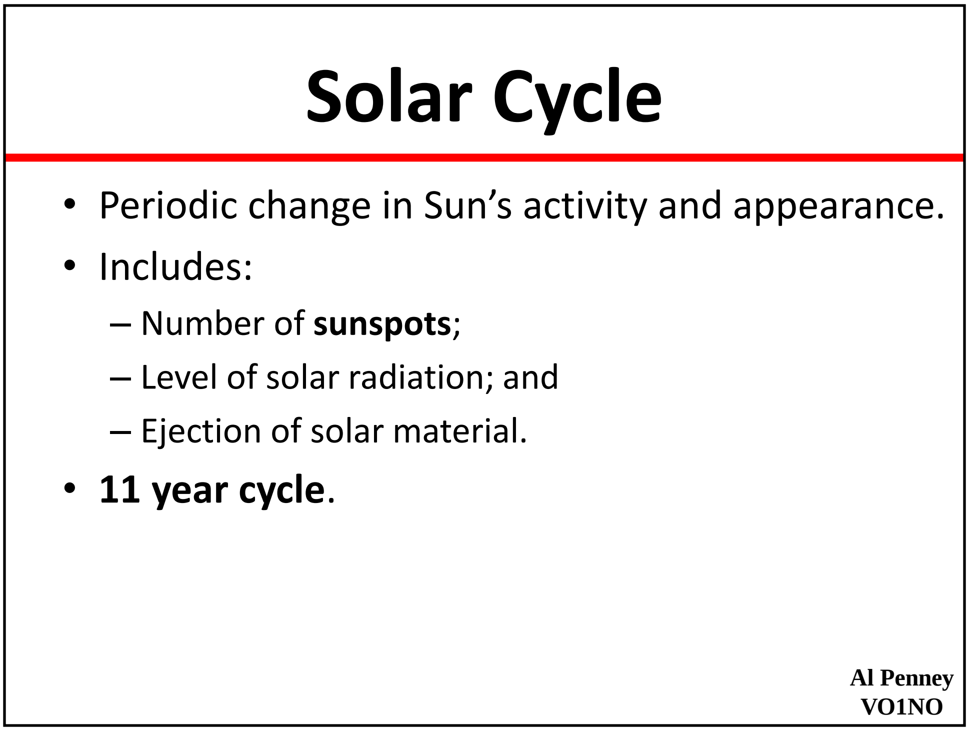
Al Penney
VO1NO

Radio waves passing through the Earth's ionosphere are likewise subject to the Faraday effect. In conjunction with the earth's magnetic field, rotation of the polarization of radio waves occurs. Since the density of electrons in the ionosphere varies greatly on a daily basis, as well as over the sunspot cycle, the magnitude of the effect varies. However the effect is always proportional to the square of the wavelength, so even at the UHF television frequency of 500 MHz ($\lambda = 60$ cm), there can be more than a complete rotation of the axis of polarization. A consequence is that although most radio transmitting antennas are either vertically or horizontally polarized, the polarization of a medium or short wave signal after reflection by the ionosphere is rather unpredictable. However the Faraday effect due to free electrons diminishes rapidly at higher frequencies (shorter wavelengths) so that at microwave frequencies, used by satellite communications, the transmitted polarization is maintained between the satellite and the ground.

Solar Cycles



Al Penney
VO1NO



Solar Cycle

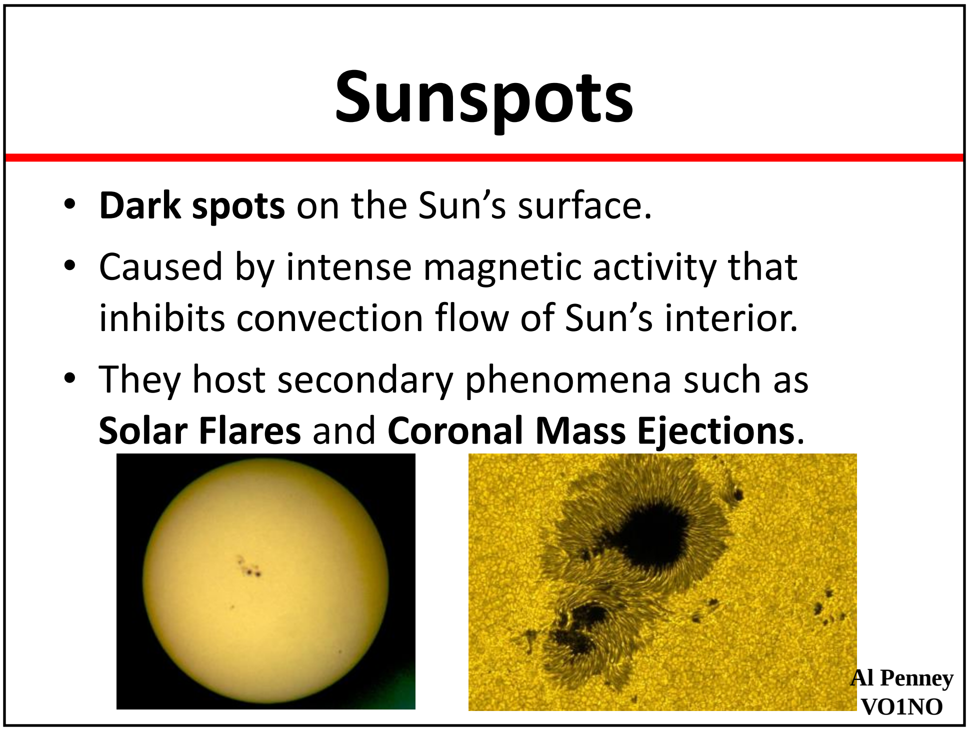
- Periodic change in Sun’s activity and appearance.
- Includes:
  - Number of **sunspots**;
  - Level of solar radiation; and
  - Ejection of solar material.
- **11 year cycle**.

Al Penney
VO1NO

The **solar cycle** or **solar magnetic activity cycle** is a nearly periodic 11-year change in the Sun's activity measured in terms of variations in the number of observed sunspots on the solar surface. Sunspots have been observed since the early 17th century and the sunspot time series is the longest, continuously observed (recorded) time series of any natural phenomena. Accompanying the 11 year quasi-periodicity in sunspots, the large-scale dipolar (north-south) magnetic field component of the Sun also flips every 11 years, however, the peak in the dipolar field lags the peak in the sunspot number, with the former occurring at the minimum between two cycles. Levels of solar radiation and ejection of solar material, the number and size of sunspots, solar flares, and coronal loops all exhibit a synchronized fluctuation, from active to quiet to active again, with a period of 11 years. This cycle has been observed for centuries by changes in the Sun's appearance and by terrestrial phenomena such as auroras. Solar activity, driven both by the sunspot cycle and transient aperiodic processes govern the environment of the Solar System planets by creating space weather and impact space- and ground-based technologies as well as the Earth's atmosphere and also possibly climate fluctuations on scales of centuries and longer.

Understanding and predicting the sunspot cycle remains one of the grand challenges in astrophysics with major ramifications for space science and the understanding of magnetohydrodynamic phenomena elsewhere in the Universe.

Solar cycles have an average duration of about 11 years. Solar maximum and solar minimum refer to periods of maximum and minimum sunspot counts. Cycles span from one minimum to the next.



Sunspots

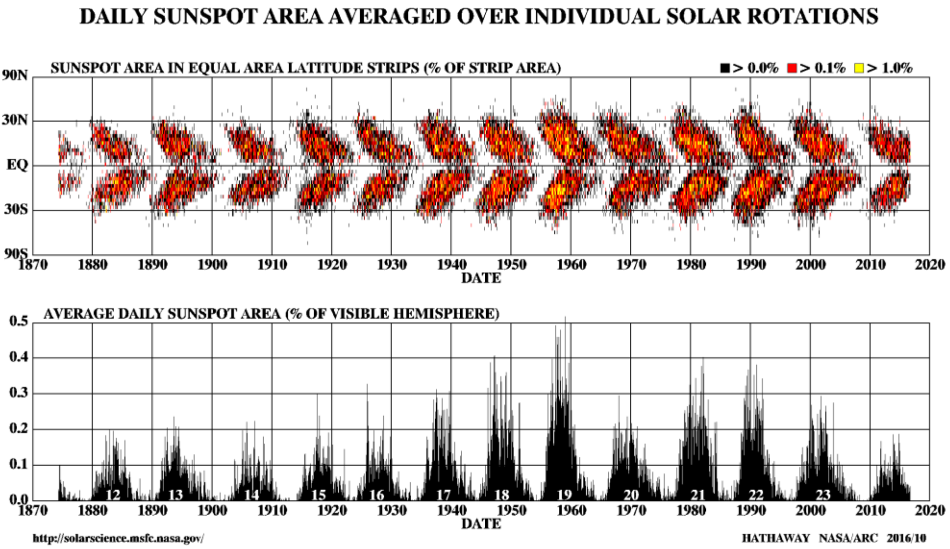
- **Dark spots** on the Sun’s surface.
- Caused by intense magnetic activity that inhibits convection flow of Sun’s interior.
- They host secondary phenomena such as **Solar Flares** and **Coronal Mass Ejections**.

Al Penney
VO1NO

Sunspots are temporary phenomena on the photosphere of the Sun that appear visibly as dark spots compared to surrounding regions. They are caused by intense magnetic activity, which inhibits convection by an effect comparable to the eddy current brake, forming areas of reduced surface temperature. They usually appear as pairs, with each sunspot having the opposite magnetic pole to the other.

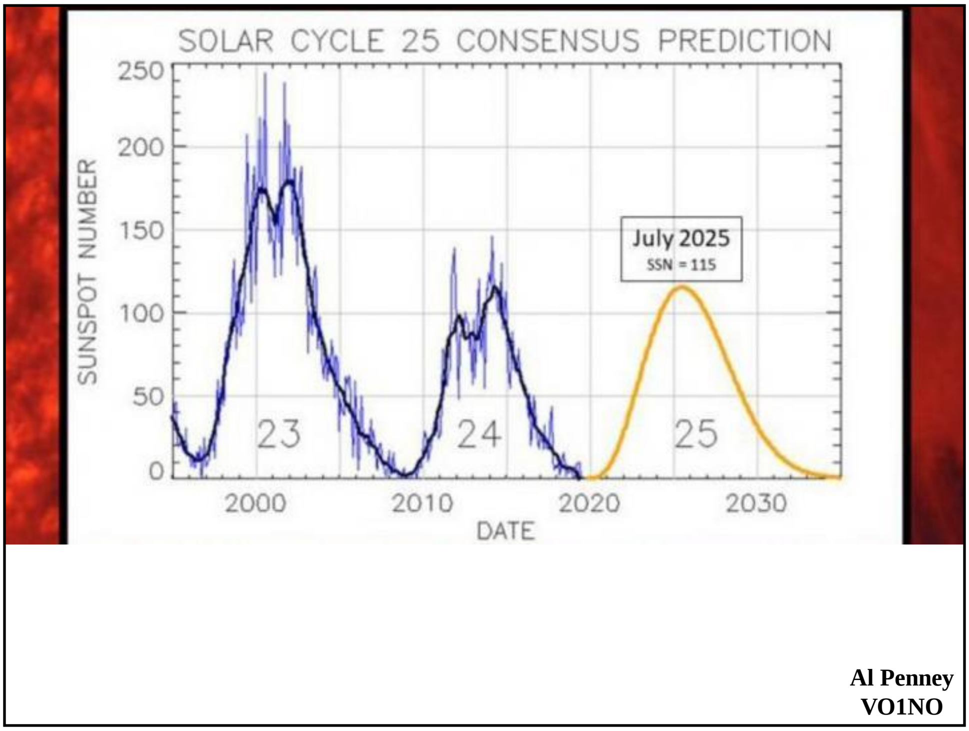
Although they are at temperatures of roughly 3000–4500 K (2700–4200 °C), the contrast with the surrounding material at about 5,780 K (5,500 °C) leaves them clearly visible as dark spots, as the luminous intensity of a heated black body (closely approximated by the photosphere) is a function of temperature to the fourth power. If the sunspot were isolated from the surrounding photosphere it would be brighter than the Moon. Sunspots expand and contract as they move across the surface of the Sun and can be as small as 16 kilometers (10 mi) and as large as 160,000 kilometers (100,000 mi) in diameter, making the larger ones visible from Earth without the aid of a telescope. They may also travel at relative speeds ("proper motions") of a few hundred meters per second when they first emerge onto the solar photosphere.
Manifesting intense magnetic activity, sunspots host secondary phenomena such as coronal loops (prominences) and reconnection events. Most solar flares and coronal mass ejections originate in magnetically active regions around visible sunspot groupings. Similar phenomena indirectly observed on stars are commonly called starspots and both light and dark spots have been measured.

The sun is mostly composed of the elements hydrogen (H) and helium (He). By mass the composition of the sun is 92.1% hydrogen and 7.9% helium. Various metals make up less than 0.1% of the mass of the sun. The temperature of the sun's surface is about 10,340 degrees Fahrenheit (5,726 degrees Celsius).



Al Penney
VO1NO

Detailed observations of sunspots have been obtained by the Royal Greenwich Observatory since 1874. These observations include information on the sizes and positions of sunspots as well as their numbers. These data show that sunspots do not appear at random over the surface of the sun but are concentrated in two latitude bands on either side of the equator. A butterfly diagram (142 kb GIF image) (184 kb pdf-file) (updated monthly) showing the positions of the spots for each rotation of the sun since May 1874 shows that these bands first form at mid-latitudes, widen, and then move toward the equator as each cycle progresses.

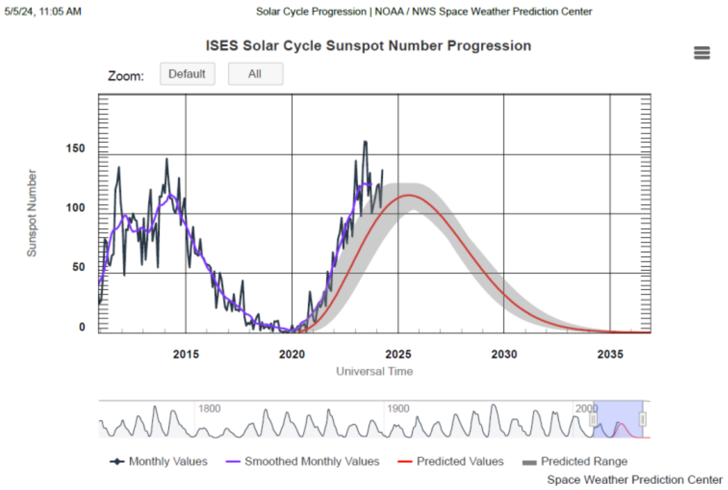


Al Penney
VO1NO

The **initial extended forecast was that Solar Cycle 25 will below average, quiet, and cool.** This is very similar to its predecessor Solar Cycle 24—the weakest cycle since record-keeping began in 1755.

The 13-month smoothed monthly sunspot number is derived by a "tapered-boxcar" running mean of monthly sunspot numbers over 13 months centered on the corresponding month (Smoothing function: equal weights = 1, except for first and last elements (-6 and +6 months) = 0.5, Normalization by 1/12 factor).

Sunspot Count



Al Penney
VO1NO

Feb. 1, 2023: In a continued sign of strength for Solar Cycle 25, sunspot counts just hit a 9-year high. This plot from NOAA shows how the monthly sunspot number skyrocketed in January 2023:

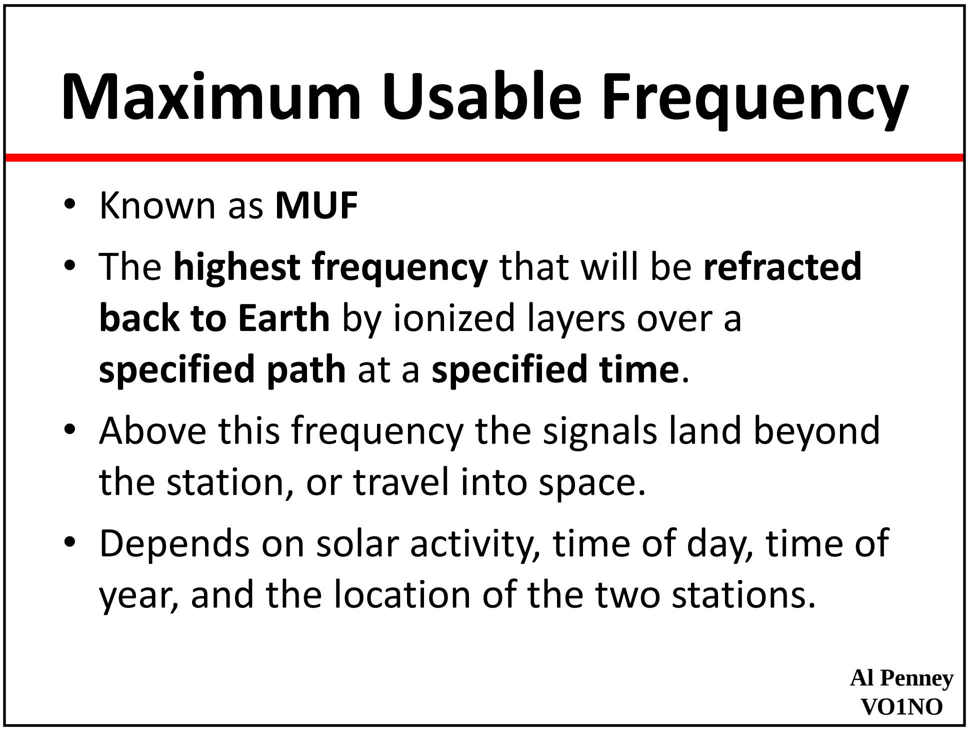
The monthly sunspot number of 144 in January 2023 was only percentage points away from topping the previous solar cycle, Solar Cycle 24, which peaked in Feb. 2014 with a monthly value of 146.

Originally, forecasters thought Solar Cycle 25 would be about the same as Solar Cycle 24, one of the weakest solar cycles in a century. Current trends suggest Solar Cycle 25 will surpass that low threshold, at least. Solar Maximum is not expected until 2024 or 2025, so it has plenty of time to strengthen further, perhaps far exceeding Solar Cycle 24.

Effect on Propagation

- **Low solar activity = less ionization**;
  - Higher frequencies pass through ionosphere into space.
- **High solar activity = more ionization**;
  - Higher frequencies refracted back to earth, and at greater distances.

Al Penney
VO1NO



Maximum Usable Frequency

- Known as **MUF**
- The **highest frequency** that will be **refracted back to Earth** by ionized layers over a **specified path** at a **specified time**.
- Above this frequency the signals land beyond the station, or travel into space.
- Depends on solar activity, time of day, time of year, and the location of the two stations.

Al Penney
VO1NO

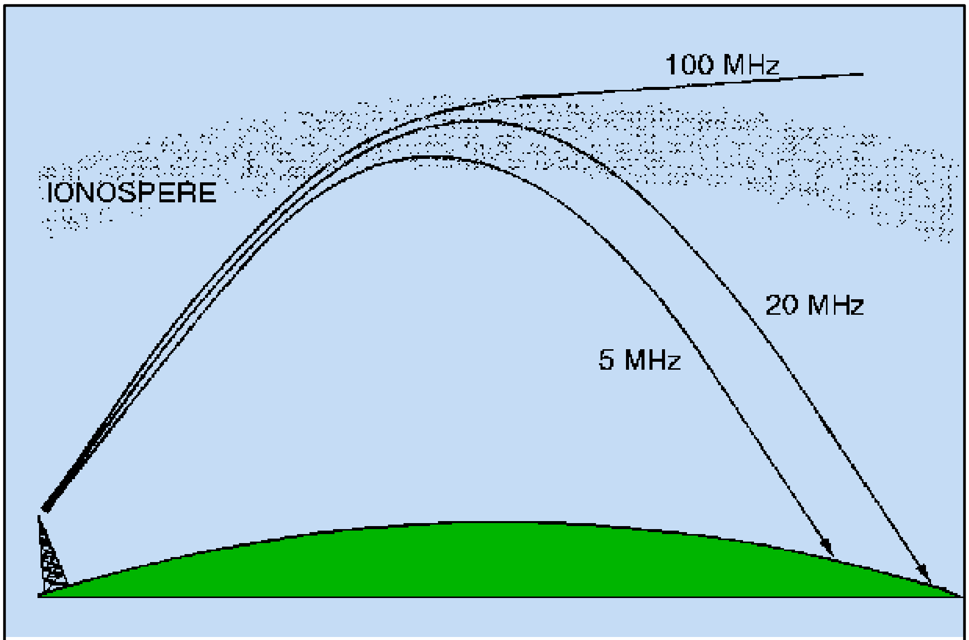
In radio transmission **maximum usable frequency** (MUF) is the highest radio frequency that can be used for transmission between two points via reflection from the ionosphere (skywave or "skip" propagation) at a specified time, independent of transmitter power.

MUF and LUF stand respectively for Maximum and Lowest Usable Frequency. These two values define the maximum usable spectrum range in which propagation is open, allowing HF communications, what could be the other perturbations or conditions. It doesn't tell thus all the story as many other "system" factors affect the propagation of sky waves (all parameters that characterize a communication circuit between two stations like the emission power, antenna gain, takeoff angle, QRM, S/N ratio, etc).

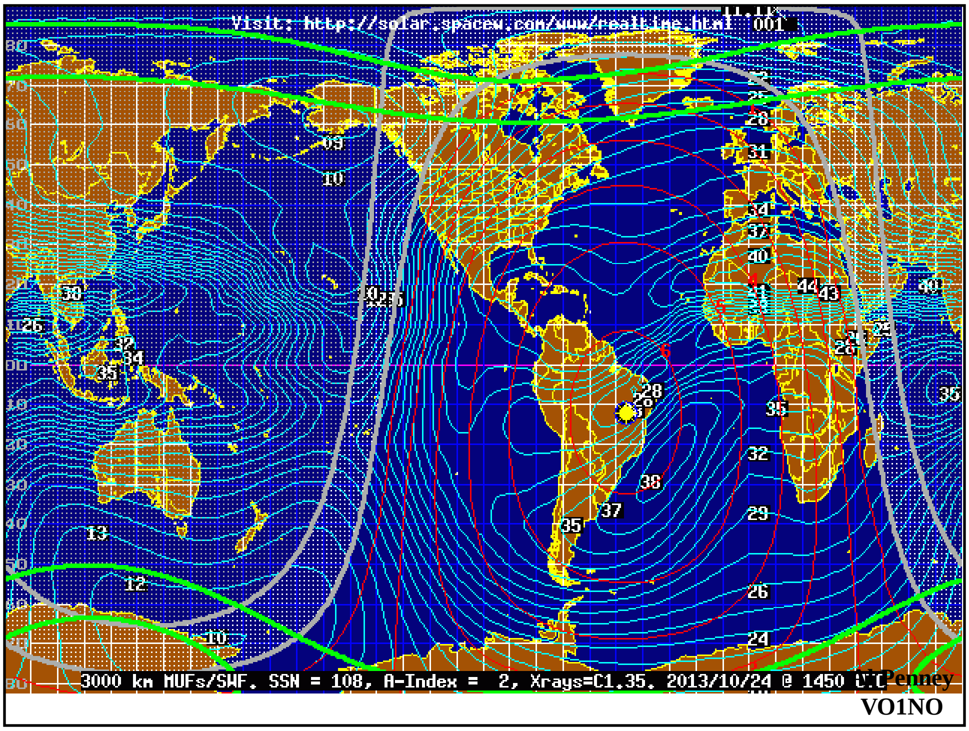
The MUF represents the statistical frequency during which a 3000 km-single hop refraction via the F2-layer is generally open 50% of the time. This is thus a median value. That means that you have a 50-50 chance to work in the specified conditions. That means also that sometimes you will only have 1% of chance to work up to that frequency, at another occasion 100% of chance to work it, but nobody can tell you what days are the best. The MUF only tells you that in average 15 days per month the higher frequency will be open as predicted.

Frequencies well below the MUF are affected by the D-layer that shows a strong absorption while the E-layer reflect shortwaves back to earth more often than expected. Above the MUF your chance to make contacts are almost null. Due to their high frequency, sky waves are not more reflected by the F-layers (F2 or F) and escape into space.

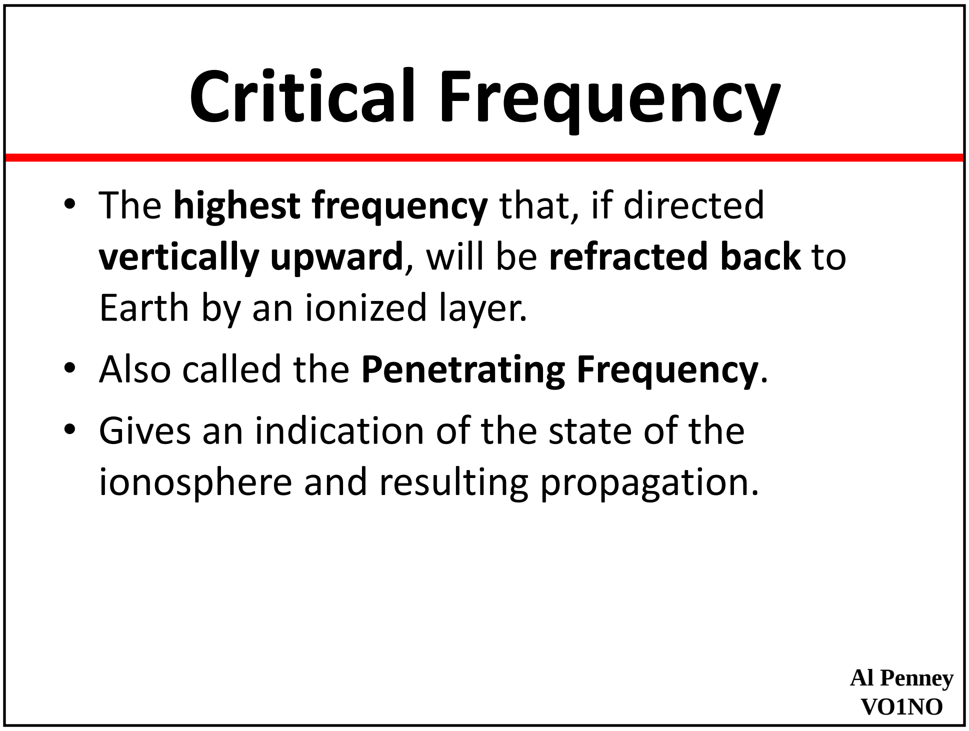
Using sky waves it is thus impossible to work on frequencies too away below or above the MUF. The Highest Possible Frequency, HPF, is the upper usable limit exceeded 10% of the time, or 3 days per month, or say in other words, in exceptional conditions. During the 90% of time we use the Frequency of Optimal Transmission (after the French words), aka FOT. It is defined as the statistical frequency during which the MUF can be exceeded of 85% (see below). This range of frequencies spreading between the FOT and the HPF is 4 MHz wide or larger, sometimes so wide that it include two ham bands. To know the probability to use such exceptional conditions, there is only parameter to check in propagation prediction programs : the "required reliability"of the signal-to-noise ratio (SNRxx or SN-Rel) for the specified circuit.



Al Penney
VO1NO



Example of an online propagation calculator.
http://www.spacew.com/www/realtime.php



Critical Frequency

- The **highest frequency** that, if directed **vertically upward**, will be **refracted back** to Earth by an ionized layer.
- Also called the **Penetrating Frequency**.
- Gives an indication of the state of the ionosphere and resulting propagation.

Al Penney
VO1NO

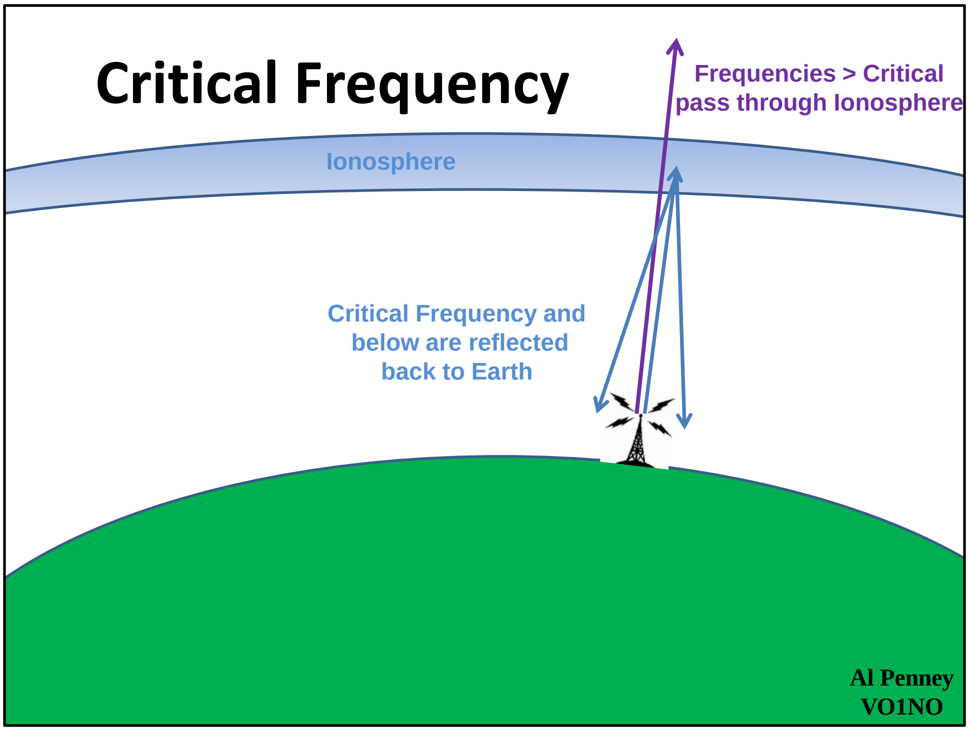
The critical frequency is an important figure that gives an indication of the state of the ionosphere and the resulting HF propagation. It is obtained by sending a signal pulse directly upwards. This is reflected back and can be received by a receiver on the same site as the transmitter. The pulse may be reflected back to earth, and the time measured to give an indication of the height of the layer. As the frequency is increased a point is reached where the signal will pass right through the layer, and on to the next one, or into outer space. The frequency at which this occurs is called the critical frequency.

The equipment used to measure the critical frequency is called an ionosonde. In many respects it resembles a small radar set, but for the HF bands. Using these sets a plot of the reflections against frequency can be generated. This will give an indication of the state of the ionosphere for that area of the world

In radio propagation by way of the ionosphere, the limiting frequency at or below which a wave component is reflected by, and above which it penetrates through, an ionospheric layer.

Critical Frequency changes with time of day, atmospheric conditions and angle of fire of the radio waves by antenna.

The existence of the critical frequency is the result of electron limitation, *i.e.*, the inadequacy of the existing number of free electrons to support reflection at higher frequencies.



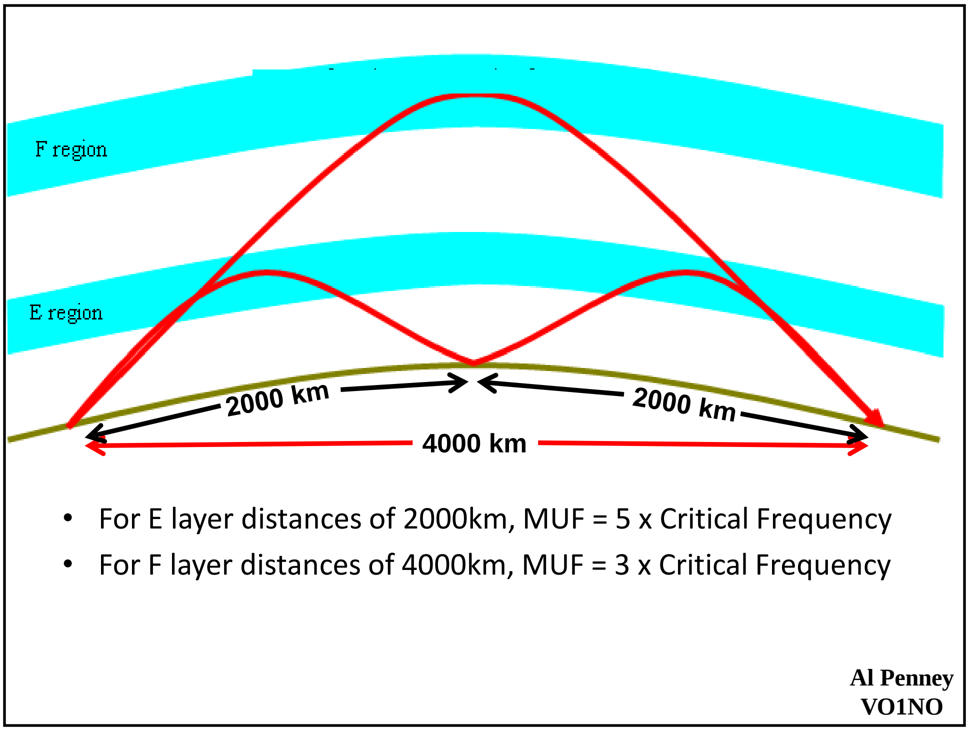
Critical Frequency

Frequencies > Critical
pass through Ionosphere

Ionosphere

Critical Frequency and
below are reflected
back to Earth

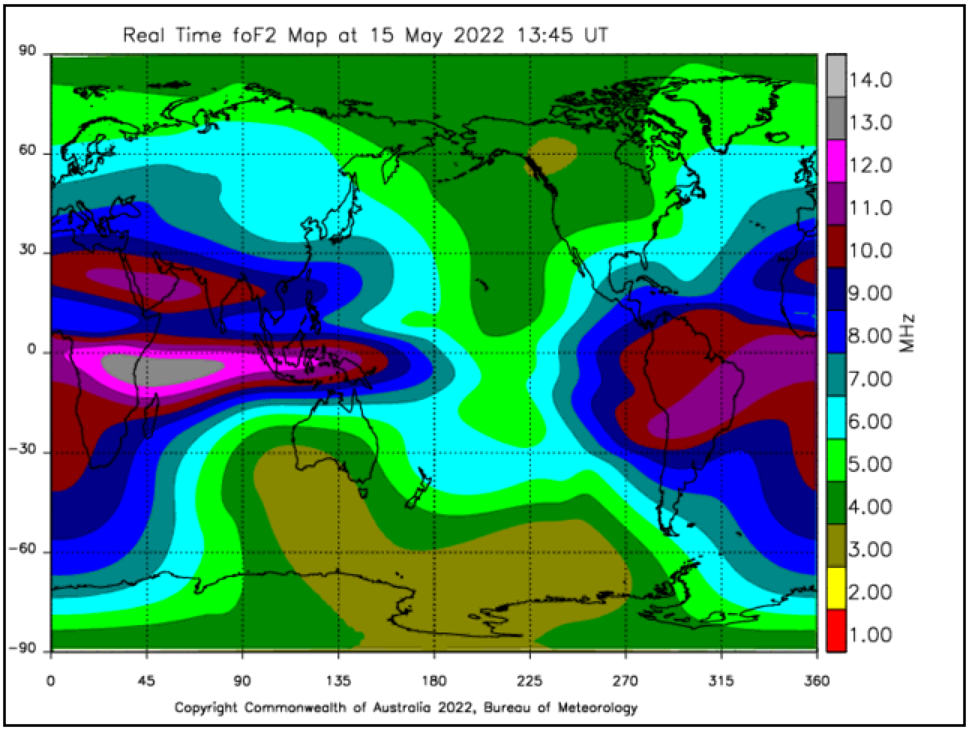
Al Penney
VO1NO



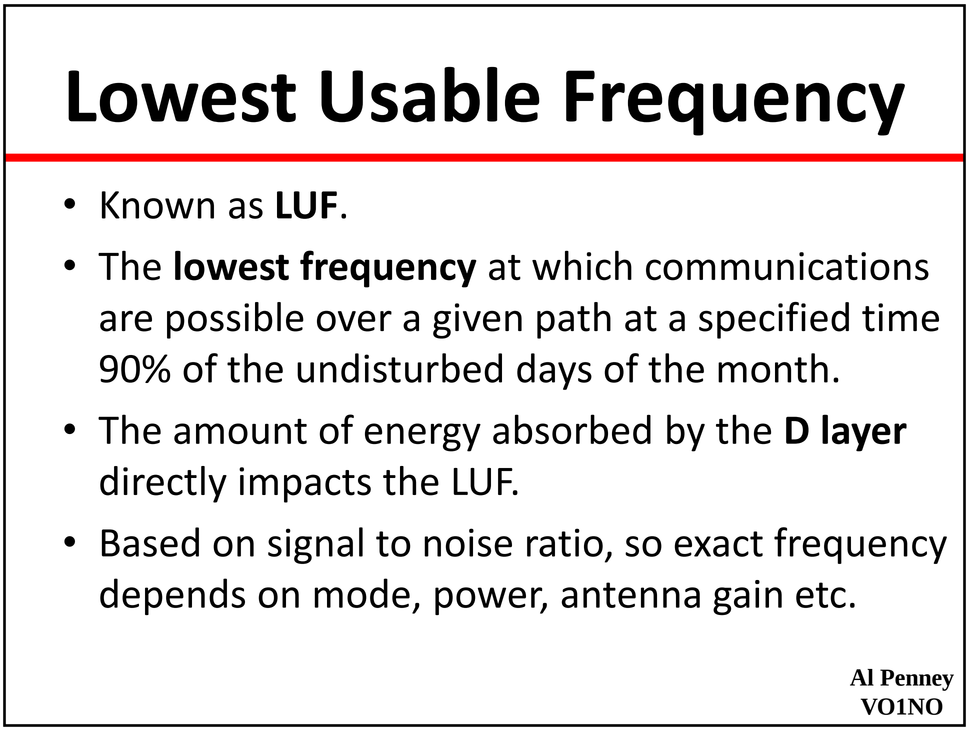
- For E layer distances of 2000km, MUF = 5 x Critical Frequency
- For F layer distances of 4000km, MUF = 3 x Critical Frequency

Al Penney
VO1NO

The Critical Frequency can be used to calculate the MUF.



https://www.sws.bom.gov.au/HF_Systems/6/5

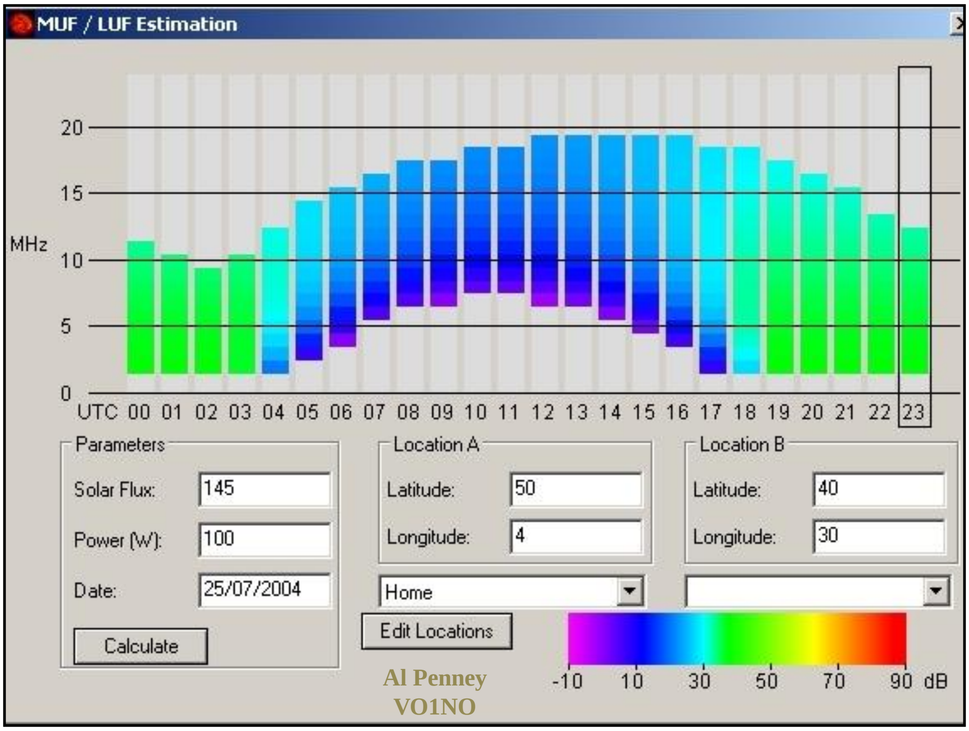


Lowest Usable Frequency

- Known as **LUF**.
- The **lowest frequency** at which communications are possible over a given path at a specified time 90% of the undisturbed days of the month.
- The amount of energy absorbed by the **D layer** directly impacts the LUF.
- Based on signal to noise ratio, so exact frequency depends on mode, power, antenna gain etc.

Al Penney
VO1NO

The **lowest usable high frequency** (**LUF**), in radio transmission, is that frequency in the HF band at which the received field intensity is sufficient to provide the required signal-to-noise ratio for a specified time period, e.g., 0100 to 0200 UTC, on 90% of the undisturbed days of the month. The amount of energy absorbed by the lower regions of the ionosphere (D region, primarily) directly impacts the LUF.



Parameters

Solar Flux: 145

Power (W): 100

Date: 25/07/2004

Location A

Latitude: 50

Longitude: 4

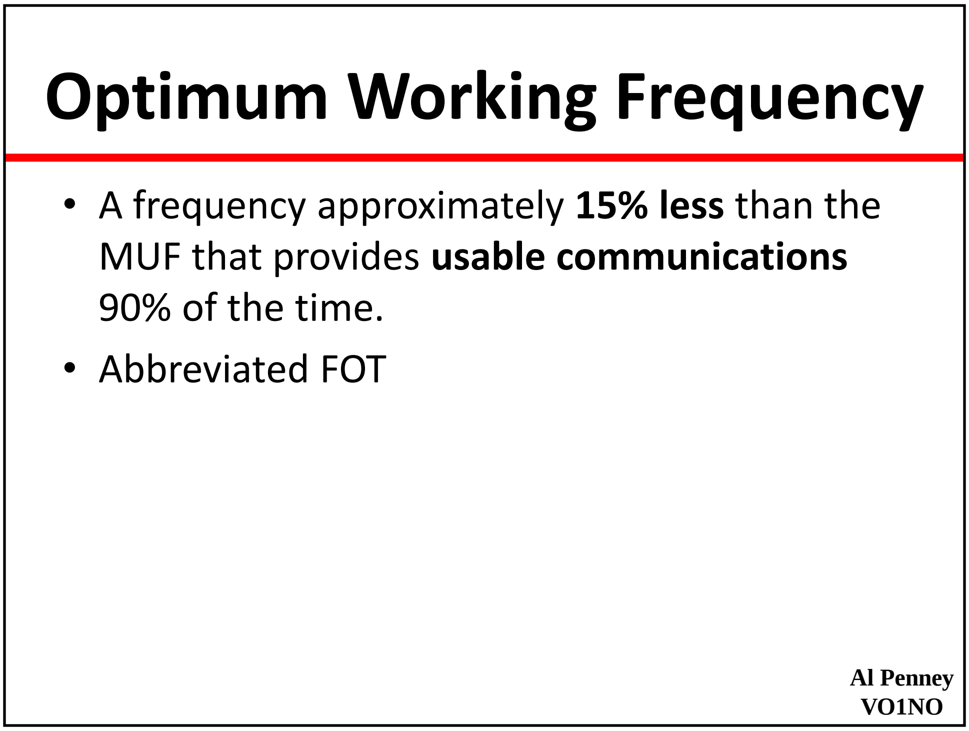
Home

Location B

Latitude: 40

Longitude: 30

MUF/LUF taking into consideration the communication circuit (path from Belgium to Turkey with 100 W PEP). The propagation looks open on low bands with signals at night 40 dB stronger than at daytime.



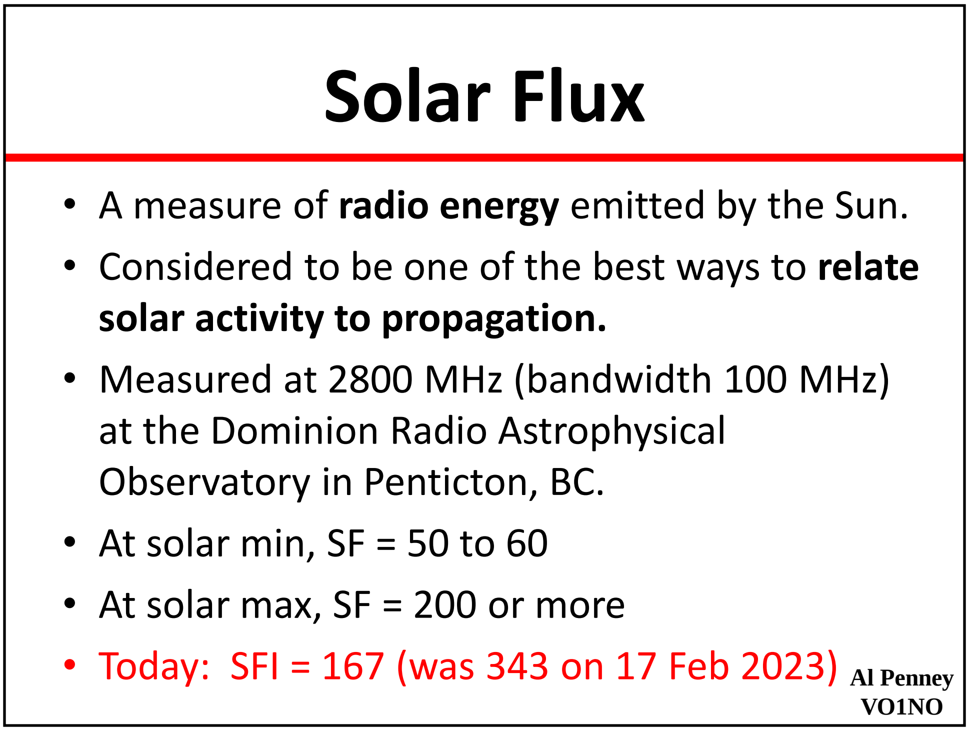
Optimum Working Frequency

- A frequency approximately **15% less** than the MUF that provides **usable communications** 90% of the time.
- Abbreviated FOT

Al Penney
VO1NO

Frequency of optimum transmission, in the transmission of radio waves via ionospheric reflection, is the highest effective (i.e. working) frequency that is predicted to be usable for a specified path and time for 90% of the days of the month. It is often abbreviated as **FOT**. The FOT is normally just below the value of the maximum usable frequency (MUF). In the prediction of usable frequencies, the FOT is commonly taken as 15% below the monthly median value of the MUF for the specified time and path.

The FOT is usually the most effective frequency for ionospheric reflection of radio waves between two specified points on Earth.



Solar Flux

- A measure of **radio energy** emitted by the Sun.
- Considered to be one of the best ways to **relate solar activity to propagation.**
- Measured at 2800 MHz (bandwidth 100 MHz) at the Dominion Radio Astrophysical Observatory in Penticton, BC.
- At solar min, SF = 50 to 60
- At solar max, SF = 200 or more
- Today: SFI = 167 (was 343 on 17 Feb 2023)

Al Penney
VO1NO

Emission from the Sun at centimetric (radio) wavelength is due primarily to coronal plasma trapped in the magnetic fields overlying active regions. The F10.7 index is a measure of the solar radio flux per unit frequency at a wavelength of 10.7 cm, near the peak of the observed solar radio emission. F10.7 is often expressed in SFU or solar flux units (1 SFU = 10^{-22} W m^{-2} Hz^{-1}). It represents a measure of diffuse, nonradiative heating of the coronal plasma trapped by magnetic fields over active regions. It is an excellent indicator of overall solar activity levels and correlates well with solar UV emissions.

The solar F10.7 index is measured daily at local noon in a bandwidth of 100 MHz centered on 2800 MHz at the Penticton site of the Dominion Radio Astrophysical Observatory (DRAO), Canada. The solar F10.7 cm record extends back to 1947, and is the longest direct record of solar activity available, other than sunspot-related quantities.

Sunspot activity has a major effect on long distance radio communications particularly on the shortwave bands although medium wave and low VHF frequencies are also affected. High levels of sunspot activity lead to improved signal propagation on higher frequency bands, although they also increase the levels of solar noise and ionospheric disturbances. These effects are caused by impact of the increased level of solar radiation on the ionosphere.

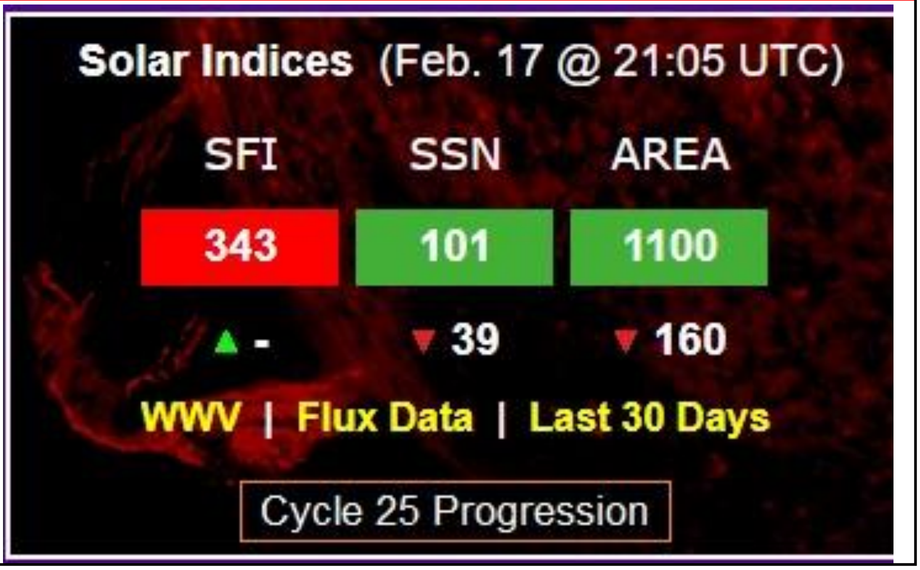
Note – 2800 MHz corresponds to a wavelength of 10.7 cm, hence F10.7

Sunday's Solar Flux report:

SFI: **167**

A-index: **6**
K-Index: **2.33**

Solar Flux



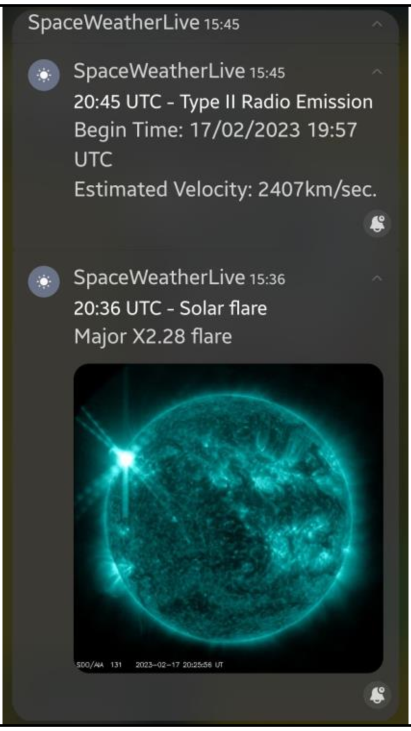
Solar Indices (Feb. 17 @ 21:05 UTC)

SFI	SSN	AREA
343	101	1100
▲ -	▼ 39	▼ 160

WWV | Flux Data | Last 30 Days

Cycle 25 Progression

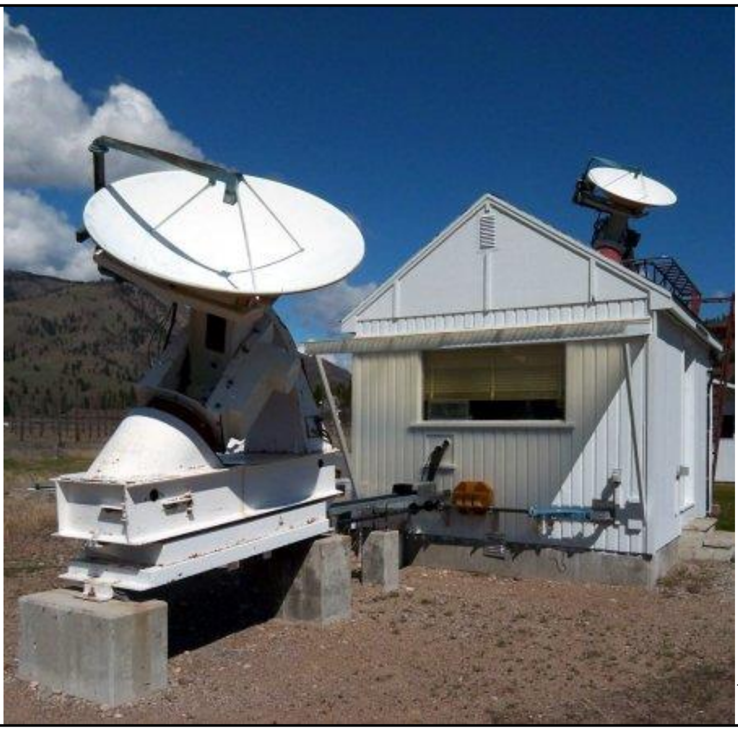
Friday 17 Feb 2023 X2.2 solar flare is the strongest solar flare of SC25 thus far. The eruption is impressive and despite it taking place near the NE limb, an asymmetrical halo CME became visible which indicates there is a good chance that part of the cloud will impact Earth.



SpaceWeatherLive 15:45

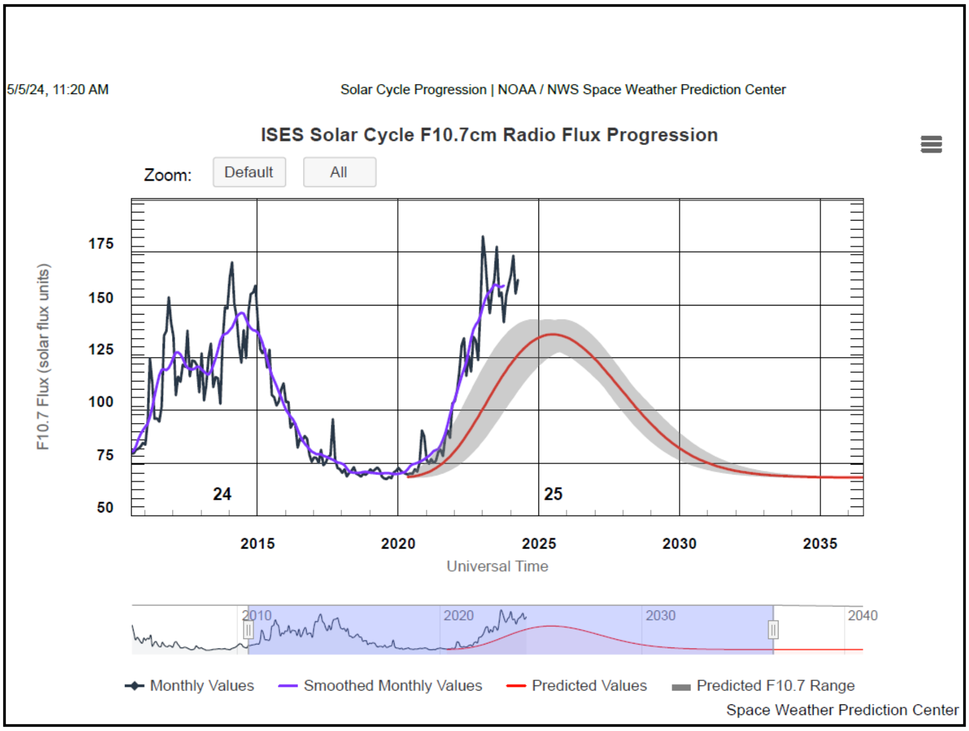
SpaceWeatherLive 15:45
20:45 UTC - Type II Radio Emission
Begin Time: 17/02/2023 19:57 UTC
Estimated Velocity: 2407km/sec.

SpaceWeatherLive 15:36
20:36 UTC - Solar flare
Major X2.28 flare



Al Penney
VO1NO

The **Dominion Radio Astrophysical Observatory** is a research facility founded in 1960 and located south-west of Okanagan Falls, British Columbia, Canada. The site houses three instruments – an interferometric radio telescope, a 26-m single-dish antenna, and a solar flux monitor – and supports engineering laboratories. The DRAO is operated by the Herzberg Institute of Astrophysics of the National Research Council of the Canadian government.

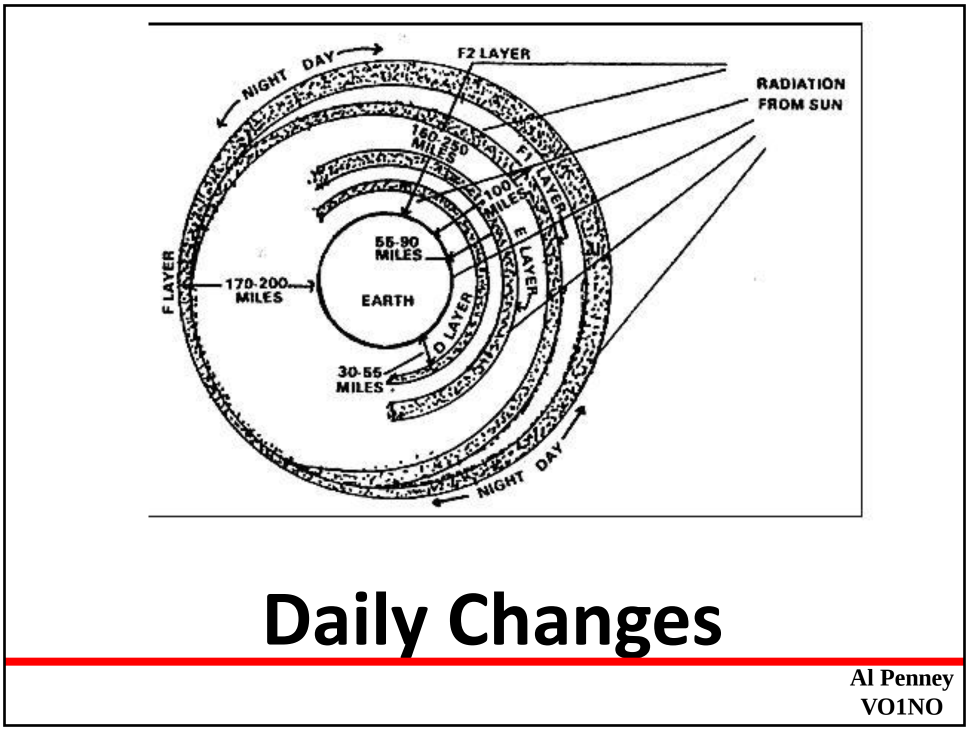


Saturday’s Solar Flux Index was 185

Just what we need when propagation is poor!

Fading

- **Variations** in received signal strength.
- Some reasons for these variations in signal strength:
  - Daily changes in ionosphere's structure;
  - Variations in shape/density of the ionosphere;
  - Loss of signal due to multipath propagation; and
  - Ionospheric disturbances.



Daily Changes

Al Penney
VO1NO

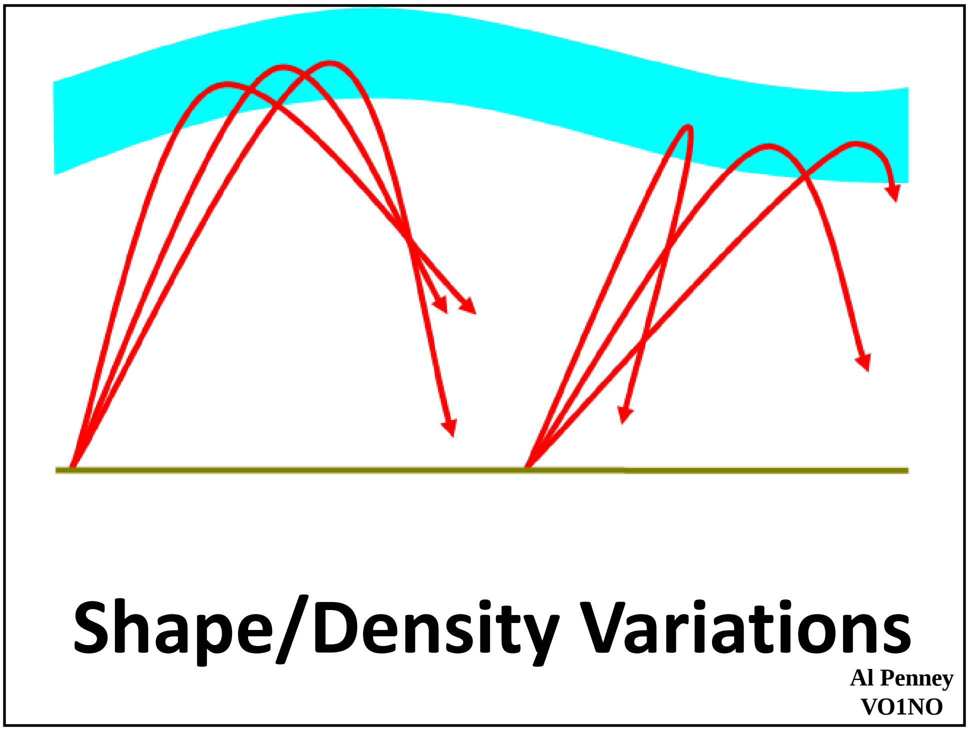
As the ionosphere changes over time, signals will fade or increase in strength. Example – European stations on 80M will gradually fade as the sun begins to rise in Europe and over the Atlantic. The increased ionization will cause the D layer to reconstitute, absorbing signals. On the other hand, as that is beginning, it will be time to look for stations towards the West. North Americans can start listening for Asia and Oceania before sunrise.

-Reduction in ionization levels near sunset.

-Increased absorption as D layer builds up.

-Differences in path length as ionization level changes in the refracting layer.

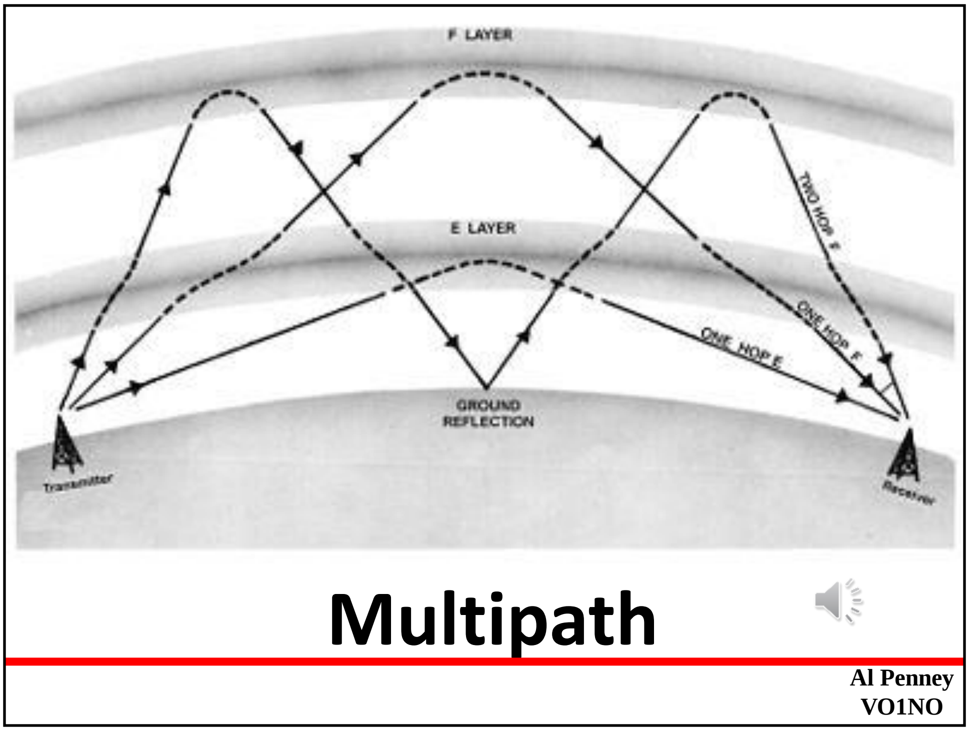
-Signals being reflected by different levels as ionization changes e.g.: E layer weakens and signal refracted off the F layer, meaning signal passes over the listener.



Shape/Density Variations

Al Penney
VO1NO

Random and time-varying differences in the shape and density of the ionosphere can result in fading as the signal path alternately increases and decreases in efficiency.



Multipath

Al Penney
VO1NO

Selective fading or **frequency selective fading** is a radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by two different paths, and at least one of the paths is changing (lengthening or shortening). This typically happens in the early evening or early morning as the various layers in the ionosphere move, separate, and combine. The two paths can both be skywave or one be groundwave.

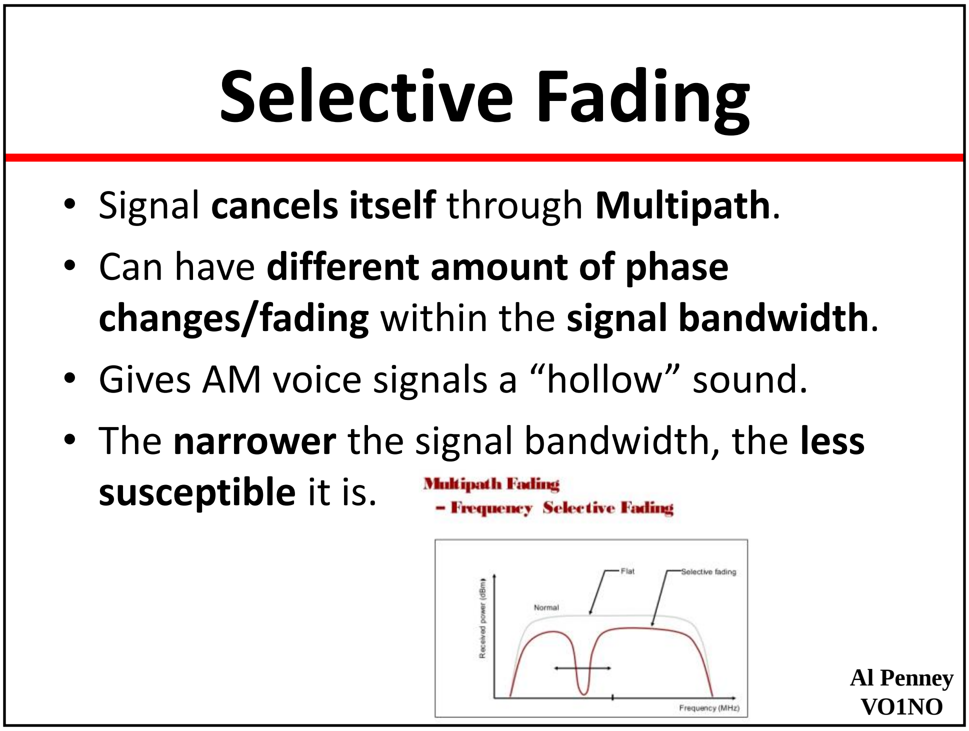
Selective fading manifests as a slow, cyclic disturbance; the cancellation effect, or "null", is deepest at one particular frequency, which changes constantly, sweeping through the received audio.

As the carrier frequency of a signal is varied, the magnitude of the change in amplitude will vary. The coherence bandwidth measures the separation in frequency after which two signals will experience uncorrelated fading.

•In **flat fading**, the coherence bandwidth of the channel is larger than the bandwidth of the signal. Therefore, all frequency components of the signal will experience the same magnitude of fading.

•In **frequency-selective fading**, the coherence bandwidth of the channel is smaller than the bandwidth of the signal. Different frequency components of the signal therefore experience uncorrelated fading.

•In general, the wider the signal bandwidth, the more susceptible it is to selective fading.



Selective Fading

- Signal **cancels itself** through **Multipath**.
- Can have **different amount of phase changes/fading** within the **signal bandwidth**.
- Gives AM voice signals a “hollow” sound.
- The **narrower** the signal bandwidth, the **less susceptible** it is.

Multipath Fading
– Frequency Selective Fading

Al Penney
VO1NO

Selective fading or frequency **selective fading** is a radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by two different paths, and at least one of the paths is changing (lengthening or shortening).

Earth’s Geomagnetic Field

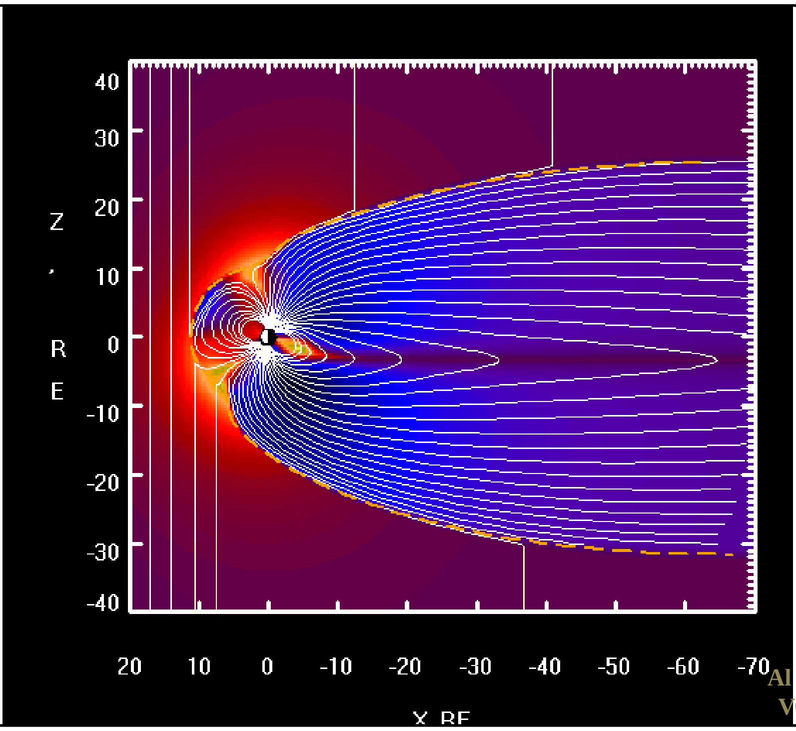
- The **magnetic field** that extends from the Earth's interior to where it meets the solar wind, a stream of charged particles emanating from the Sun.
- **Interaction with charged particles** in the solar wind can affect propagation.

Al Penney
VO1NO

Some of the charged particles from the solar wind are trapped in the Van Allen radiation belt. A smaller number of particles from the solar wind manage to travel, as though on an electromagnetic energy transmission line, to the Earth's upper atmosphere and ionosphere in the auroral zones. The only time the solar wind is observable on the Earth is when it is strong enough to produce phenomena such as the aurora and geomagnetic storms. Bright auroras strongly heat the ionosphere, causing its plasma to expand into the magnetosphere, increasing the size of the plasma geosphere, and causing escape of atmospheric matter into the solar wind. Geomagnetic storms result when the pressure of plasmas contained inside the magnetosphere is sufficiently large to inflate and thereby distort the geomagnetic field.

The solar wind is responsible for the overall shape of Earth's magnetosphere, and fluctuations in its speed, density, direction, and entrained magnetic field strongly affect Earth's local space environment. For example, the levels of ionizing radiation and radio interference can vary by factors of hundreds to thousands; and the shape and location of the magnetopause and bow shock wave upstream of it can change by several Earth radii, exposing geosynchronous satellites to the direct solar wind. These phenomena are collectively called space weather. The mechanism of atmospheric stripping is caused by gas being caught in bubbles of magnetic field, which are ripped off by solar winds. Variations in the magnetic field strength have been correlated to rainfall variation within the tropics.

Note: Mars has no intrinsic magnet field, and so the atmosphere is constantly escaping to space because of the solar wind.



Al Penney
VO1NO

Ionospheric Disturbances

- Characterized by:
  - **Increased ionization in D Layer**;
  - Weakening or decomposition of F Layer; or
  - Both.

Al Penney
VO1NO

Al Penney
VO1NO

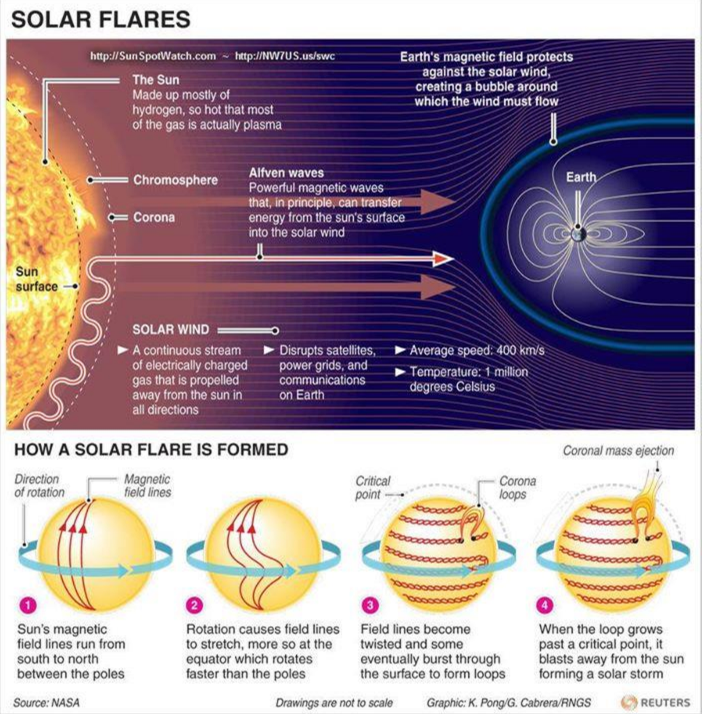
A **solar flare** is a sudden flash of increased brightness on the Sun, usually observed near its surface and in close proximity to a sunspot group. Powerful flares are often, but not always, accompanied by a coronal mass ejection. Even the most powerful flares are barely detectable in the total solar irradiance (the "solar constant").

Solar flares occur in a power-law spectrum of magnitudes; an energy release of typically 10^{20} joules of energy suffices to produce a clearly observable event, while a major event can emit up to 10^{25} joules.

In just 100 to 1,000 seconds, the disturbance can release an energy of 10 exponent 24 Joule. A single flare then creates an explosion equivalent to 2.5 million nuclear bombs on Earth, each with a destructive force of 100 Megatons of trinitrotoluene, or TNT.

Flares are closely associated with the ejection of plasmas and particles through the Sun's corona into outer space; flares also copiously emit radio waves. If the ejection is in the direction of the Earth, particles associated with this disturbance can penetrate into the upper atmosphere (the ionosphere) and cause bright auroras, and may even disrupt long range radio communication. It usually takes days for the solar plasma ejecta to reach Earth. Flares also occur on other stars, where the term stellar flare applies. High-energy particles, which may be relativistic, can arrive almost simultaneously with the electromagnetic radiations.

On July 23, 2012, a massive, potentially damaging, solar storm (solar flare, coronal mass ejection and electromagnetic radiation) barely missed Earth. In 2014, Pete Riley of Predictive Science Inc. published a paper in which he attempted to calculate the odds of a similar solar storm hitting Earth within the next 10 years, by extrapolating records of past solar storms from the 1960s to the present day. He concluded that there may be as much as a 12% chance of such an event occurring.



SOLAR FLARES

http://SunSpotWatch.com ~ http://NW7US.us/swc

The Sun
Made up mostly of hydrogen, so hot that most of the gas is actually plasma

Earth's magnetic field protects against the solar wind, creating a bubble around which the wind must flow

Alfven waves
Powerful magnetic waves that, in principle, can transfer energy from the sun's surface into the solar wind

SOLAR WIND

- A continuous stream of electrically charged gas that is propelled away from the sun in all directions
- Disrupts satellites, power grids, and communications on Earth
- Average speed: 400 km/s
- Temperature: 1 million degrees Celsius

HOW A SOLAR FLARE IS FORMED

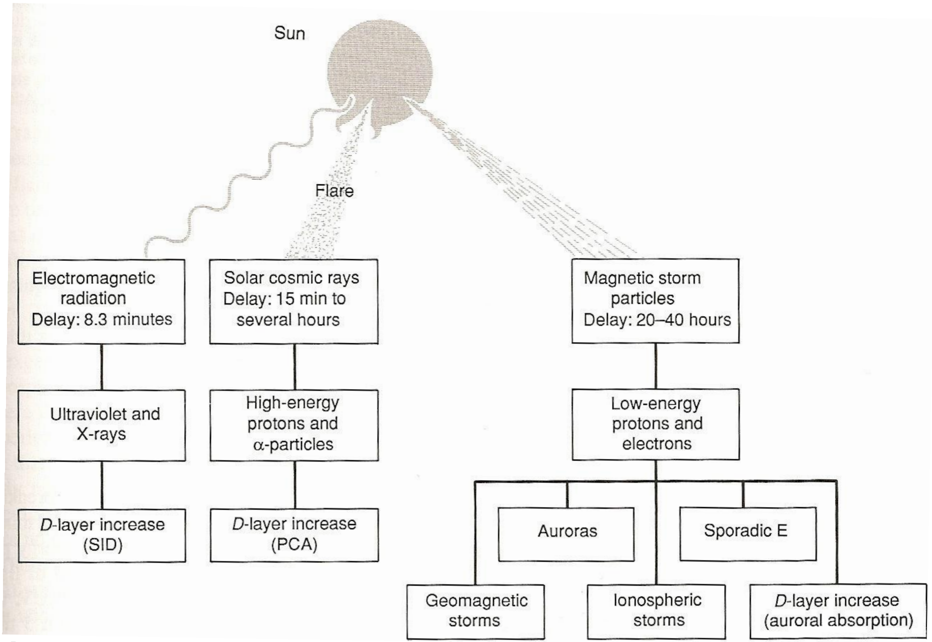
1. Sun's magnetic field lines run from south to north between the poles
2. Rotation causes field lines to stretch, more so at the equator which rotates faster than the poles
3. Field lines become twisted and some eventually burst through the surface to form loops
4. When the loop grows past a critical point, it blasts away from the sun forming a solar storm

Source: NASA

Drawings are not to scale

Graphic: K. Pong/G. Cabrera/RNGS

REUTERS



Al Penney
VO1NO

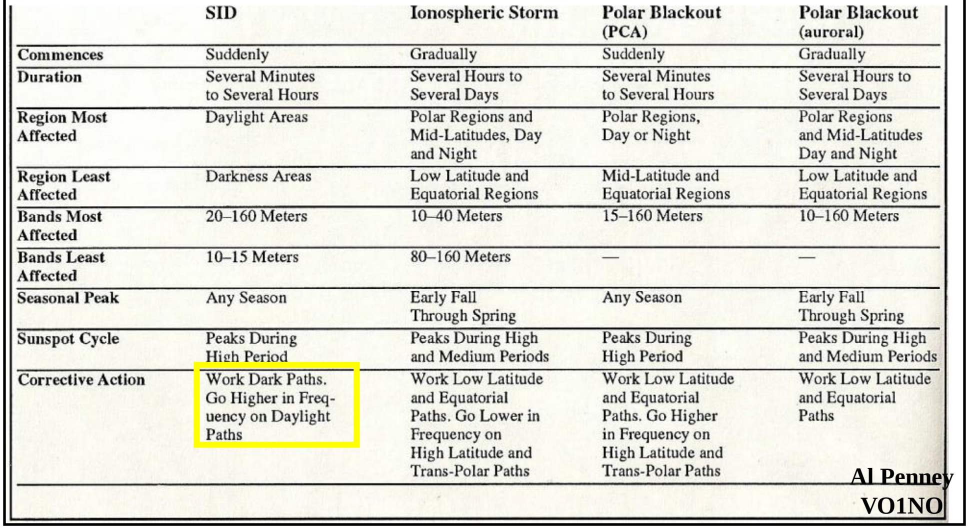
Solar flares strongly influence the local space weather in the vicinity of the Earth. They can produce streams of highly energetic particles in the solar wind or stellar wind, known as a solar proton event. These particles can impact the Earth's magnetosphere, and present radiation hazards to spacecraft and astronauts. Additionally, massive solar flares are sometimes accompanied by coronal mass ejections (CMEs) which can trigger geomagnetic storms that have been known to disable satellites and knock out terrestrial electric power grids for extended periods of time.

The soft X-ray flux of X class flares increases the ionization of the upper atmosphere, which can interfere with short-wave radio communication and can heat the outer atmosphere and thus increase the drag on low orbiting satellites, leading to orbital decay. Energetic particles in the magnetosphere contribute to the aurora borealis and aurora australis. Energy in the form of hard x-rays can be damaging to spacecraft electronics and are generally the result of large plasma ejection in the upper chromosphere.

The radiation risks posed by solar flares are a major concern in discussions of a manned mission to Mars, the Moon, or other planets. Energetic protons can pass through the human body, causing biochemical damage, presenting a hazard to astronauts during interplanetary travel. Some kind of physical or magnetic shielding would be required to protect the astronauts. Most proton storms take at least two hours from the time of visual detection to reach Earth's orbit. A solar flare on January 20, 2005 released the highest concentration of protons ever directly measured, giving astronauts as little as 15 minutes to reach shelter.

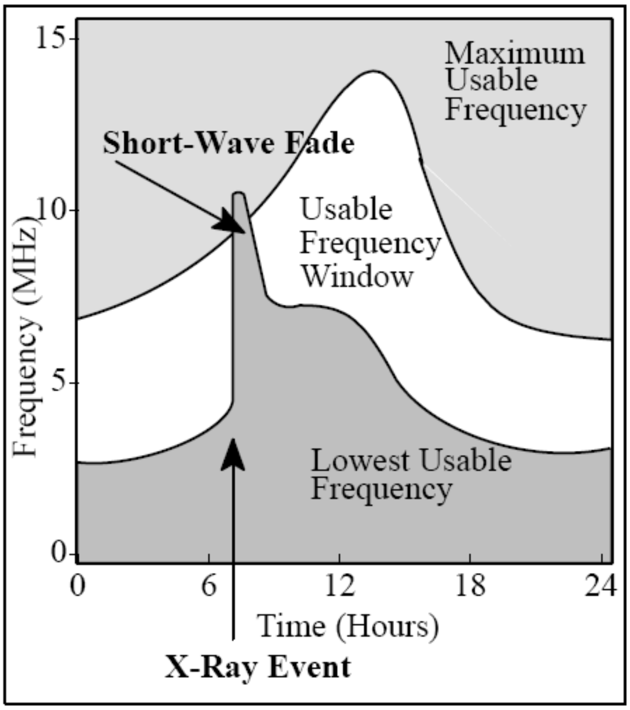
Alpha particles, also called **alpha rays** or **alpha radiation**, consist of two protons and two neutrons bound together into a particle identical to a helium-4 nucleus. They are generally produced in the process of alpha decay, but may also be produced in other ways. Alpha particles are named after the first letter in the Greek alphabet, α. The symbol for the alpha particle is α or α^{2+}. Because they are identical to helium nuclei, they are also sometimes written as He^{2+} or ${}^{4}_{2}He^{2+}$ indicating a helium ion with a +2 charge (missing its two electrons). Once the ion gains electrons from its environment, the alpha particle becomes a normal (electrically neutral) helium atom ${}^{4}_{2}He$.

Ionospheric Disturbances



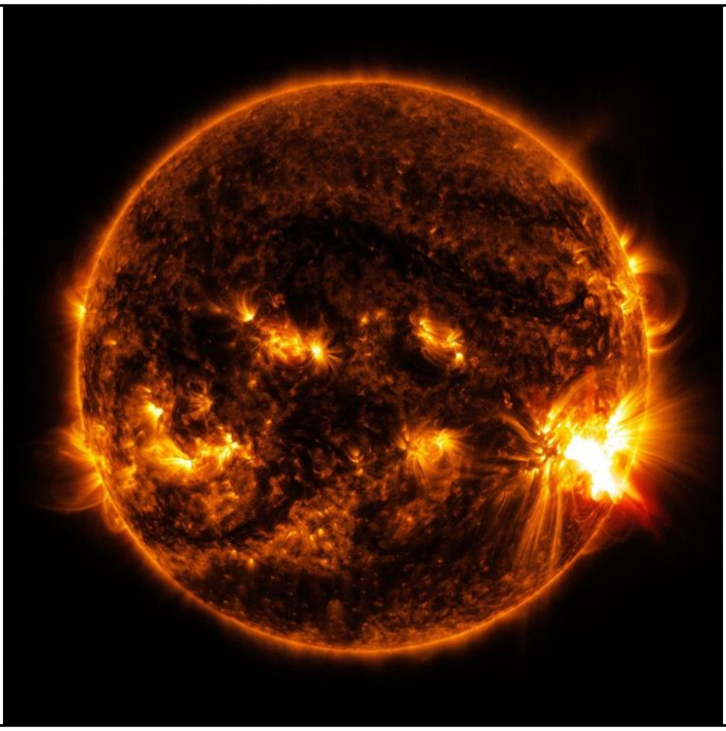
	SID	Ionospheric Storm	Polar Blackout (PCA)	Polar Blackout (auroral)
Commences	Suddenly	Gradually	Suddenly	Gradually
Duration	Several Minutes to Several Hours	Several Hours to Several Days	Several Minutes to Several Hours	Several Hours to Several Days
Region Most Affected	Daylight Areas	Polar Regions and Mid-Latitudes, Day and Night	Polar Regions, Day or Night	Polar Regions and Mid-Latitudes Day and Night
Region Least Affected	Darkness Areas	Low Latitude and Equatorial Regions	Mid-Latitude and Equatorial Regions	Low Latitude and Equatorial Regions
Bands Most Affected	20–160 Meters	10–40 Meters	15–160 Meters	10–160 Meters
Bands Least Affected	10–15 Meters	80–160 Meters	—	—
Seasonal Peak	Any Season	Early Fall Through Spring	Any Season	Early Fall Through Spring
Sunspot Cycle	Peaks During High Period	Peaks During High and Medium Periods	Peaks During High Period	Peaks During High and Medium Periods
Corrective Action	Work Dark Paths. Go Higher in Frequency on Daylight Paths	Work Low Latitude and Equatorial Paths. Go Lower in Frequency on High Latitude and Trans-Polar Paths	Work Low Latitude and Equatorial Paths. Go Higher in Frequency on High Latitude and Trans-Polar Paths	Work Low Latitude and Equatorial Paths

Al Penney
VO1NO



**Al Penney
VO1NO**

Ax X-ray event such as a SID can suddenly cause the D layer to become so dense that the LUF is greater than the MUF. This results in no signals being able to get through until the effect dies off within an hour or two.



K Index

- Quantifies **disturbances** in Earth's **magnetic field**.
- Quasi-logarithmic scale 0 to 9
- 1 = calm
- 5 or higher = geomagnetic storm
- Updated every 3 hours (8 measurements per day)
- Planet's K Index (K_p) is average of all observatories' K Index around the world.

Al Penney
VO1NO

The **K-index** quantifies disturbances in the horizontal component of earth's magnetic field with an integer in the range 0-9 with 1 being calm and 5 or more indicating a geomagnetic storm. It is derived from the maximum fluctuations of horizontal components observed on a magnetometer during a three-hour interval. The label 'K' comes from the German word 'Kennziffer' meaning 'characteristic digit.' The **K-index** was introduced by Julius Bartels in 1938. **SATURDAY: K=2.33**

There are two indices that are used to determine the level of geomagnetic acitivity: the A index and the K index. These give indications of the severity of the magnetic fluctuations and hence the disturbance to the ionosphere. The first of the two indices used to measure geomagnetic activity is the K index. Each magnetic observatory calibrates its magnetometer so that its K index describes the same level of magnetic disturbance, no matter whether the observatory is located in the auroral regions or at the Earth's equator. At three hourly intervals starting at 0000 UTC each day, the maximum deviations from the quiet day curve at a particular observatory are determined and the largest value is selected. This value is then manipulated mathematically and the K index is calculated for that location

The K-scale is quasi-logarithmic. The conversion table from maximum fluctuation R (nT) to K-index, varies from observatory to observatory in such a way that the historical rate of occurrence of certain levels of K are about the same at all observatories. In practice this means that observatories at higher geomagnetic latitude require higher levels of fluctuation for a given K-index. For example, at Godhaven, Greenland, a value of K equal to 9 is derived with R=1500 nT, while in Honolulu, HI, a fluctuation of only 300 nT is recorded as K=9. In Kiel, Germany, K=9 corresponds to R=500 nT or greater.[3] The real-time K-index is determined after the end of prescribed three-hour intervals (0000-0300, 0300-0600, ..., 2100-2400). The maximum positive and negative deviations during the 3-hour period are added together to determine the total maximum fluctuation. These maximum deviations may occur any time during the 3-hour period.

The Kp index and estimated Kp index

The official planetary **Kp index** is derived by calculating a weighted average of K-indices from a network of geomagnetic observatories. Since these observatories do not report their data in real-time, various operations centers around the globe estimate the index based on data available from their local network of observatories. The Kp-index was introduced by Bartels in 1949.[1]

The K_p index is used for the study and prediction of ionospheric propagation of high frequency radio signals. Geomagnetic storms, indicated by a K_p of 5 or higher, have no direct effect on propagation. However they disturb the F-layer of the ionosphere, especially at middle and high geographical latitudes, causing a so-called *ionospheric storm* which degrades radio propagation. The degradation mainly consists of a reduction of the maximum usable frequency (MUF) by as much as 50%.[6] Sometimes the E-layer may be affected as well. In contrast with sudden ionospheric disturbances (SID), which affect high frequency radio paths near the Equator, the effects of ionospheric storms are more intense in the polar regions

A Index

- Measure of **daily level** of **geomagnetic activity**.
- Values of 8 daily K indices at observatories around the world are used to calculate daily A Index for each observatory.
- Can range in value from 0 to 400 or so.
- **0 = very calm**, while **400 = Very major magnetic storm!**
- Planet's overall A Index (A_p) is average of A indices for all observatories around the world.

Al Penney
VO1NO

The A-index provides a daily average level for geomagnetic activity. Because of the non-linear relationship of the K-scale to magnetometer fluctuations, it is not meaningful to take averages of a set of K indices. What is done instead is to convert each K back into a linear scale called the "equivalent three hourly range" a-index (note the lower case).

The K index is a "quasi logarithmic" number and as such cannot be averaged to give a longer-term view of the state of the Earth's magnetic field. Thus was born the A index, a daily average. At each 3- hour increment the K index at an observatory is converted to an equivalent "a"

index using a Table, and the 8 a-index values are averaged to produce the A index for that day. It can vary up to values around 100. During very severe geomagnetic storms it can reach values of up to 200 and very occasionally more. The A index reading varies from one observatory to the next, since magnetic disturbances can be local. To overcome this, the indices are averaged over the globe to provide the Ap index, the planetary value

TODAY A=6 - Quiet

https://www.wm7d.net/hamradio/solar/

A Index

The A index is a linear measure of the Earth's field. As a result of this, its values extend over a much wider range. It is derived from the K index by scaling it to give a linear value which is termed the "a" index. This is then averaged over the period of a day to give the A index. Like the K index, values are averaged around the globe to give the planetary Ap index.

Values for the A index range up to 100 during a storm and may rise as far as 400 in a severe geomagnetic storm.

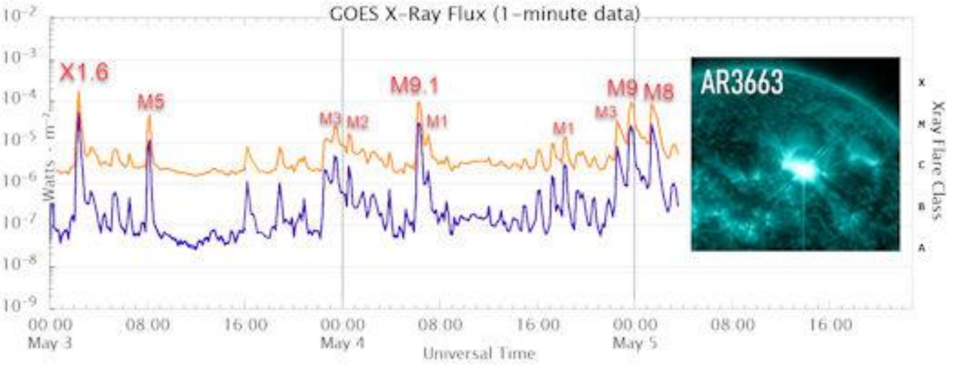
A index & Kp index relationship

Although the A index and K index are different values it is possible to relate these indices together. A summary of this relationship is given int he table below.

RELATIONSHIP BETWEEN KP INDEX AND A INDEX

AP INDEX	KP INDEX	DESCRIPTION
0	0	Quiet
4	1	Quiet
7	2	Unsettled
15	3	Unsettled
27	4	Active
48	5	Minor storm
80	6	Major storm
132	7	Severe storm
208	8	Very major storm
400	9	Very major storm

Solar Conditions This Week

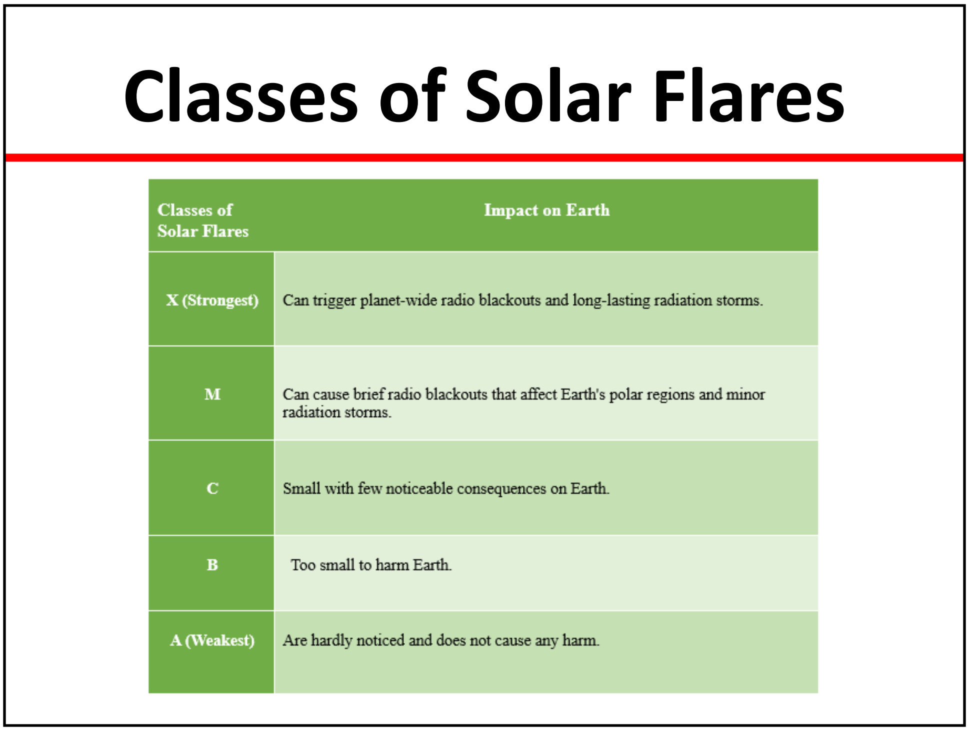


A LOT OF SOLAR FLARES: By the time you finish reading this, there will probably be another solar flare. Sunspot AR3663 is crackling with them, including multiple X and near-X flares in the past 48 hours:

Each of these flares has created a brief but deep radio blackout on Earth, causing loss of signals below 30 MHz. These are events easily noticed by ham radio operators, aviators and mariners using shortwave to communicate.

The flares are expected to continue. AR3663 has a 'beta-gamma-delta' magnetic field where mixed polarities are bumping together in explosive proximity. NOAA forecasters estimate a 75% chance of M-class flares and a 25% chance of X-flares on May 5th.

GEOMAGNETIC STORM WATCH (G2): A CME might hit Earth today. It was hurled into space May 3rd by an X1.6-class solar flare from active sunspot AR3663. NASA and NOAA models agree that the bulk of the CME should pass north of our planet, with its southern flank glancing Earth late on May 5th. Moderately strong G2-class geomagnetic storms are possible when the CME arrives.



Classes of Solar Flares

Classes of Solar Flares	Impact on Earth
X (Strongest)	Can trigger planet-wide radio blackouts and long-lasting radiation storms.
M	Can cause brief radio blackouts that affect Earth's polar regions and minor radiation storms.
C	Small with few noticeable consequences on Earth.
B	Too small to harm Earth.
A (Weakest)	Are hardly noticed and does not cause any harm.

Flares happen when the powerful magnetic fields in and around the sun reconnect. They're usually associated with active regions, often seen as sun spots, where the magnetic fields are strongest. Flares are classified according to their strength.

The smallest ones area and B-class, followed by C, M and X, the largest. Similar to the Richter scale for earthquakes, each letter represents a ten-fold increase in energy output. So an X is 10 times an M and 100 times a C.

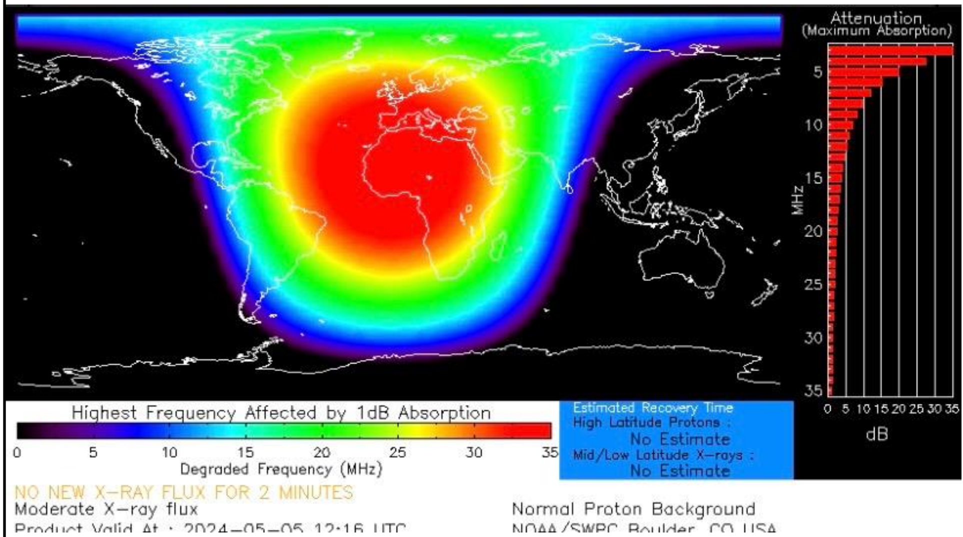
Within each letter class, there is a finer scale from 1 to 9. C-class flares are too weak to noticeably affect Earth.

M-class flares can cause brief radio blackouts at the poles and minor radiation storms that might endanger astronauts.

Although X is the last letter, there are flares more than 10 times the power of an X1, so X-class flares can go higher than 9.

The most powerful flare on record was in 2003, during the last solar maximum. It was so powerful that it overloaded the sensors measuring it. They cut-out at X17, and the flare was later estimated to be about X45. A powerful X-class flare like that can create long lasting radiation storms, which can harm satellites and even give airline passengers, flying near the poles, small radiation doses. X flares also have the potential to create global transmission problems and world-wide blackouts.

Solar Conditions Today

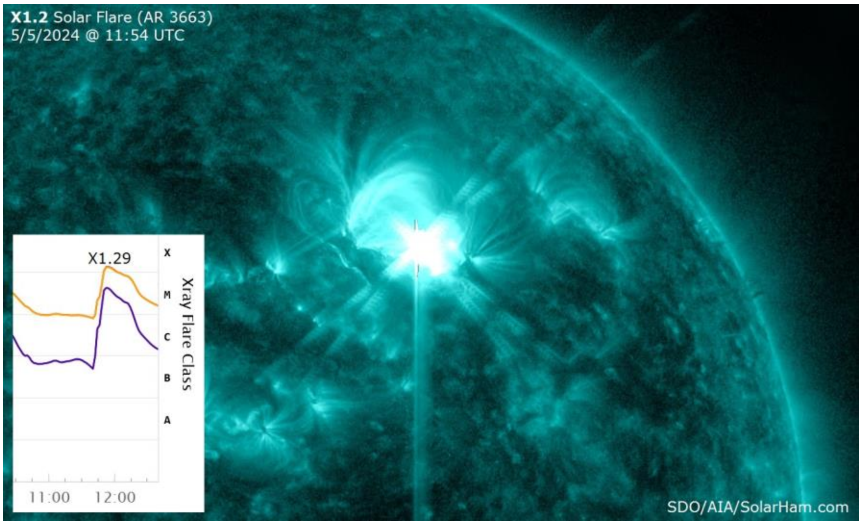


Estimated Recovery Time
High Latitude Protons :
No Estimate
Mid/Low Latitude X-rays :
No Estimate

NO NEW X-RAY FLUX FOR 2 MINUTES
Moderate X-ray flux
Product Valid At : 2024-05-05 12:16 UTC

Normal Proton Background
NOAA/SWPC Boulder, CO USA

A Few Hours Ago



Another X-Flare!

AR 3663 is proving to be quite the firecracker. Another strong flare was just detected, this time an X1.29 solar flare at 11:54 UTC. This flare is in addition to an M8.4, X1.3 and M7.4 also produced today alone. Coronagraph imagery courtesy of LASCO is still not up to date, however imagery by STEREO Ahead shows any plasma that is being released will be directed mostly north of the Sun-Earth line.

NVIS Propagation

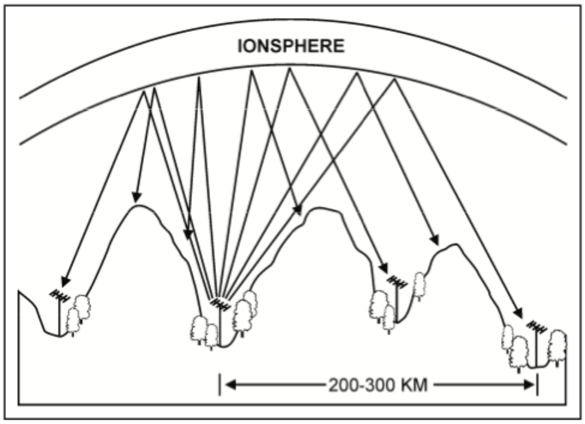
- **Near Vertical Incidence Skywave**
- Skywave propagation 0 – 650 km.
- Signals travel **vertically or near vertically** before being refracted back to Earth.
- Used on 160, 80, 60 and 40M bands.
- Suitable for emergency communications, regional communications and mountainous regions.

Al Penney
VO1NO

Near vertical incidence skywave, or **NVIS**, is a skywave radio-wave propagation path that provides usable signals in the distances range — usually 0–650 km (0–400 miles). It is used for military and paramilitary communications, broadcasting, especially in the tropics, and by radio amateurs for nearby contacts circumventing line-of-sight barriers. The radio waves travel near-vertically upwards into the ionosphere, where they are refracted back down and can be received within a circular region up to 650 km (400 miles) from the transmitter. If the frequency is too high (that is, above the critical frequency of the ionospheric F layer), refraction fails to occur and if it is too low, absorption in the ionospheric D layer may reduce the signal strength.

There is no fundamental difference between NVIS and conventional skywave propagation; the practical distinction arises solely from different desirable radiation patterns of the antennas (near vertical for NVIS, near horizontal for conventional long-range skywave propagation).

NVIS Propagation



NVIS propagation

Al Penney
VO1NO

Near vertical incidence skywave, or **NVIS**, is a skywave radio-wave propagation path that provides usable signals in the distances range — usually 0–650 km (0–400 miles). It is used for military and paramilitary communications, broadcasting, especially in the tropics, and by radio amateurs for nearby contacts circumventing line-of-sight barriers. The radio waves travel near-vertically upwards into the ionosphere, where they are refracted back down and can be received within a circular region up to 650 km (400 miles) from the transmitter. If the frequency is too high (that is, above the critical frequency of the ionospheric F layer), refraction fails to occur and if it is too low, absorption in the ionospheric D layer may reduce the signal strength.

There is no fundamental difference between NVIS and conventional skywave propagation; the practical distinction arises solely from different desirable radiation patterns of the antennas (near vertical for NVIS, near horizontal for conventional long-range skywave propagation).

The most reliable frequencies for NVIS communications are between 1.8 MHz and 8 MHz. Above 8 MHz, the probability of success begins to decrease, dropping to near zero at 30 MHz. Usable frequencies are dictated by local ionospheric conditions, which have a strong systematic dependence on geographical location. Common bands used in amateur radio at mid-latitudes are 3.5 MHz at night and 7 MHz during daylight, with experimental use of 5 MHz (60 meters) frequencies. During winter nights at the bottom of the sunspot cycle, the 1.8 MHz band may be required. Broadcasting uses the tropical broadcast bands between 2.3 and 5.06 MHz, and the international broadcast bands between 3.9 and 6.2 MHz. Military NVIS communications mostly take place on 2–4 MHz at night and on 5–7 MHz during daylight.

Optimum NVIS frequencies tend to be higher towards the tropics and lower towards the arctic regions. They are also higher during high sunspot activity years. The usable frequencies change from day to night, because sunlight causes the lowest layer of the ionosphere, called the D layer, to increase, causing attenuation of low frequencies during the day while the maximum usable frequency (MUF) which is the critical frequency of the F layer rises with greater sunlight. Real time maps of the critical frequency are available. **Use of a frequency about 15% below the critical frequency should provide reliable NVIS service.** This is sometimes referred to as the optimum working frequency or FOT.

NVIS is most useful in mountainous areas where line-of-sight propagation is ineffective, or when the communication distance is beyond the 50 mile (80 km) range of groundwave (or the terrain is so rugged and barren that groundwave is not effective), and less than the 300–1500 mile (500–2500 km) range of lower-angle sky-wave propagation. Another interesting aspect of NVIS communication is that direction finding of the sender is more difficult than for ground-wave communication (i.e. VHF or UHF). For broadcasters, NVIS allows coverage of an entire medium-sized country at much lower cost than with VHF (FM), and daytime coverage, similar to mediumwave (AM broadcast) nighttime coverage at lower cost and often with less interference.

NVIS Frequency

- Generally in the range **1.8 – 8 MHz.**
- Must be **less** than **Critical Frequency** of **F2 layer**.
- Main criteria is local ionospheric conditions:
  - D-layer absorption attenuates low frequencies during day;
  - F2 Critical Frequency higher during day, lower at night;
  - Optimum frequencies higher in tropics, lower in Arctic; and
  - Optimum frequencies lower during solar minimum.
- Will usually need daytime and nighttime frequencies.
- Optimum frequency generally **10-15% below F2 Critical Frequency (foF2).**

Al Penney
VO1NO

The selection of an appropiated working frequency is essential for a successful operation in NVIS. As a general rule, **we will choose a frequency 10% to 15% below the ionosphere's F2 layer critical frequency (foF2) at a given time**.

It is of particular importance not to confuse the foF2 with the MUF. The critical frequency foF2 is the maximum frequency that a radio wave can have in order to be reflected in the F2 layer when arriving at this layer with an angle of incidence of 90 degrees (perpendicular). In the MUF, angles of incidence different of 90 degrees are considered, which practically means that a different MUF will exist for each distance of a HF radio link.

Our goal now is to get foF2 forecasts or, much better, real time measurements of the foF2 made with an ionosonde nearby our transmitter station at a close time. Let's not forget that the foF2 has significant changes over the day and also that it will be different depending on the transmitter location.

In order to get this data, we can check the web site of the Mass Lowel University Center for Atmospheric Research (Massachussetts, USA), where there is a record of foF2 values (among other parameters) measured by ionosondes all around the world.

http://ulcar.uml.edu/stationmap.html

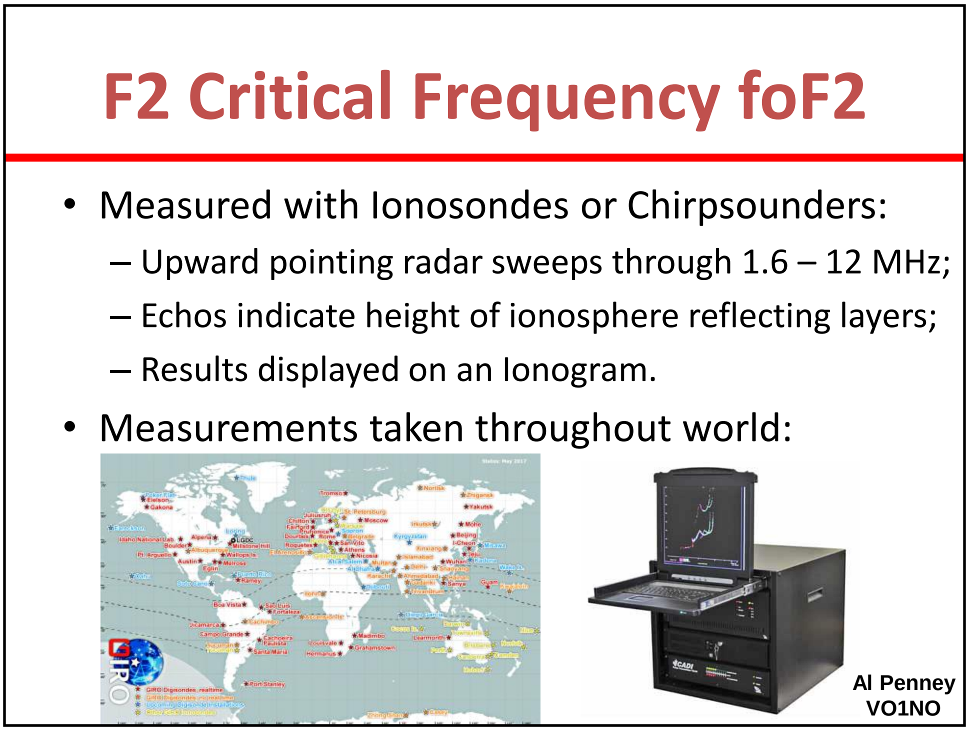
Near vertical incidence skywave, or **NVIS**, is a skywave radio-wave propagation path that provides usable signals in the distances range — usually 0–650 km (0–400 miles). It is used for military and paramilitary communications, broadcasting, especially in the tropics, and by radio amateurs for nearby contacts circumventing line-of-sight barriers. The radio waves travel near-vertically upwards into the ionosphere, where they are refracted back down and can be received within a circular region up to 650 km (400 miles) from the transmitter. If the frequency is too high (that is, above the critical frequency of the ionospheric F layer), refraction fails to occur and if it is too low, absorption in the ionospheric D layer may reduce the signal strength.

There is no fundamental difference between NVIS and conventional skywave propagation; the practical distinction arises solely from different desirable radiation patterns of the antennas (near vertical for NVIS, near horizontal for conventional long-range skywave propagation).

The most reliable frequencies for NVIS communications are between 1.8 MHz and 8 MHz. Above 8 MHz, the probability of success begins to decrease, dropping to near zero at 30 MHz. Usable frequencies are dictated by local ionospheric conditions, which have a strong systematic dependence on geographical location. Common bands used in amateur radio at mid-latitudes are 3.5 MHz at night and 7 MHz during daylight, with experimental use of 5 MHz (60 meters) frequencies. During winter nights at the bottom of the sunspot cycle, the 1.8 MHz band may be required. Broadcasting uses the tropical broadcast bands between 2.3 and 5.06 MHz, and the international broadcast bands between 3.9 and 6.2 MHz. Military NVIS communications mostly take place on 2–4 MHz at night and on 5–7 MHz during daylight.

Optimum NVIS frequencies tend to be higher towards the tropics and lower towards the arctic regions. They are also higher during high sunspot activity years. The usable frequencies change from day to night, because sunlight causes the lowest layer of the ionosphere, called the D layer, to increase, causing attenuation of low frequencies during the day while the maximum usable frequency (MUF) which is the critical frequency of the F layer rises with greater sunlight. Real time maps of the critical frequency are available. **Use of a frequency about 15% below the critical frequency should provide reliable NVIS service.** This is sometimes referred to as the optimum working frequency or FOT.

NVIS is most useful in mountainous areas where line-of-sight propagation is ineffective, or when the communication distance is beyond the 50 mile (80 km) range of groundwave (or the terrain is so rugged and barren that groundwave is not effective), and less than the 300–1500 mile (500–2500 km) range of lower-angle sky-wave propagation. Another interesting aspect of NVIS communication is that direction finding of the sender is more difficult than for ground-wave communication (i.e. VHF or UHF). For broadcasters, NVIS allows coverage of an entire medium-sized country at much lower cost than with VHF (FM), and daytime coverage, similar to mediumwave (AM broadcast) nighttime coverage at lower cost and often with less interference.



F2 Critical Frequency foF2

- Measured with Ionosondes or Chirpsounders:
  - – Upward pointing radar sweeps through 1.6 – 12 MHz;
  - – Echos indicate height of ionosphere reflecting layers;
  - – Results displayed on an Ionogram.
- Measurements taken throughout world:

Al Penney
VO1NO

An **ionosonde**, or **chirpsounder**, is a special radar for the examination of the ionosphere. The basic ionosonde technology was invented in 1925 by Gregory Breit and Merle A. Tuve [1] and further developed in the late 1920s by a number of prominent physicists, including Edward Victor Appleton. The term *ionosphere* and hence, the etymology of its derivatives, was proposed by Robert Watson-Watt.

An ionosonde consists of:

•A high frequency (HF) radio transmitter, automatically tunable over a wide range. Typically the frequency coverage is 0.5–23 MHz or 1–40 MHz, though normally sweeps are confined to approximately 1.6–12 MHz.

•A tracking HF receiver which can automatically track the frequency of the transmitter.

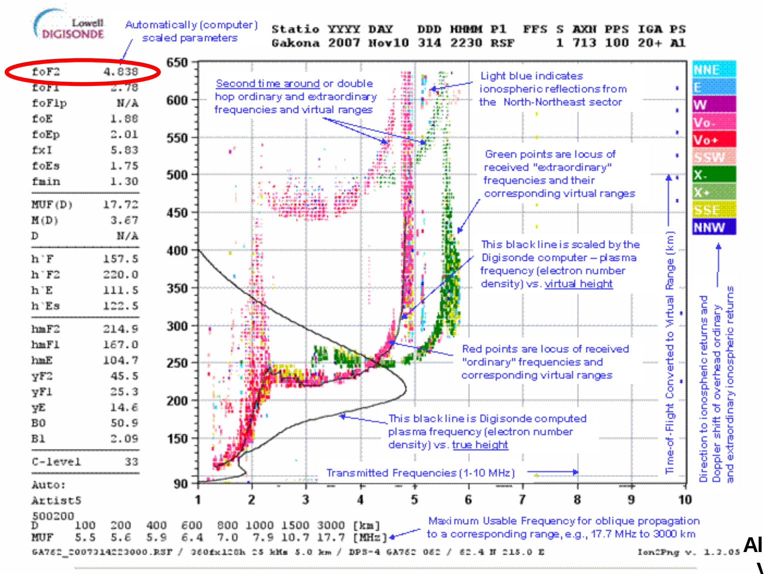
•An antenna with a suitable radiation pattern, which transmits well vertically upwards and is efficient over the whole frequency range used.

•Digital control and data analysis circuits.

The transmitter sweeps all or part of the HF frequency range, transmitting short pulses. These pulses are reflected at various layers of the ionosphere, at heights of 100–400 km, and their echos are received by the receiver and analyzed by the control system. The result is displayed in the form of an ionogram, a graph of reflection height (actually time between transmission and reception of pulse) versus carrier frequency.

An ionosonde is used for finding the optimum operation frequencies for broadcasts or two-way communications in the high frequency range.

Ionogram



**Al Penney
VO1NO**

- Digisonde ionogram presents signals reflected from the ionosphere in the frequency vs travel time frame, with signal strength indicated by the pixel intensity, and wave polarization, angle of arrival, and Doppler frequency indicated by colors
- Individual reflected signals (echoes) observed on each sounding frequency form traces in the ionogram image
- Red (green) colors indicate vertical echoes with O-polarization (X-polarization)
- ARTIST software scales the ionogram and calculates the vertical Electron Density Profile (EDP) in real time
- Thin black lines show the ARTIST-identified O-traces
- The black line with uncertainty bars shows the calculated bottomside EDP
- Extraction and interpretation of the signal traces in ionogram images is an intelligent, machine-hard problem of feature recognition

Extraordinary Frequency - As a wave approaches the reflection point, its group velocity approaches zero and this increases the time-of-flight of the signal. Eventually, a frequency is reached that enables the wave to penetrate the layer without being reflected. For ordinary mode waves, this occurs when the transmitted frequency just exceeds the peak plasma frequency of the layer. In the case of the extraordinary wave, the magnetic field has an additional effect, and reflection occurs at a frequency that is higher than the ordinary wave by half the electron gyrofrequency.

In order to gain a view of the state of the ionosphere for various forms of radio communication, a test instrument known as an ionosonde is used.

The test instrument is sometimes also known as a vertical incidence sounder, VIS, and this name gives an indication of the operation of the ionosonde.

Ionosondes, and the ionograms they produce are essential test instruments used for investigating the state of the ionosphere. The outputs they produce are able to give an indication of the state of the ionosphere above them that can be used to create a picture of what the ionospheric conditions are like at that moment.

By detecting the state of the ionosphere using an ionosonde it is possible to build up a picture of the actual state of the ionosphere at that moment and also at that point on the globe. Using a network of these test instruments around the globe a more accurate picture can be built up and this data can be used to determine the optimum frequencies for HF broadcasting and radio communication links, both short range and long distance radio communication.

The concept of the ionosonde is that it is a form of test instrument that transmits pulses of RF power vertically upwards. It then receives the signal that is reflected and this shows many details about the ionosphere above it.

The signal is directed upwards towards the ionosphere. The signal rises and at some point it is possible that it is reflected back to Earth and received by a receiving antenna and system.

The signal is normally pulsed, like that of a conventional radar, and using the time delay for the returned signal, it is possible to determine the height of reflection.

Accordingly, it can be seen that the ionosonde is effectively a specialised form of pulsed radar that is used to detect the ionisation in the ionosphere.

The plot of the ionosonde output is called an ionograph and in early days this would have been printed out on paper, but modern systems will obviously use computer technology, storing the data for processing and display as required.

The signal from the ionosonde starts at a low frequency and is stepped up in frequency. Initially the signal is reflected back by the ionosphere, but as the frequency is increased it penetrates deeper into the relevant region and eventually passes on to the next ionised region where the same process occurs as the frequency is swept upwards. Eventually a point is reached where the signal passes though all the regions of the ionosphere and it is not reflected.

There is a time delay between when the signal is transmitted and the reflected signal is received. Knowing the speed that the signals travel, it is possible to convert this into a distance or height figure.

There is a variety of instruments that have been used over the years from different manufacturers and with different specifications but in essence they all provide the same function.

There have been many developments in ionosonde technology. Analogue systems were used up until the 1970s. These systems all swept through the relevant parts of the spectrum, normally from about 1 MHz up to between 15 and 25 MHz.

They generally used a relatively high power level, often up to 25 kW. Sweeps could take anywhere between about 30 seconds and 2 minutes which gave them the ability to look at relatively short term variations in the ionosphere.

Since the 1970s digital systems have been used. These provide essentially the same as the analogue ones, but provide considerably more facilities and they are able to manipulate the data far more easily as they use computing and digital signal processing technology.

What is an Ionogram

An ionogram is the form of plot that is produced by an ionosonde. It is essentially a plot of the altitude against frequency.

The vertical axis shows the height and the horizontal axis shows the frequency.

From the ionogram it is possible to see the critical frequencies for each of the ionospheric regions or layers. These are labelled as f_0 for each layer or region. In other words f_0 E is the critical frequency for the E region, etc.

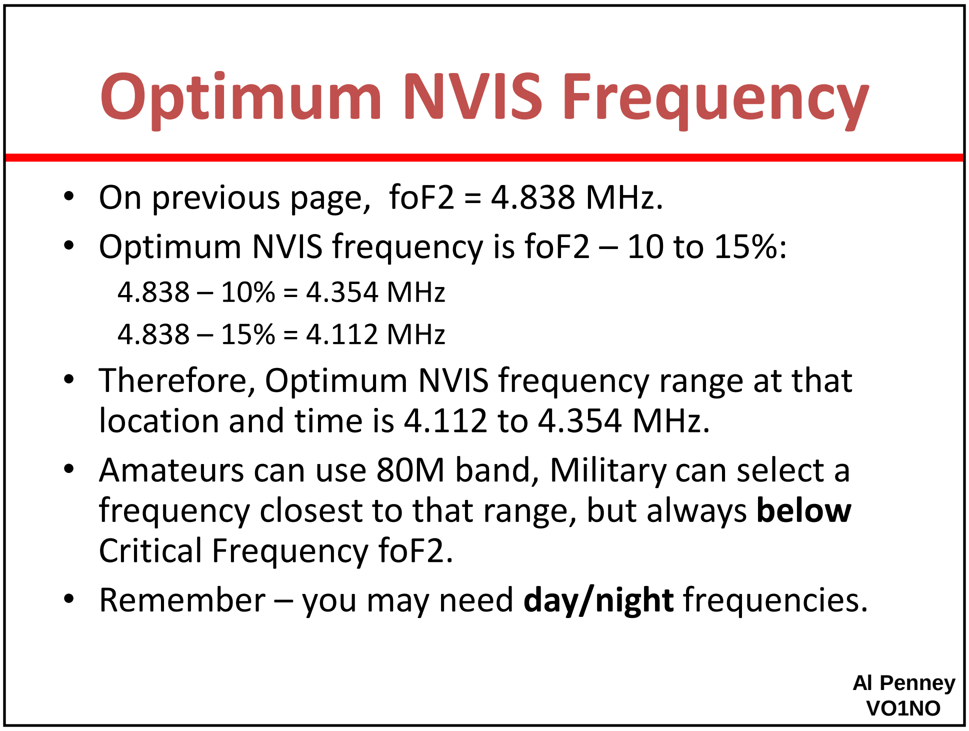
From the diagram, it can be seen that the signal is sent upwards and initially it is absorbed by the D layer and no reflection is seen.

As the signal moves up in frequency, it starts to be reflected back to the ground by the E region and the delay in receiving the pulse enables the approximate height to be determined.

As the frequency increases, the height of the reflection increases as the signal penetrates further into the E region. Ultimately the rate at which the signal penetrates the region for a given increase in frequency increases as the signal reaches the point at which it passes through the region. The actual frequency at which it passes through the E region is called the critical frequency, f_0 E.

Above f_0 E, the signal reaches the F_1 region (assuming the F region has split into two) and the process repeats. Again the same process repeats for the F_2, until the signal passes through all the different regions and travels on into outer space.

In reality the actual ionograms are less distinct than the diagrammatic ones, but the same basic patters can be made out.



Optimum NVIS Frequency

- On previous page, foF2 = 4.838 MHz.
- Optimum NVIS frequency is foF2 – 10 to 15%:

  4.838 – 10% = 4.354 MHz
  4.838 – 15% = 4.112 MHz
- Therefore, Optimum NVIS frequency range at that location and time is 4.112 to 4.354 MHz.
- Amateurs can use 80M band, Military can select a frequency closest to that range, but always **below** Critical Frequency foF2.
- Remember – you may need **day/night** frequencies.

Al Penney
VO1NO

An **ionogram** is a display of the data produced by an ionosonde. It is a graph of the virtual height of the ionosphere plotted against frequency. Ionograms are often converted into electron density profiles. Data from ionograms may be used to measure changes in the Earth's ionosphere due to space weather events.

Chirp transmitter

A chirp transmitter is a shortwave radio transmitter that sweeps the HF radio spectrum on a regular schedule. If one is monitoring a specific frequency, then a *chirp* is heard (in CW or SSB mode) when the signal passes through. In addition to their use in probing ionospheric properties, these transmitters are also used for over-the-horizon radar systems.

Ionosonde Data

- Canadian data available at (account required):
  - http://chain.physics.unb.ca/chain/pages/rules
- Other data at Global Ionosphere Radio Observatory:
  - http://giro.uml.edu/ionogram-data.html
  - Select closest location:
    https://ulcar.uml.edu/stationlist.html
    http://giro.uml.edu/IonogramMovies/
  - One Canadian location – Argentia
  - Millstone Hill, Massachussetts may be closest for Ontario

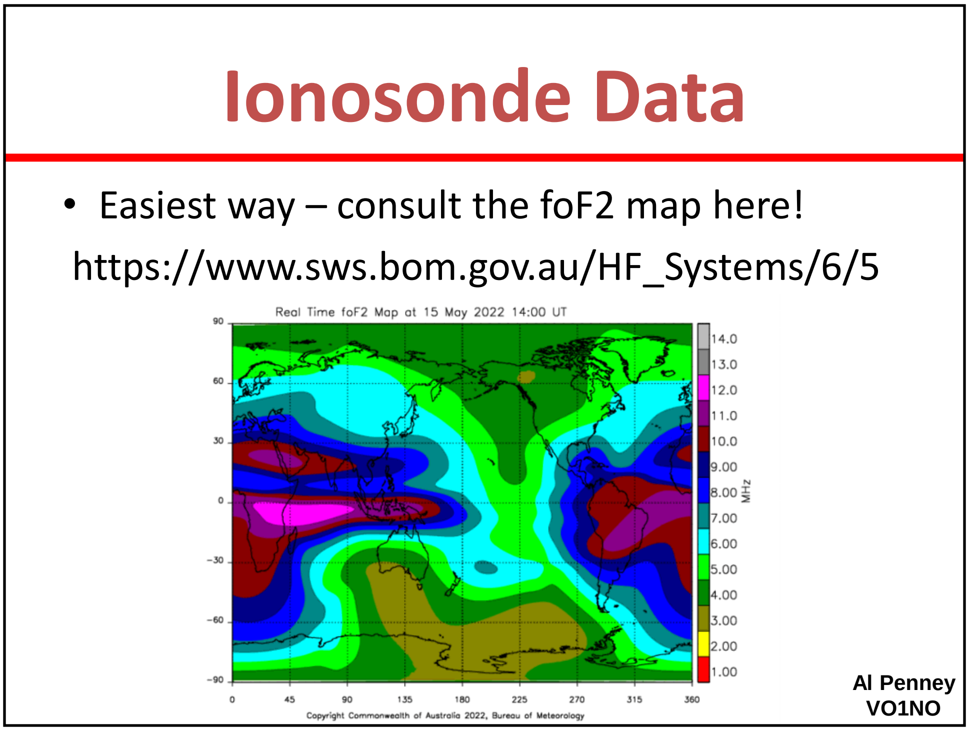
Al Penney
VO1NO

The **Canadian High Arctic Ionospheric Network (CHAIN)** is an array of ground-based radio instruments deployed in the Canadian Arctic and operated by the University of New Brunswick. The CHAIN instruments include high data-rate GPS receivers and digital ionosondes. After passing through the Earth's ionosphere, microwave GPS signals carry information about the total electron content (TEC). This information is commonly used to improve the precision of GPS and to study ionospheric morphology. Ionosondes transmit pulses of radio signals in the Medium Frequency (MF) and High Frequency (HF) ranges, whose echos are analyzed to measure height and density of the ionosphere. Advanced digital ionosondes used in the CHAIN network are also able to measure the bulk motion of ionospheric plasma.

Most of the CHAIN instruments are located within the polar cap defined as a region of open magnetic field lines. The polar cap ionosphere is directly linked to the interplanetary magnetic field carried by the solar wind. Polar cap thus provides a vantage point for the study of energy exchange between the solar wind, magnetosphere and ionosphere.

CHAIN is an integral part of the Canadian Geospace Monitoring (CGSM) programme. It provides ground support for Canadian and international scientific space missions such as THEMIS and CASSIOPE.

In January 2012, the Canada Foundation for Innovation announced funding for the Expanded Canadian High-Arctic Ionospheric Network (ECHAIN). This funding was used to add 15 Global Positioning System (GPS) receivers to the existing network of GPS receivers and radars of the Canadian High Arctic Ionospheric Network (CHAIN). The data will contribute significantly to the progress of space research by providing a better understanding of the processes in the Sun-Earth system.



Ionosonde Data

- Easiest way – consult the foF2 map here!

https://www.sws.bom.gov.au/HF_Systems/6/5

Copyright Commonwealth of Australia 2022, Bureau of Meteorology

Al Penney
VO1NO

Near-Real-Time F2-Layer Critical Frequency Map

The following image is a recent high-resolution global map of F2-layer critical frequencies. This corresponds to the maximum radio frequency that can be reflected by the F2-region of the ionosphere at vertical incidence (that is, when the signal is transmitted straight up into the ionosphere). It is also a map showing the current location of the auroral ovals, the sunrise/sunset terminator and the regions of the world where the sun is 12 degrees below the horizon (which estimates the gray-line corridor where HF propagation is usually enhanced). This is one of a plethora of constructable maps that is produced by ***PROPLAB-PRO Version 2.0*** (formerly known as SKYCOM PRO), a very powerful radio propagation software package for IBM or compatible computers, ideal for amateur or professional radio communicators.

Using this Map

This map can be used to determine the frequencies that will **always** be returned to the Earth. Transmitted frequencies *higher* than the indicated contours (which are given in MHz) may penetrate the ionosphere, resulting in lost power to space. Frequencies *lower* than the indicated contours will never penetrate the ionosphere. Lower foF2 values indicate a weaker ionosphere and correspond to regions with lower Maximum Usable Frequencies (MUFs). Higher foF2 values indicate a stronger ionosphere and correspond to regions with higher MUFs.It is important to remember that these contours refer to the transmitted signals that are vertically incident on the ionosphere. All long-distance communications use signals that are obliquely incident on the ionosphere (that is, the radio signals are passing through the ionosphere at an angle instead of head-on).

The purpose of this map is to help illustrate regions of the ionosphere that are weak and strong. Critical F2 layer frequencies in excess of about 8 MHz correspond to regions of the ionosphere that are relatively strong and capable of reflecting high-frequency signals over longer distances. Critical frequencies below about 4 MHz are weaker and will result in greater signal loss to space, lower MUFs and greater signal instability.

The map shows the ***radio auroral zones*** as green bands near the northern and southern poles. The area within the green bands is known as the auroral zone. Radio signals passing through these auroral zones will experience increased signal degradation in the form of fading, multipathing and absorption.

The radio auroral zones are typically displaced equatorward from the *optical* auroral zones (or the regions where visible auroral activity can be seen with the eye).

The great-circle signal path from the Eastern United States to Tokyo is shown along with the distance of the path (in km) and the bearing from the U.S. to Tokyo (in degrees from north).

If this signal path crosses through the green lines indicating the position and width of the radio auroral zones, propagation will be less stable and degraded compared to if the signal never crossed through the auroral zones. Using your mouse, PROPLAB-PRO will let you plot the great-circle paths and azimuths between any two points *while this display is continually updated.*

The ***yellow Sun symbol*** near the equator indicates the location where the Sun is directly overhead. The regions of the world where the Sun is exactly ***rising or setting*** is known as the ***Grayline*** and is shown as the solid gray-colored line that is closest to the Sun symbol. The second solid gray-colored line defines the regions of the world where the Sun is exactly 12 degrees below the horizon. This line defines the end of ***evening twilight***. Everything inside of this second line is experiencing night-time conditions. The area between the two lines (shaded a lighter shade than the night-time sector) is known as the ***grayline*** and has special significance to radio communicators. Signals which travel *inside* the grayline region often experience significant improvements in propagation because of the loss of ionization in the D-region as the Sun sets. However, because the higher F-regions of the ionosphere remain strongly ionized for longer periods of time, signals with higher frequencies are able to travel to greater distances with less attenuation when they are within the grayline. The ***great-circle path*** from the eastern U.S. to Japan is also shown with the accompanying ***distance*** (in kilometers) and ***bearing*** (clockwise from north). Notice how this path may occassionally pass into the influential auroral zones if geomagnetic activity increases or during the night-times.

Online Propagation Resources

- https://www.sws.bom.gov.au/HF_Systems/6/5
- https://www.voacap.com/hf/
- https://spaceweather.com/
- https://www.wm7d.net/hamradio/solar/

Al Penney
VO1NO

NVIS Antenna Pattern

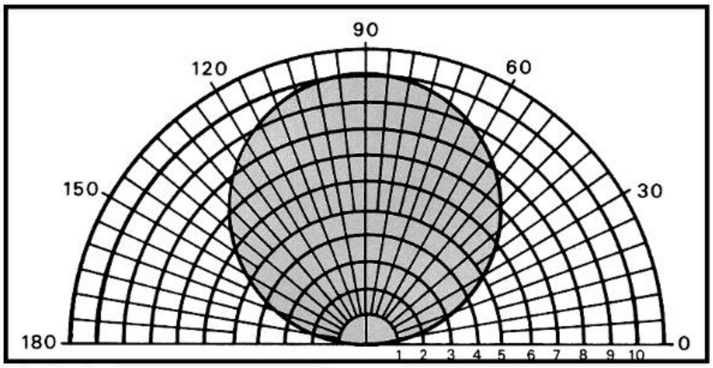


Figure M-4. Typical elevation plane pattern.

Al Penney
VO1NO

We’ll look at NVIS antennas in more detail in Ch 8.

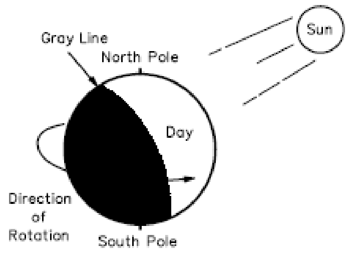
Greyline Propagation

- Greyline or Terminator is line that separates sunlight from darkness around Earth.
- Enhanced propagation along Greyline (sunrise and sunset).
- D layer disappears,

but F layer still there.

- Used primarily on low

bands (160M and 80M).



Al Penney
VO1NO

Grey line or gray line propagation is a form of radio signal propagation that provides surprisingly long distance radio communications at dawn and dusk sometimes when other forms of ionospheric propagation may not be expected to provide signal paths of these distances.

Grey line propagation is only present around dawn and dusk and therefore it cannot be used to support global radio communications at any time. Accordingly it tends to be used chiefly by radio amateurs and a few other users who can accommodate the timing and other limitations of its availability.

For grey line propagation signals travel along the grey or twilight zone between night and day. This is area where night and day meet and it is also known as the terminator. In this region signals on some frequencies are attenuated much less than might normally be experienced and as a result signals can be received at surprisingly high levels over very long distances - even from the other side of the globe.

The improved propagation conditions around the grey line are most noticeable primarily on the lower frequency bands in the HF portion of the spectrum where the level of ionisation in the D layer has a much greater effect on signals that on those frequencies higher up.

The diagram below shows how the illumination remains on the F region much longer than on the D region, and this creates a situation where the D region has faded away, but the F region remains intact.

In reality, the D region fades before dusk as the illumination from the sun reduces around dusk at the Earths surface. The level of ionisation in the D region drops very quickly around dusk and after dark because the air density is high and recombination of the free electrons and positive ions occurs comparatively quickly.

This occurs while the level of ionisation is still high within the F layer, which gives most of the radio propagation for long distance radio communications. This occurs because the F region is much higher in altitude, and as the Sun sets it remains illuminated by the Sun's radiation for longer than the D region, which is lower down. Also recombination of the ions takes longer because the air is very much thinner at the altitude of the F region compared to that of the D region.

The same occurs in the morning as the Sun rises. The F region receives radiation from the Sun before the D region and its ionisation level starts to rise before that of the D region. As the level of the D region ionisation is low, this means that the degree of attenuation to which the lower frequency signals are subjected to is very much less than in the day. This also occurs at a time when the F region ionisation is still very high, and good reflections are still achievable. Accordingly this results in much lower overall path losses around the grey line than are normally seen.

In fact, when looking at the region of the radio terminator it should be remembered that there are a variety of variables that mean that it does not exactly follow the day time / night time terminator as seen on the Earth's surface. The ionised regions are well above the Earth's surface and are accordingly illuminated for longer, although against this the Sun is low in the sky and the level of ionisation is low. Furthermore there is a finite time required for the level of ionisation to rise and decay. As there are many variables associated with the "radio signal propagation" terminator, the ordinary terminator should only be taken as a rough guide for radio signal propagation conditions.

Although it may be obvious to mention, grey line propagation can only exist for stations at locations that fall along the grey line or terminator. This significantly limits the number of areas for a given station at a particular location to set up long distance communication, although there will be slight changes over the course of the year for many stations.

Frequencies that are affected by this form of propagation are generally limited to frequencies up to about 10 MHz. Frequencies higher in frequency than 10 MHz tend to be attenuated to only a minor degree by the D region and therefore there is little or no enhancement around dusk and dawn by this mechanism.

Grey line propagation is particularly noticeable on lower frequencies, for example the 3.5 MHz amateur radio band. Normally signals may be heard over distances of a few hundred kilometres in the day, and possibly up to or two thousand kilometres at night for those stations with good antennas.

Grey line propagation regularly enables long distance radio communication contacts to be made with stations the other side of the globe at very good strength levels.

The optimum times are normally around the spring and autumn equinoxes as neither end of the link is subject to the propagation extremes of summer and winter. It is at these times of year that long distance radio communication can be established with stations onth e other side of the globe at remarkably good signal strength levels.

Grey line enhancements over the course of the year

The path of the grey line changes during the course of the year. As the angle subtended by the Sun's rays changes with the seasons, so the line taken by the terminator changes. This results from the fact that during the winter months, the Northern Hemisphere of the earth is titled away from the Sun, and towards it during the summer months.

The converse is obviously true for the southern hemisphere. In addition to this the width of the grey line also changes. It is much wider towards the poles because the line between dark and light is less will defined as a result of the fact that the Sun never rises high in the sky at the poles. It is also much narrower at the equator. This results in grey line propagation being active for longer at the poles than at the equator.

Grey line propagation provides an opportunity for long distance radio communication contacts and links to be made, often with stations the other side of the globe. Signals travel along the grey line, or terminator and suffer comparatively little attenuation. An opening via grey line propagation may only last for half an hour, but it gives the opportunity for radio communication to be established between stations as far away as the other side of the globe.

The *gray line*, sometimes called the *twilight zone*, is a band around the Earth between the sunlit portion and darkness. Astronomers call this the *terminator*. The terminator is a somewhat diffused region because the Earth's atmosphere tends to scatter the light into the darkness. **Fig 34** illustrates the gray line. Notice that on one side of the Earth, the gray line is coming into daylight (sunrise), and on the other side it is coming into darkness (sunset). Propagation along the gray line is very efficient, so greater distances can be covered than might be expected for the frequency in use. One major reason for this is that the D layer, which absorbs HF signals, disappears rapidly on the sunset side of the gray line, and has not yet built up on the sunrise side.

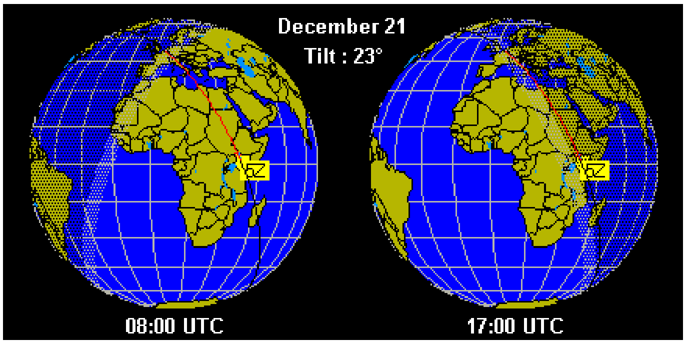
The gray line runs generally north and south, but varies as much as 23° either side of the north-south line. This variation is caused by the tilt of the Earth's axis relative to its orbital plane around the Sun. The gray line will be exactly north and south at the equinoxes (March 21 and September 21). On the first day of Northern Hemisphere summer, June 21, it is tilted to the maximum of 23° one way, and on December 21, the first day of winter, it is tilted 23° the other way.

To an observer on the Earth, the direction of the terminator is always at right angles to the direction of the Sun at sunrise or sunset. It is important to note that, except at the equinoxes, the gray-line direction will be different at sunrise from that at sunset. This means you can work different areas of the world in the evening than you worked in the morning.

It isn't necessary to be located inside the twilight zone in order to take advantage of gray-line propagation. The effects can be used to advantage before sunrise and after sunset. This is because the Sun "rises" earlier and "sets" later on the ionospheric layers than it does on the Earth below.

Greyline Propagation

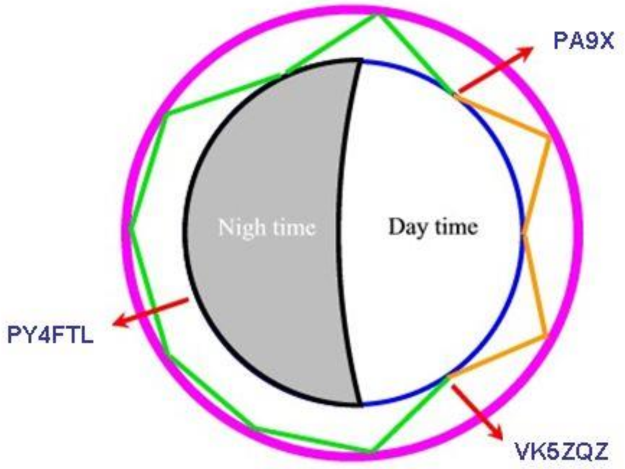
- Position of greyline changes throughout year because of 23 degree tilt of Earth's axis.
- Also changes dawn to dusk of same day.



Al Penney
VO1NO

5Z is Kenya

Long Path vs Short Path



Al Penney
VO1NO

Let’s pretend we have two stations making a QSO on 10m: PA9X near Rotterdam in The Netherlands and imaginary station VK5ZQZ down in Adelaide in Australia. The solar flux is high enough (140) and K-index low enough (<5) to allow propagation between the two stations. We are making a nice QSO, I have got my antenna directed at 70° bearing and the Australian has got his antenna directed at 340°. The signal follows the shortest path with a distance of about 16,500km from The Netherlands across north east Europe, Asiatic Russia, China, south east Asia to Adelaide. It hops between the F2 layer, which floats between roughly 250-400km altitude and the Earth’s surface. Using F2-layer propagation one single hop can do a distance between 1800km and 3500km on 10m. So for the complete path to Australia, the signal makes about 5 to 6 hops. With each hop, bouncing off the Earth’s surface, there is significant signal loss, especially bouncing of land. But there is another path, the long path.

Long path propagation signals can be stronger than short path

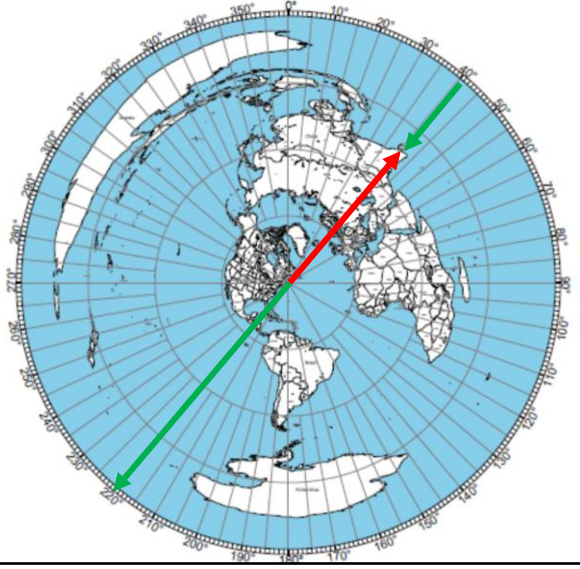
The long path runs the other way around the globe. Starting from The Netherlands, along the Azores, Atlantic Ocean northern Brazil, Peru, Pacific Ocean, across New Zealand’s Southern Island into Sydney, a distance of roughly 23,500km. The long path to Australia would be 7 to 8 hops, in theory. But but why are long path signals sometimes remarkably stronger than short path signals when they make more hops? Could be because the long path runs mainly over salt water with less attenuation, but this only counts for this specific path. But there is more going on, a propagation mode that is believed to be responsible for long path propagation with strong signals is called chordal hop propagation.

Signal that bounces along the ionosphere

Chordal hop propagation is a propagation mode involving the daylight F2 layer and night time F layer. At daytime there are two upper layers in the ionosphere, the F1-layer at approximately 150-200km and the F2 layer at 250-400km. Shortly after sunset these two layers merge into the F layer and split up again into F1 and F2 layer at sunrise. During night time the F layer loses it’s ionization density, and it’s ability to reflect signals back to Earth. But sometimes the F-layer is just dense enough to reflect the signal back, but with a less steep angle, causing the signal to be directed to another part of the ionosphere thousands of km’s ahead, not touching the ground.

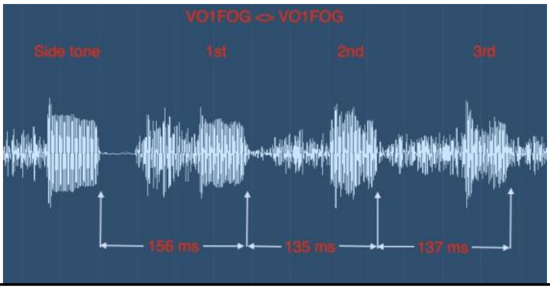
With chordal hop propagation you have much less attenuation due to the fact the signals does not reflect against Earth’s surface. In this occasion the signal that uses long path propagation arrives at the other station with much less attenuation, thus with a stronger signal than the short path. One remarkable thing is that a station at night time, like imaginary station PY4FTL in Rio de Janeiro in Brazil, has signals traveling far above through the ionosphere, but he cannot receive them.

Long Path vs Short Path



Round the World!

- Sometimes signals can travel completely around the world and be heard by the transmitting station.
- This was recently observed by Larry, VO1FOG in Newfoundland:



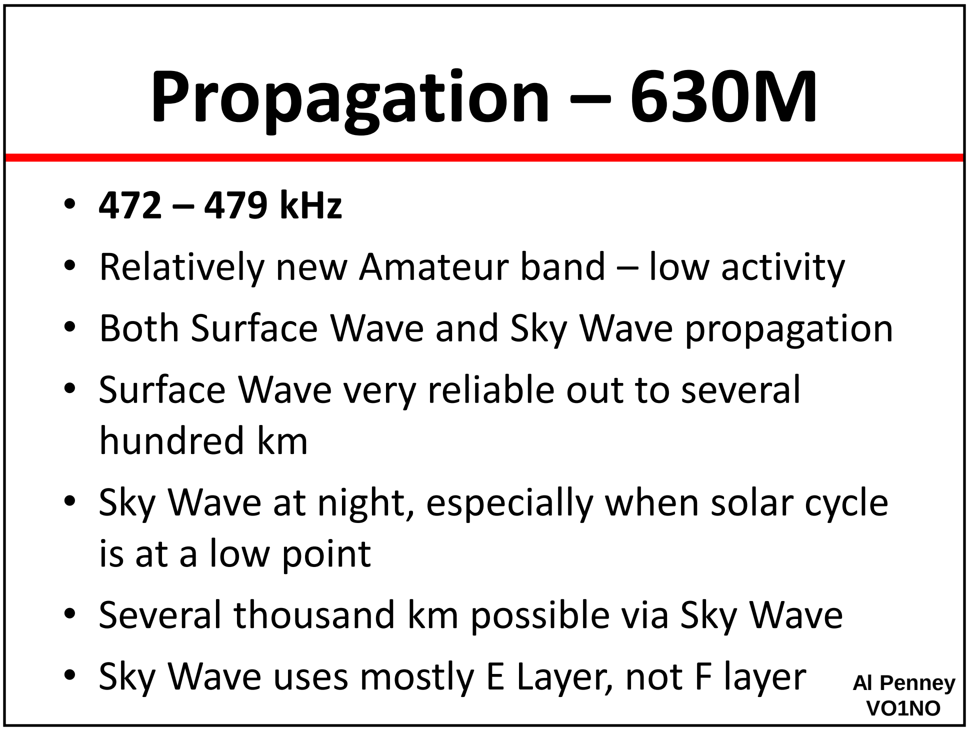
Al Penney
VO1NO

Attached are 2 files: the audio file is a recording of a single transmitted "dit", but arriving back at my receiver 3 times around the Earth. I have looped that audio 3 times in the file. The graphic is the actual wave form when the audio file is loaded into an audio analyzer. The side tone is the "bump" on the far left - the 3 return dits are on the right. Note the space between those dits. The calculated time for RF to travel -at the speed of light- around the Earth is approximately 138 ms. My measurement in the software confirms. The first value of 158 ms is the longer because the audio side tone does not match exactly the transmitted RF envelope as heard in the transceiver's speaker.

Time was 0913 local and my power was 1 kw. Antenna: 3 el SteppIR in bi-directional mode, so 1/2 the energy in each direction. Beam heading was 60-240. It's amazing that after 3 rev. there is still enuf energy left to be demodulated by the receiver. Obviously most of the path was chordal - meaning that it was an ionospheric "ducted" path and not a multi-hop path where each hop has ground contact. There would be too much energy lost this way.

Attached is a longer, continuous recording. Date, time and band is the file name. I set my keyer memory to transmit "E" with about 1.5 sec. between each dit. Each sequence is 5 dits long and you can hear the confirmation "beep" initiating each sequence. Most of the returns are 2x (3 dits = 1 side tone and 2 revs.) and only 3 or 4 instances of the 3rd rev.There may even be a weak 4th rev. at one point, but I could not clearly see it in the waveform - too close to the noise floor.

Pretty cool stuff. Al . You should have no trouble recreating at least 2 return dits by transmitting in an easterly direction in your morning. Pick as quiet a frequency as you can find. It seems that 15m works best, but I've done it on all bands from 20m to 10m inclusive.



Propagation – 630M

- **472 – 479 kHz**
- Relatively new Amateur band – low activity
- Both Surface Wave and Sky Wave propagation
- Surface Wave very reliable out to several hundred km
- Sky Wave at night, especially when solar cycle is at a low point
- Several thousand km possible via Sky Wave
- Sky Wave uses mostly E Layer, not F layer

Al Penney
VO1NO

Propagation on the 630m band is different in many respects from that in the HF spectrum. Because propagation will have an impact on how the band will be used, a quick description is in order.

Propagation at MF wavelengths is via both ground waves and skywaves. Ground waves, also know as surface waves, spread out from the transmitter along the surface of the Earth but instead of travelling in a straight line however, the radio signals tend to follow the curvature of the Earth. This is because currents are induced in the surface of the Earth, slowing the wave-front in this region, and causing the wave-front to tilt downwards. With the wave-front tilted in this direction it is able to curve around the Earth and be received well beyond the horizon.

Medium Wave (MW) broadcasting stations use ground waves to cover their listening areas. At MW wavelengths they can diffract over hills, and cover a radius of several hundred kilometers from the transmitter. Terrain with good conductivity gives the best result. Thus soil type and the moisture content are of importance. Sea water is by far the best, and rich agricultural, or marshy land is also good. Dry sandy terrain and city centres are much worse. This means sea paths are optimum, although even these are subject to variations due to the roughness of the sea, resulting on path losses being slightly dependent upon the weather.

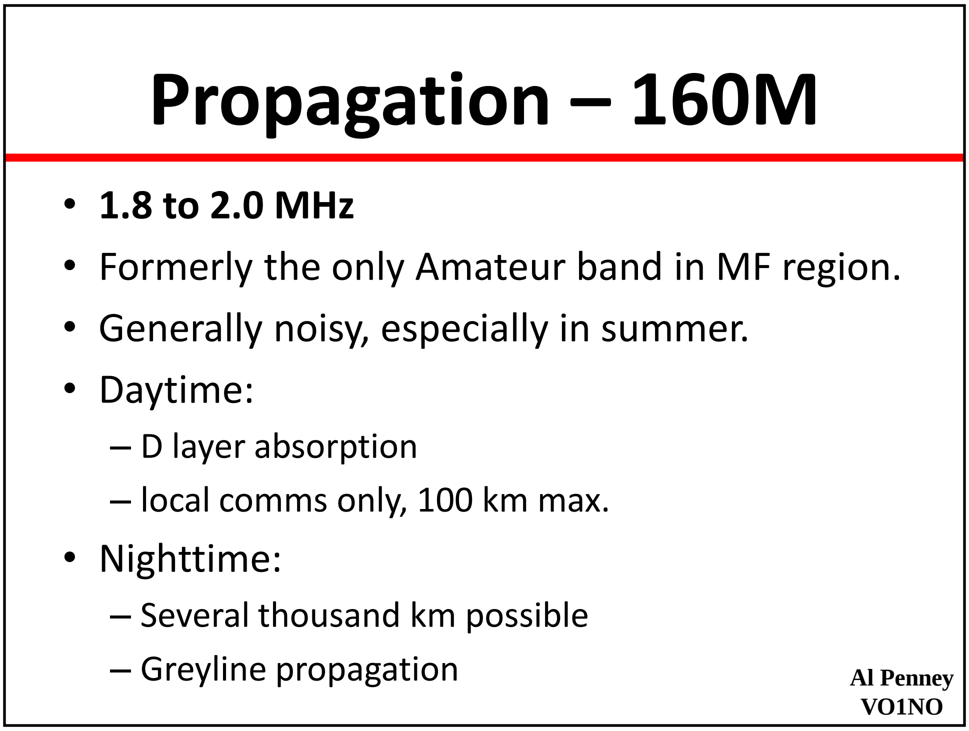
As the wavefront of the ground wave travels along the Earth's surface it is attenuated. While the degree of attenuation is dependent upon a variety of factors, the frequency of the radio signal is the major determining factor. Losses rise with increasing frequency. As a result it makes this form of propagation impracticable above the bottom end of the HF portion of the spectrum. Typically a signal at 3.0 MHz will suffer an attenuation that may be in the region of 20 to 60 dB more than one at 0.5 MHz over typical ground wave paths. In view of this it can be seen why even high power HF radio broadcast stations may only be audible for a few kilometers from the transmitting site via the ground wave. The ability for a MW signal to be reliably received hundreds of kilometers away via ground wave is a prime difference between MF and HF propagation.

MF can also travel longer distances via skywave propagation, in which radio waves radiated at an angle into the sky are refracted back to Earth by the ionosphere’s E and F layers. The D layer absorbs rather than refracts MF waves, interfering with skywave propagation. This happens when the ionosphere is heavily ionized, such as during the day, in summer and especially at times of high solar activity.

At night, especially in winter months and at times of low solar activity, the ionospheric D layer can virtually disappear. When this happens, MF radio waves can easily be received hundreds or even thousands of kilometers away as the signal will be refracted by the remaining E and F layers. Note that skywave propagation at MF is primarily due to the E layer however, so conventional HF propagation forecast software is often not suitable.

Latitude is also a very significant factor in determining the received strength of a sky-wave signal. MW skywave field strength decreases with increasing geomagnetic latitude. There is not much that Canadian Amateurs can do about that. The good news is that European broadcast band and MW DX’ers (listeners) at higher latitudes than most Canadians have still had much success copying weak signals.

The MF Amateur band is characterized by relatively stable carrier phase on received signals, accompanied by low Doppler shift. The band has very strong lightning interference, but this is mostly local, not the background of random impulse noise typical of the lower HF spectrum. There can also be considerable man-made interference. While there is multi-path reception, the path changes are slow. The slow fades can be very deep, and signals can be quite weak, so in order to have a conversation at typing speed on 630m, what is needed is a mode that is very sensitive, narrow band, has excellent impulse noise tolerance, but need not have strong phase or Doppler tolerance.



Propagation – 160M

- **1.8 to 2.0 MHz**
- Formerly the only Amateur band in MF region.
- Generally noisy, especially in summer.
- Daytime:
  - D layer absorption
  - local comms only, 100 km max.
- Nighttime:
  - Several thousand km possible
  - Greyline propagation

Al Penney
VO1NO

During the day propagation is limited to local contacts, but long distance contacts are possible at night, especially around sunrise and sunset and during periods of sunspot minima.

Much about ionospheric and propagation on 160 meters is still not completely understood. Phenomena such as "chordal hop" propagation are frequently observed, as well as other unexplained long-distance propagation mechanisms

Not much shorter than medium waves, at daytime the "top band" is deeply affected by the D-layer absorption and only waves entering the

ionosphere at very high angle can be reflected to the ground. At daytime this band is thus mainly dedicated to local QSOs by ground waves up

to distances reaching about 120 km. It is thus relatively quiet compared to the other HF bands. Checking my logs, I worked on this band most of

the time after the sunset. Indeed, at night the D-layer disappearing, low-angle signals reflect easier on the F-layer, and DX contacts are possible

at several thousands kilometers at the condition to use a suited antenna system. So this is a band to mainly use at night, and if you can, in winter

especially during the cycles of weak solar activities to reduce atmospheric noises. It is affected by the sunrise/sunset, weather conditions (noise

of thunderstorm) and the electron gyro-frequency.

160 Meters
1.8-2.0 MHz.
A neighbor to the AM Broadcast band just slightly higher in frequency, 160 has very similar conditions to what you hear on AM Broadcast, quite localized during the day, with long distance capability at night. During the summer months the long distances at night can be several hundreds of miles and during the winter it can be several thousand miles.
Lots of noise created by static crashes hinder communications in the summer months but very nice in the winter! When there is no static, seems like you can hear.....forever!

Propagation – 80M

- **3.5 to 4.0 MHz**
- Very popular band.
- D layer absorption in daylight, max 400 km.
- Several thousand km possible at night.
- Many regional nets in early evening.

Al Penney
VO1NO

As the maximum usable frequency for long distance communication seldom dips below 3.5 MHz anywhere on the planet, the main propagation barrier to long distance communication is heavy D-layer absorption during the daytime, ensuring that DX paths must be largely, although not entirely, in darkness. At times, there is pronounced dark-side gray-line propagation, which is most useful on polar routes, away from equatorial thunderstorm activity.

At higher latitudes, a noticeable skip zone sometimes appears on the band during nighttime hours in midwinter, which can be as much as 300 miles/500 km, rendering communication with closer stations impossible. This is not generally a problem at middle or equatorial latitudes, or for large parts of the year anywhere, but it does occasionally limit local wintertime traffic on the band in areas such as Northern Europe, the northern tier of the United States and Canada.

During spring and summer (year-round in the tropics), lightning from distant storms creates significantly higher background noise levels, often becoming an insurmountable obstacle to maintaining normal communications. Nearby convective weather activity during the summer months can make the band completely unusable, even for local communications. In the winter months during the peak years of the sunspot cycle, auroral effects can also render the band useless for hours at a time.

This band is similar to the 160m but the frequency increasing, the D-layer absorption begin to decrease as it is proportional to the inverse

square of the frequency. At daytime most contacts are worked with near countries, up to about 2000 km from your QTH. At night or using the

gray line it is possible to exceed 9000 km (e.g. Europe to W, UA or JA). If you wake up in winter a few hours before the sunrise to avoid

atmospheric noises you can work most DX stations (e.g. VK, ZL from Europe). In Region 1 the frequencies ranging between 3790-3800 kHz

are usually dedicated to DX hunters.

80 Meters
3.5-4.0 MHz.
80 Meters is very similar to 160 meters but with greater distances especially at night. 80 tends to be a very reliable band less subject to variations of the sunspot cycle and is used a lot for regular net operations and message handling and "local rag chewing".
Again can be very noise prone in the summer static. You will meet lots of "local yocals" and make some very good friends with the "local" gang that hang out here. Various states and groups seem to frequent a particular frequency so tune around.

Propagation – 40M

- **7.0 to 7.3 MHz**
- Similar to 80M, but overall greater distances possible.
- Worldwide communications at night.

Al Penney
VO1NO

This band supports both long distance (DX) communications between late afternoon and a few hours after sunrise, and short distance NVIS contacts during most daylight hours.

With its unique combination of intra- and intercontinental communications possibilities, 40 meters is considered a key band in building a winning HF contesting score during any part of the sunspot cycle.

This band is still under the influence of the D-layer and is the lowest band showing an appreciable skip distance, up to 500 km at night. At

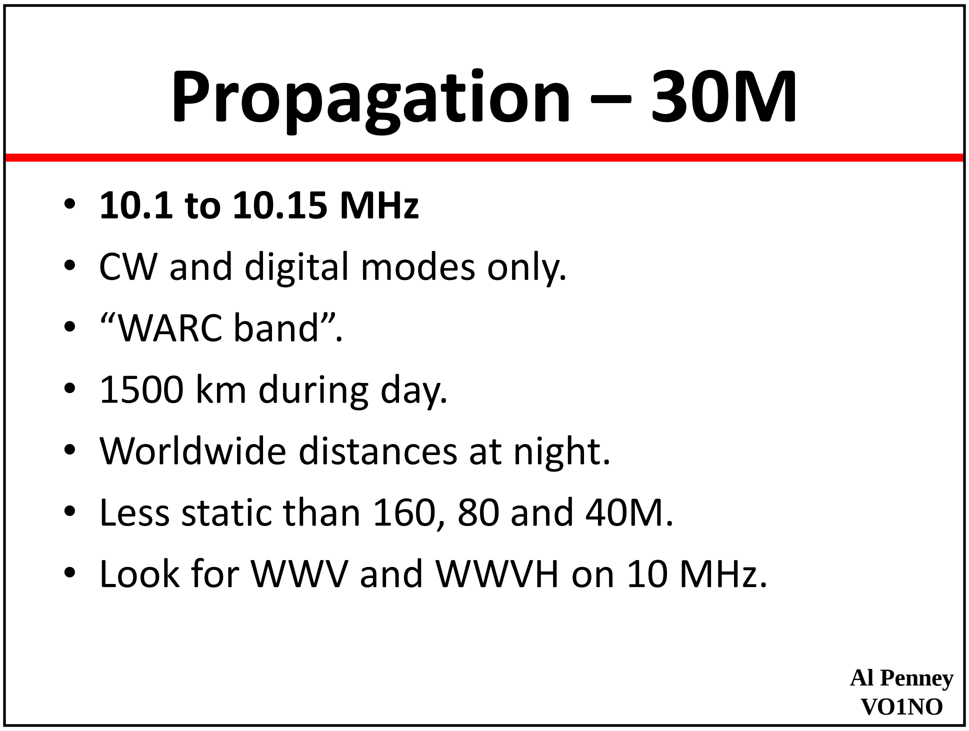
noon it is hard to work station located over 800 km away, while working with the gray line or at night, this band is open to DX contacts. This

band is slightly influenced by 11-year solar cycle. Atmospheric noises are still present but not as strong as on the lower bands. QSOs can

however be difficult to confirm during the summer months but signals are not completely overriden by static. This is also one of the most

crowded band and do not be surprised to find in Europe and during weekends each station within 1 kHz or so from each another.

40 Meters
7.0-7.3 MHz
This is many ham's favorite band. It is always open somewhere. During the summer daytime distances of 300-400 miles and night time distances of 1000 miles are very common. Winter days with 500 miles or more are usual and night time conditions bring DX intercontinental communications.This band is shared with short-wave broadcast from countries outside of North America. Between these interfering signals a ham with a reasonable station can work stations worldwide if you can find a clear spot!. Not as affected by the sunspot cycle as 20-10 meters. Many nets frequent 40 meters both day and night.
Check out the 1721 hf Group on 40 Meters (Just a friendly bunch of Hams who think they are one big family! Join them!)



Propagation – 30M

- **10.1 to 10.15 MHz**
- CW and digital modes only.
- “WARC band”.
- 1500 km during day.
- Worldwide distances at night.
- Less static than 160, 80 and 40M.
- Look for WWV and WWVH on 10 MHz.

Al Penney
VO1NO

Conditions are similar to the 40m band but it works better in summer showing some of the properties of the 20m band. As communications reach 1600 km at daytime and 12000 km or more at night, this band is considered as open 24 hours a day. It is also band the least affected by variations of the solar cycle. However this band is affected by the ionization level of E and F-layers and at night, during the minimum of the solar cycle, it is regularly above the MUF for most DX paths, becoming thus the higher workable frequency for daytime communications. With very few exceptions this band is reserved for digimodes and CW.

30 Meters
10.100-10.150 MHz.
A lot like 40 meters but can only be used on CW and RTTY. No broadcast interference and has slightly longer range than 40 meters. Daytime ranges of 1000 miles are quite common.

Propagation – 20M

- **14.0 to 14.35 MHz**
- Most popular DX band!
- Worldwide communications.
- Open around the clock at solar max.
- Open in daytime at solar minimum.
- Look to east in morning, and west later in day.

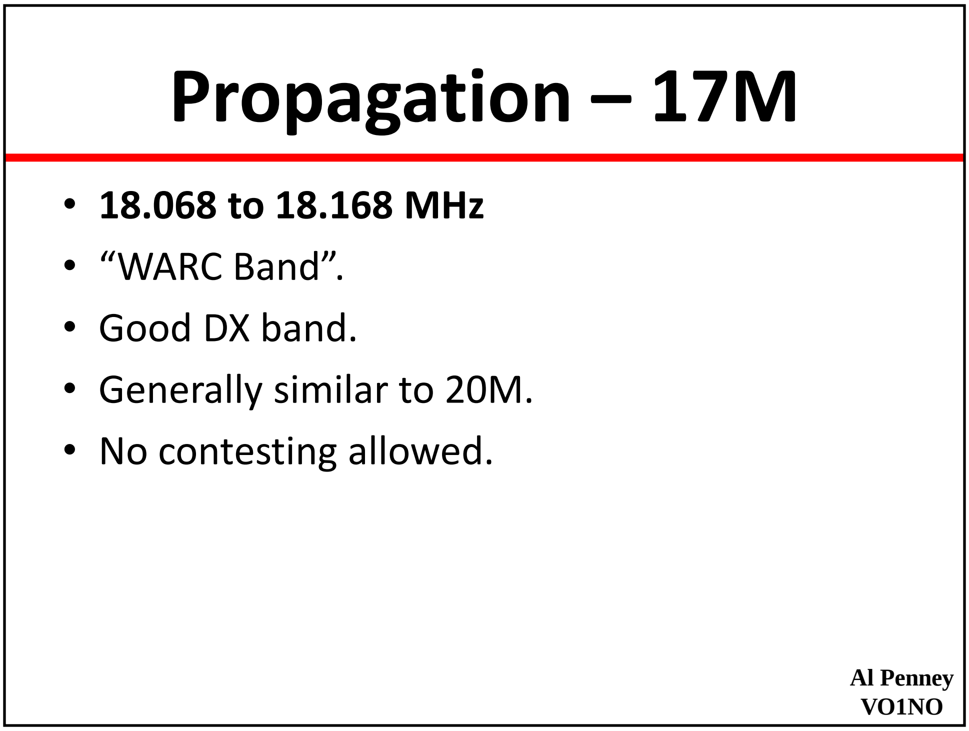
Al Penney
VO1NO

If you ask to active amateurs, including listeners, what is the band they use the most, taking all modes together and over a full solar cycle, without hesitation all will place the 20 meter band first for its "overall performance". Indeed, the 20m band is the DX band per excellence and is considered by many hams as the most reliable band for hunting DX stations because atmospheric noises are weak.

With some rare exceptions (blackouts) whatever your position in the 11-year solar cycle, world-wide communications are open at daytime on the 20m band. It is practically usable all the day long as soon as there is propagation, and mainly in summer, and all the more during periods of high solar activity. This is only during the winter months in condition of low solar activity that this band closes down in the late afternoon and is unusable at night.

The 20m band shows an appreciable skip distance reaching about 700 km at daytime and exceeding 1600 km at night. It is thus not suited to local QSOs. This can partly be solved placing the antenna at low height to get a high takeoff angle.

20 Meters
14.000-14.350 MHz.
Just about all of the serious DXers hang out on 20 meters!
This can be a VERY exciting band with some of the best DX found on any band. Around the world daytime communications are generally possible and when the sunspot cycle is peaking 20 can be used around the clock! Not likely to be used for short-range communications. The only way to work someone a few hundred miles away would be scatter or possibly "long path". Ground wave signals of about 50-75 miles might be all you would expect. At the bottom of the sunspot cycle, openings to other continents are short, rare and few and far between!



Propagation – 17M

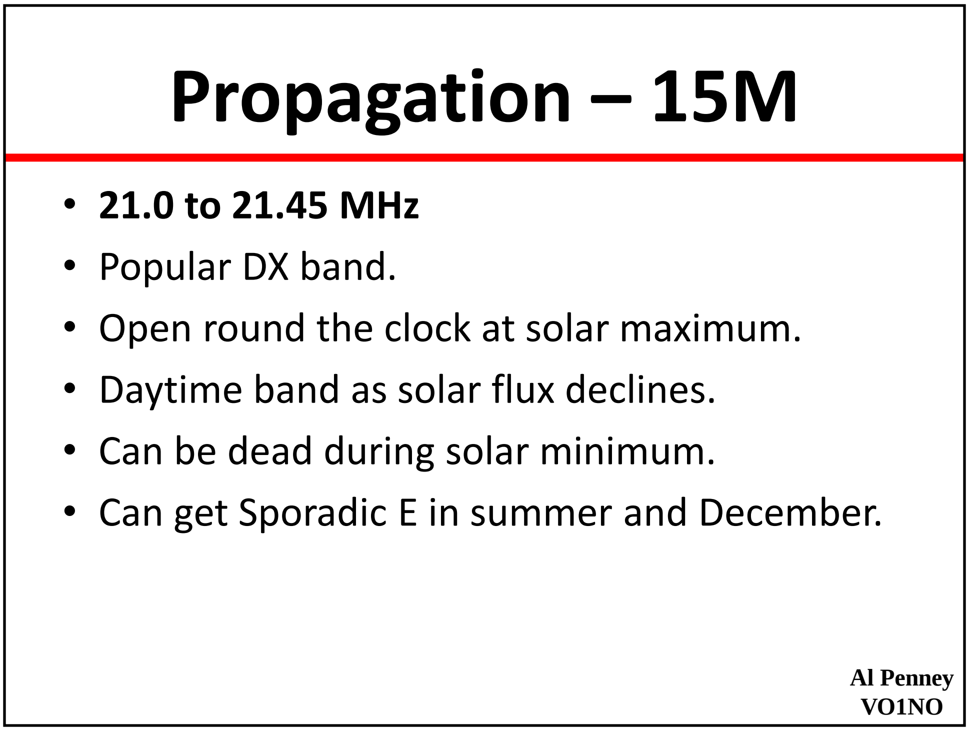
- **18.068 to 18.168 MHz**
- “WARC Band”.
- Good DX band.
- Generally similar to 20M.
- No contesting allowed.

Al Penney
VO1NO

This band is similar to the 15m band in many respects although its activity is affected by the 11-year solar cycle but not as pronounced. During the maximum of the solar activity, this band is open all the day, up to well after the sunset. When the solar activity decreases this band closes earlier, just after the sunset. At the minimum of the solar cycle, this band opens to middle or equatorial latitudes, allowing north-south contacts but mainly around noon. This band is this mainly open at daytime and regularly opens before the others. The band disappears at night.

17 Meters

18.068-18.168 MHz.
Band conditions are very similar to 20 meters. This seems to be a very popular band when hams go mobile and lots of fun can be expected. You will meet some of the finest Hams in the world on 17 meters. A very cordial band!



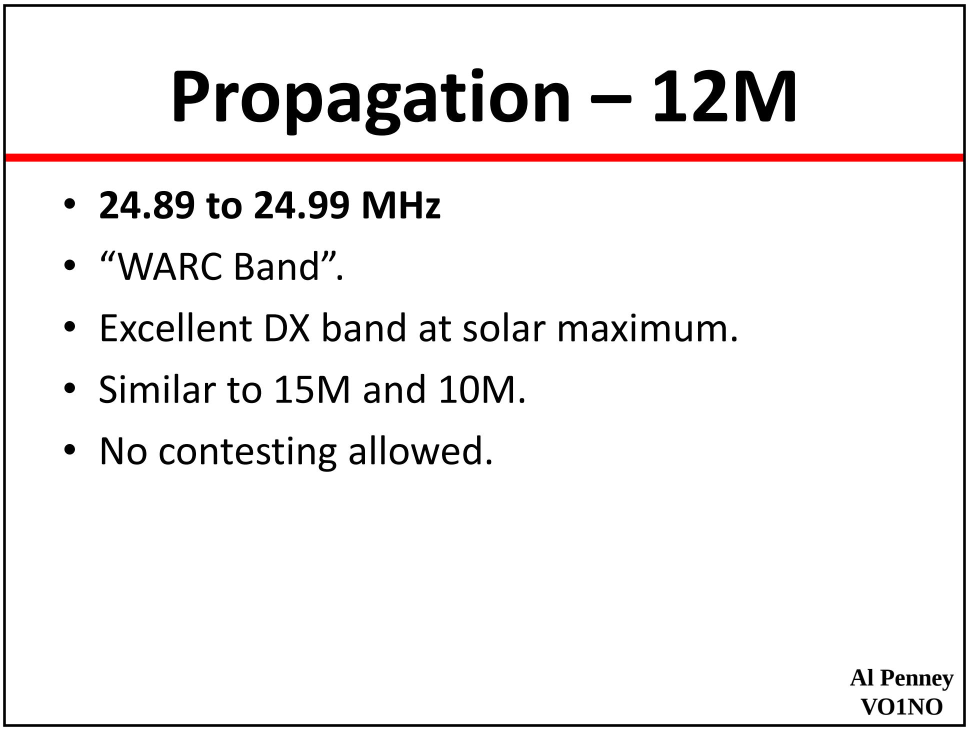
Propagation – 15M

- **21.0 to 21.45 MHz**
- Popular DX band.
- Open round the clock at solar maximum.
- Daytime band as solar flux declines.
- Can be dead during solar minimum.
- Can get Sporadic E in summer and December.

Al Penney
VO1NO

This band works in the same conditions as the 17m band and is considered by most amateurs as a quieter alternative to the 20m band. It shows however a greater sensitivity to the fluctuations of the solar cycle. It is mainly used at daytime but during the peaks of the solar acitivity DX contacts can extend to the night. On the contrary during the minimum of the solar cycle, this band can be closed excepted for a few transequatorial paths. With the 12 and 10m this band is also subject to a weak E-sporadic activity mainly in early summer and mid-winter. The band vanishes at night.

15 Meters
21.000-21.450 MHz.
A lot like 20 meters but a bit more flakey.. More influenced by the sunspot cycle. Much less night time activity than 20 meters but at the peak of the sunspot cycle, 15 can provide much greater distances!
On the down side, at the bottom of the cycle, 15 may not open for days.



Propagation – 12M

- **24.89 to 24.99 MHz**
- “WARC Band”.
- Excellent DX band at solar maximum.
- Similar to 15M and 10M.
- No contesting allowed.

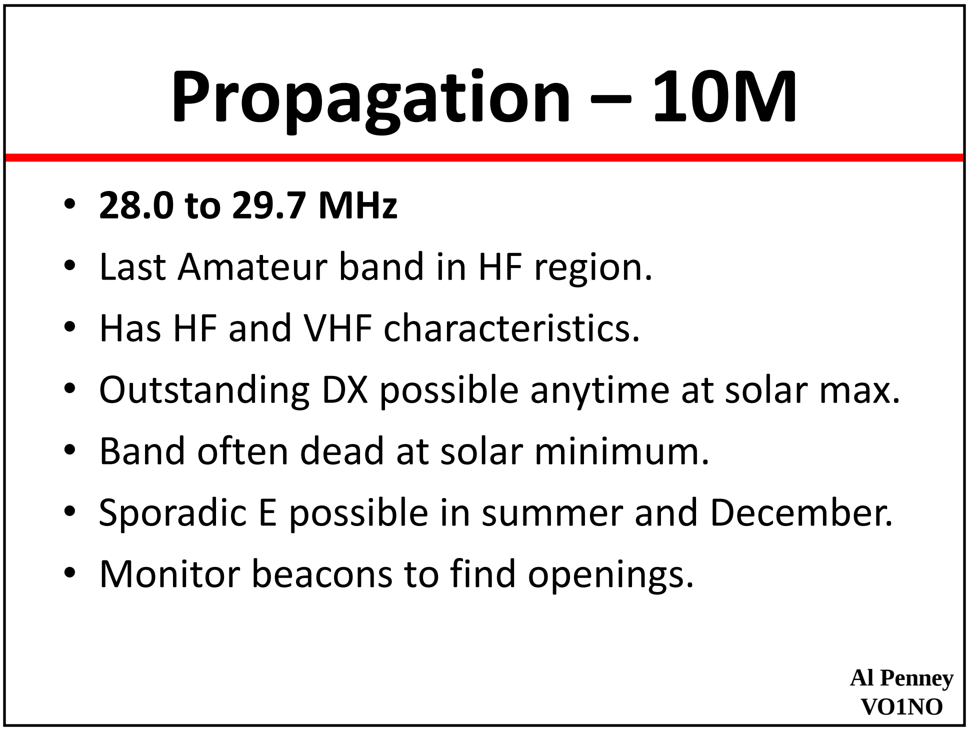
Al Penney
VO1NO

This band is very depending of the solar cycle and combines the best from the 15 and 10m bands. One year before the paroxysm of the solar activity and up to one year after this peak, this band allows DX contacts until after the sunset with practically any kind of antenna. On the contrary, when the solar activity slow down, this band is open at mid and low latitudes but only at daytime with very few openings after the sunset. Near the minimum of the solar cycle this band becomes unusable, excepting at daytime for the highest latitudes with some north-south openings. This band is open to E-sporadic traffic between the late spring and early winter. The band vanishes at night.

12 Meters

24.890-24.990 MHz.

Very heavily influenced by the sunspot cycle. At the bottom of the cycle it is suitable only for very short distance groundwave communications only, for long periods of time. At the peak of the cycle it is capable of communications over thousands of miles with a minimum of equipment. Another nice mobile band when conditions are right.



Propagation – 10M

- **28.0 to 29.7 MHz**
- Last Amateur band in HF region.
- Has HF and VHF characteristics.
- Outstanding DX possible anytime at solar max.
- Band often dead at solar minimum.
- Sporadic E possible in summer and December.
- Monitor beacons to find openings.

Al Penney
VO1NO

This band works in the same conditions as the 12m band but is characterized by a great variability according the solar activity. During the peaks of the solar activity DX contacts can be established with very low power and over 12000 km away. It is mainly a daytime band but remains open a few hours after sunset. During moderate solar activity this band open near noon for some trans-equatorial communications but is closed for the higher latitudes. During the minimum of the solar activity this band is straight out dead. There are however some exceptional openings for ionoscatter, meteor scatter and E-sporadic. This latter occurs mainly between April and early August allowing multihop communication up to 4100 km. This band is relatively quiet compared to the 15m band for example but it works globally very well for DX communications throughout the solar cycle.

10 Meters

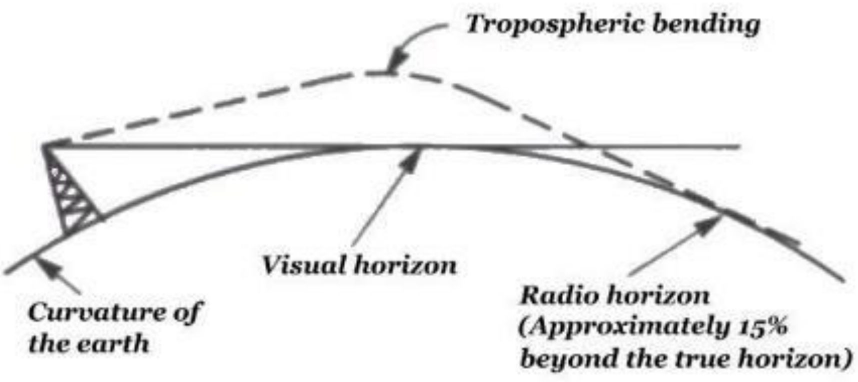
28.000-29.7000 MHz.

This can be a FUN band, when it is open!

This is the HF band most heavily affected by sunspots and the sunspot cycle and it can be erratic and exciting at the same time with lots of Dx for the qsl hunter or just as a fun band. Minimum power and simple antennas can bring you a hundred countries in a short period of time when the sunspot cycle is rising towards the peak. Five watts or even less can work half way around the earth!. Ground wave coverage is 25 miles or so. Lots of beacon stations worldwide for you DX hunters. If you can hear beacons that run very low power on 10 Meters, there is an opening to that part of the world.....keep trying!

VHF / UHF Propagation

- In general, frequencies above 30 MHz not affected by ionosphere.
- Radio Horizon is actually ~ **1.15 x Visual Horizon**.
- This is due to slight effect of refraction.



Al Penney
VO1NO

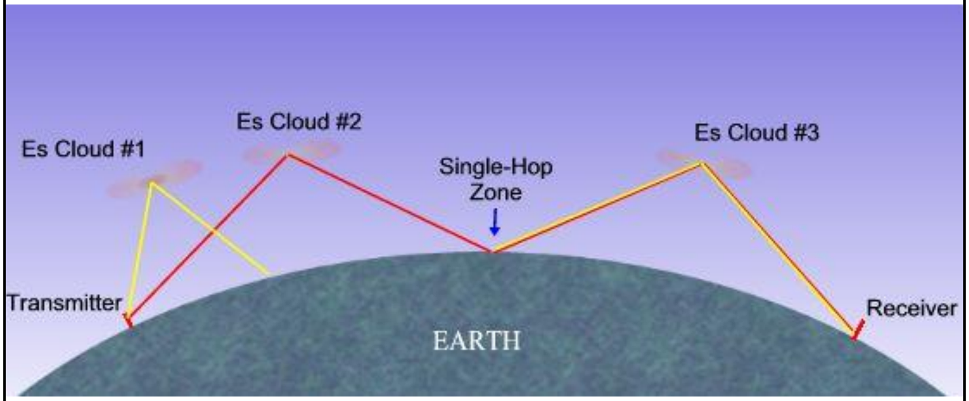
It might be thought that most radio communications links at VHF and above follow a line of sight path. This is not strictly true and it is found that even under normal conditions radio signals are able to travel or propagate over distances that are greater than the line of sight.

The reason for the increase in distance traveled by the radio signals is that they are refracted by small changes that exist in the Earth's atmosphere close to the ground. It is found that the refractive index of the air close to the ground is very slightly higher than that higher up. As a result the radio signals are bent towards the area of higher refractive index, which is closer to the ground. It thereby extends the range of the radio signals.

The refractive index of the atmosphere varies according to a variety of factors. Temperature, atmospheric pressure and water vapour pressure all influence the value. Even small changes in these variables can make a significant difference because radio signals can be refracted over whole of the signal path and this may extend for many kilometres.

http://www.dxinfocentre.com/propagation/tr-modes.htm

Sporadic E (Es)



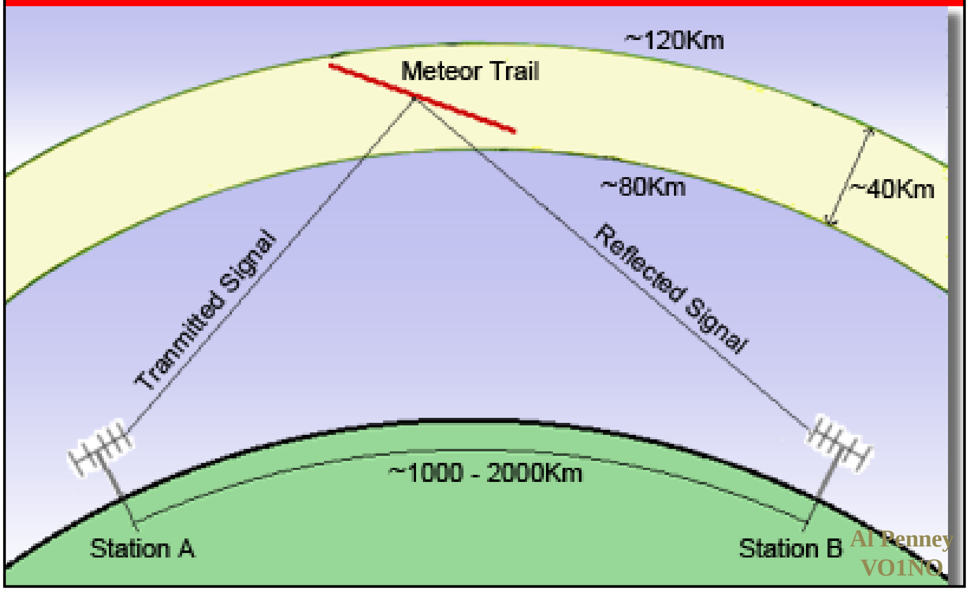
Al Penney
VO1NO

Sporadic E or **E_s** is an unusual form of radio propagation using characteristics of the Earth's ionosphere. Whereas most forms of skywave propagation use the normal and cyclic ionization properties of the ionosphere's F region to refract (or "bend") radio signals back toward the Earth's surface, sporadic E propagation bounces signals off smaller "clouds" of unusually ionized atmospheric gas in the lower E region (located at altitudes of approx. 90 to 160 km). This occasionally allows for long-distance communication at VHF frequencies not usually well-suited to such communication.

Communication distances of 800–2200 km can occur using a single E_s cloud. This variability in distance depends on a number of factors, including cloud height and density. MUF also varies widely, but most commonly falls in the 25 – 150 MHz range, which includes the FM broadcast band (87.5–108 MHz), Band I VHF television (American channels 2-6, Russian channels 1-3, and European channels 2-4, the latter no longer used in Western Europe), CB radio (27 MHz) and the amateur radio 2-meter, 6-meter, and 10-meter bands. Strong events have allowed propagation at frequencies as high as 250 MHz.

As its name suggests, sporadic E is an abnormal event, but can happen at almost any time; it does, however, display seasonal patterns. Sporadic E activity peaks predictably in the summertime in both hemispheres. In North America, the peak is most noticeable in mid-to-late June, trailing off through late July and into early August. A much smaller peak is seen around the winter solstice. Activity usually begins in mid-December in the southern hemisphere, with the days immediately after Christmas being the most active period.

Meteor Scatter



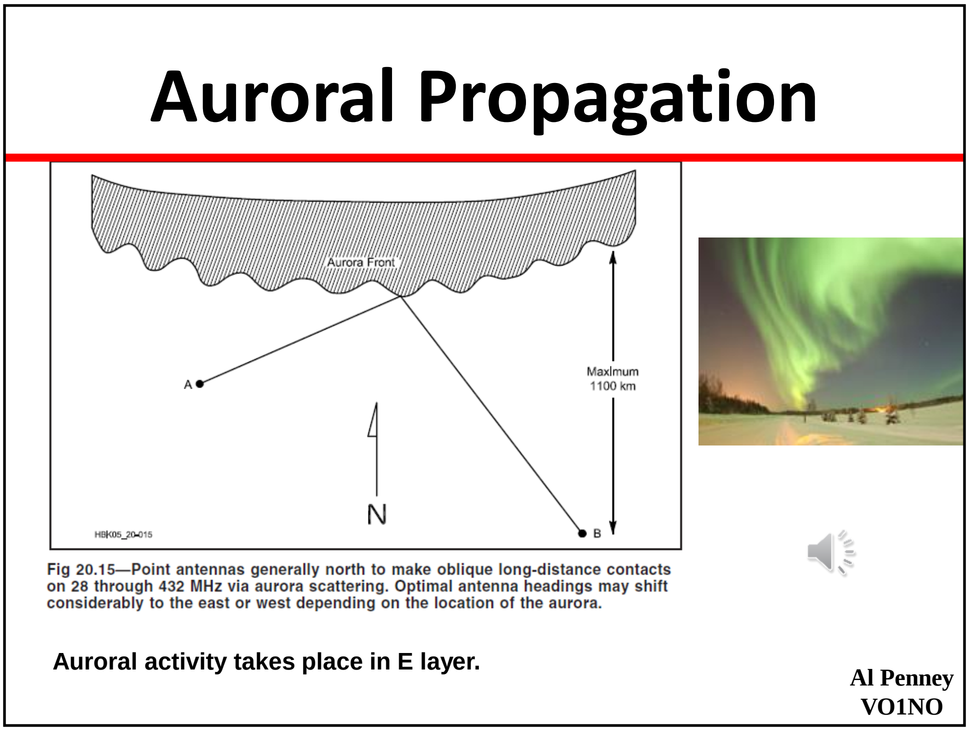
Meteor burst communications (**MBC**), also referred to as **meteor scatter communications**, is a radio propagation mode that exploits the ionized trails of meteors during atmospheric entry to **establish brief communications paths between radio stations up to 2,250 kilometres (1,400 mi) apart.**

As the earth moves along its orbital path, millions of particles known as meteors enter the earth's atmosphere every day, a small fraction of which have properties useful for point to point communication. When these meteors begin to burn up, they create a trail of ionized particles in the **E layer of the atmosphere** that can persist for up to several seconds. The ionization trails can be very dense and thus used to reflect radio waves. The frequencies that can be reflected by any particular ion trail are determined by the intensity of the ionization created by the meteor, often a function of the initial size of the particle, and are generally between 30 MHz and 50 MHz.

The distance over which communications can be established is determined by the altitude at which the ionization is created, the location over the surface of the Earth where the meteor is falling, the angle of entry into the atmosphere, and the relative locations of the stations attempting to establish communications. Because these ionization trails only exist for fractions of a second to as long as a few seconds in duration, they create only brief windows of opportunity for communications.

Most Amateur meteor scatter communications is conducted between radio stations that are engaged in a precise schedule of transmission and reception periods. Because the presence of a meteor trail at a suitable location between two stations cannot be predicted, stations attempting meteor scatter communications must transmit the same information repeatedly until an acknowledgement of reception from the other station is received. Established protocols are employed to regulate the progress of information flow between stations. While a single meteor may create an ion trail that supports several steps of the communications protocol, often a complete exchange of information requires several meteors and a long period of time to complete.

Any form of communications mode can be used for meteor scatter communications. Single sideband audio transmission has been popular among amateur radio operators in North America attempting to establish contact with other stations during meteor showers without planning a schedule in advance with the other station. The use of Morse code has been more popular in Europe, where amateur radio operators used modified tape recorders, and later computer programs, to send messages at transmission speeds as high as 800 words per minute. Stations receiving these bursts of information record the signal and play it back at a slower speed to copy the content of the transmission. Since 2000, several digital modes implemented by computer programs have replaced voice and Morse code communications in popularity. The most popular mode for amateur radio operations is MSK144, which is implemented in the WSJT-X software.



Auroral Propagation

Fig 20.15—Point antennas generally north to make oblique long-distance contacts on 28 through 432 MHz via aurora scattering. Optimal antenna headings may shift considerably to the east or west depending on the location of the aurora.

Auroral activity takes place in E layer.

Al Penney
VO1NO

Aurora

Radar signals as high as 3000 MHz have been scattered by the *aurora borealis* or northern lights (*aurora australis* in the Southern Hemisphere), but amateur aurora contacts are common only from 28 through 432 MHz. By pointing directional antennas generally north toward the center of aurora activity, oblique paths between stations up to 2300 km (1400 mi) apart can be completed.

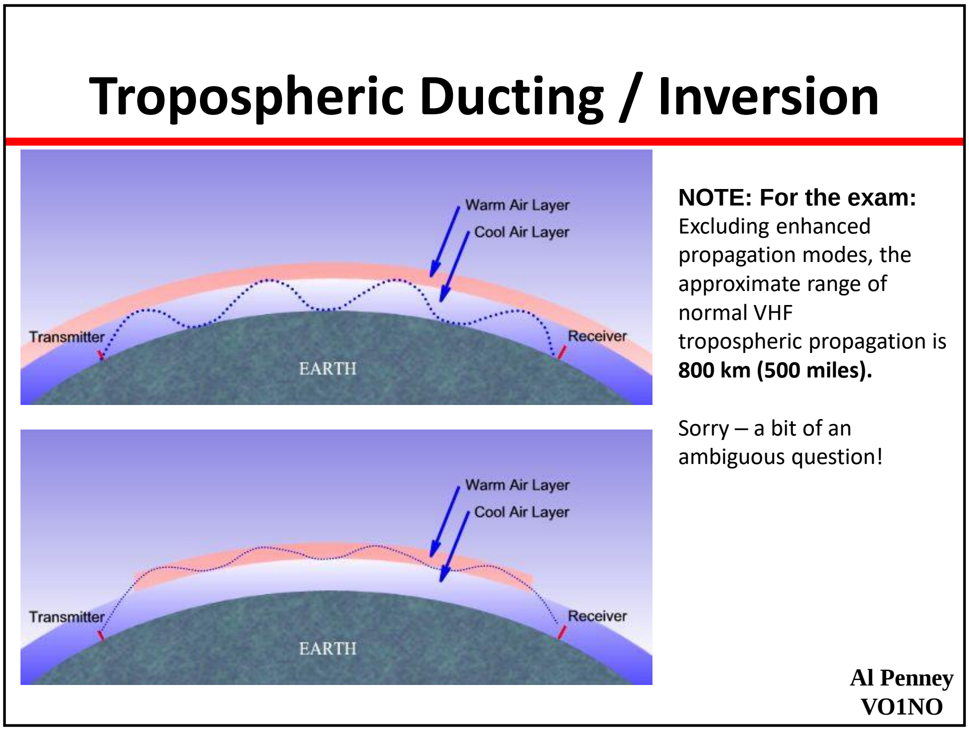
High power and large antennas are not necessary. Stations with small Yagis and as little as 10 W output have used auroras on frequencies as high as 432 MHz, but contacts at 902 MHz and higher are exceedingly rare. Auroral propagation works just as well in the Southern Hemisphere, in which case antennas must be pointed south.

The appearance of auroras is closely linked to solar activity. During massive geomagnetic storms, high-energy particles flow into the ionosphere near the polar regions, where they ionize the gases of the E layer and higher. This unusual ionization produces spectacular visual auroral displays, which often spread southward into the midlatitudes. Auroral ionization in the E layer scatters radio signals in the VHF and UHF ranges.

Aurora-scattered signals are easy to identify. On 28- and 50-MHz SSB, signals sound very distorted and somewhat wider than normal; at 144 MHz and above, the distortion may be so severe that only CW is useful. Auroral CW signals have a distinctive note variously described as a buzz, hiss or mushy sound. This characteristic auroral signal is due to Doppler broadening, caused by the movement of electrons within the aurora. An additional Doppler shift of 1 kHz or more may be evident at 144 MHz and several kilohertz at 432 MHz. This second Doppler shift is the result of massive electrical currents that sweep electrons toward the sun side of the Earth during magnetic storms. Doppler shift and distortion increase with higher frequencies, while signal strength dramatically decreases.

It is not necessary to see an aurora to make auroral contacts. Useful auroras may be 500-1000 km (310-620 mi) away and below the visual horizon. Antennas should be pointed generally north and then probed east and west to peak signals, because auroral ionization is field aligned. This means that for any pair of stations, there is an optimal direction for aurora scatter. Offsets from north are usually greatest when the aurora is closest and often provide the longest contacts. There may be some advantage to antennas that can be elevated, especially when auroras are high in the sky.

Al Penney
VO1NO



Tropospheric Ducting / Inversion

NOTE: For the exam: Excluding enhanced propagation modes, the approximate range of normal VHF tropospheric propagation is **800 km (500 miles).**

Sorry – a bit of an ambiguous question!

Al Penney
VO1NO

The troposphere is the layer of atmosphere closest to earth. It is approximately 10km deep on average but can extend to 20km in tropical areas.

"Ducting" effects occur primarily because of temperature inversions at a height of between 500m and 1500m, and occasionally up to 3000m. Such inversions are not caused by local "weather" or terrain, but rather by climatic conditions such as frontal boundaries. Temperature inversions are usually layers rather than sharp lines separating regions of different temperature.

The thickness of the inversion layer affects the LUF (Lowest usable frequency) – thinner layers only propagate higher frequencies such as microwaves, thicker layers can be used into lower frequency regions of the spectrum.

When ducting occurs, signals travel along and within the inversion layer, reflected off its boundaries.

Tropospheric ducting is a type of radio propagation that tends to happen during periods of stable, anticyclonic weather. In this propagation method, when the signal encounters a rise in temperature in the atmosphere instead of the normal decrease (known as a temperature inversion), the higher refractive index of the atmosphere there will cause the signal to be bent. Tropospheric ducting affects all frequencies, and signals enhanced this way tend to travel up to 800 miles (1,300 km) (though some people have received "tropo" beyond 1,000 miles / 1,600 km), while with tropospheric-bending, stable signals with good signal strength from 500+ miles (800+ km) away are not uncommon when the refractive index of the atmosphere is fairly high.

Tropospheric ducting of radio and television signals is relatively common during the summer and autumn months, and is the result of change in the refractive index of the atmosphere at the boundary between air masses of different temperatures and humidities. Using an analogy, it can be said that the denser air at ground level slows the wave front a little more than does the rare upper air, imparting a downward curve to the wave travel.

Ducting can occur on a very large scale when a large mass of cold air is overrun by warm air. This is termed a temperature inversion, and the boundary between the two air masses may extend for 1,000 miles (1,600 km) or more along a stationary weather front.

Temperature inversions occur most frequently along coastal areas bordering large bodies of water. This is the result of natural onshore movement of cool, humid air shortly after sunset when the ground air cools more quickly than the upper air layers. The same action may take place in the morning when the rising sun warms the upper layers.

Even though tropospheric ducting has been occasionally observed down to 40 MHz, the signal levels are usually very weak. Higher frequencies above 90 MHz are generally more favourably propagated.

High mountainous areas and undulating terrain between the transmitter and receiver can form an effective barrier to tropospheric signals. Ideally, a relatively flat land path between the transmitter and receiver is ideal for tropospheric ducting. Sea paths also tend to produce superior results.

In certain parts of the world, notably the Mediterranean Sea and the Persian Gulf, tropospheric ducting conditions can become established for many months of the year to the extent that viewers regularly receive quality reception of signals over distances of 1,000 miles (1,600 km). Such conditions are normally optimum during very hot settled summer weather.

Tropospheric ducting over water, particularly between California and Hawaii, Brazil and Africa, Australia and New Zealand, Australia and Indonesia, Strait of Florida, and Bahrain and Pakistan, has produced VHF/UHF reception ranging from 1000 to 3,000 miles (1,600 – 4,800 km). A US listening post was built in Ethiopia to exploit a common ducting of signals from southern Russia.

Tropospheric signals exhibit a slow cycle of fading.

Weather Suitable for a Duct – Tropospheric ducting most often occurs because of a dramatic increase in temperature at higher altitudes. If the temperature inversion layer has a lower humidity than the air below or above it, the refractive index of the layer will be enhanced further. There are several common weather conditions that often bring about strong temperature inversions.

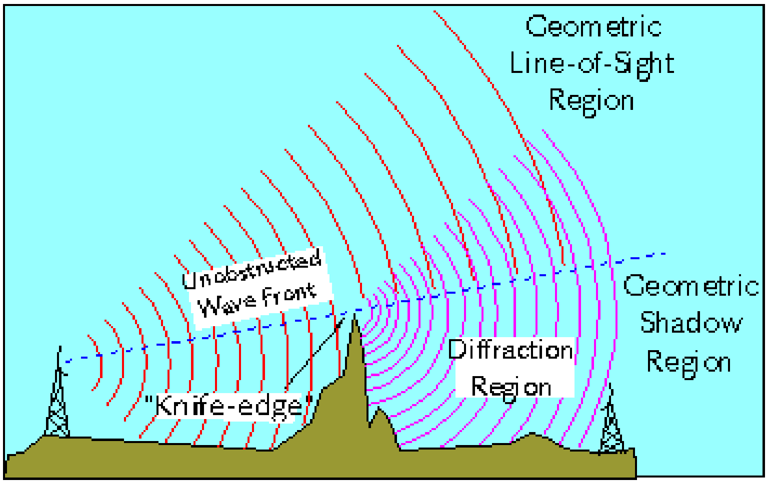
While not usually the cause of strong ducting, radiation inversions can bring about pronounced signal enhancement, extending the DX range up to a few hundred miles. This is probably the the most common and widespread form of inversion a DXer is likely to encounter on a regular basis.

A radiation inversion forms over land after sunset. The Earth cools by radiating heat into space. This is a progressive process where the radiation of surface heat upwards causes further cooling at the Earth's surface as cooler air moves in to replace the upward moving warm air. At higher altitudes the air tends to cool more slowly, thus setting up the inversion. This process often continues all the way through the night until dawn, sometimes producing inversion layers at 1,000 to 2,000 feet above the ground. Radiation inversions are most common during the summer months on clear, calm nights.

The effect is diminished by blowing winds, cloud cover and wet ground. Radiation inversions are often more pronounced in dry climates, in valleys and over large expanses of flat, open ground.

http://www.dxinfocentre.com/propagation/tr-modes.htm

Knife-Edge Diffraction



knife-edge effect

Al Penney
VO1NO

In electromagnetic wave propagation, the **knife-edge effect** or **edge diffraction** is a redirection by diffraction of a portion of the incident radiation that strikes a well-defined obstacle such as a mountain range or the edge of a building.

The knife-edge effect is explained by **Huygens–Fresnel principle, which states that a well-defined obstruction to an electromagnetic wave acts as a secondary source, and creates a new wavefront**. This new wavefront propagates into the geometric shadow area of the obstacle.

Diffraction : At first sight the shadow cast by a small object under strong light is very sharp. But examined closely, we can see that

the shadow borders are not at all sharp. In fact due to its high frequency the light bends around the edge of the object and tends to make the borders of it shadow lighter. That

means that some light reaches well some places that we considered as plunged into darkness. The same effect applies to radio waves. A spot located out of sight from a transmitter, say

behind a hill, can receive weakly its emissions because its signals are bending gradually by diffraction and can reach the remote receiver.

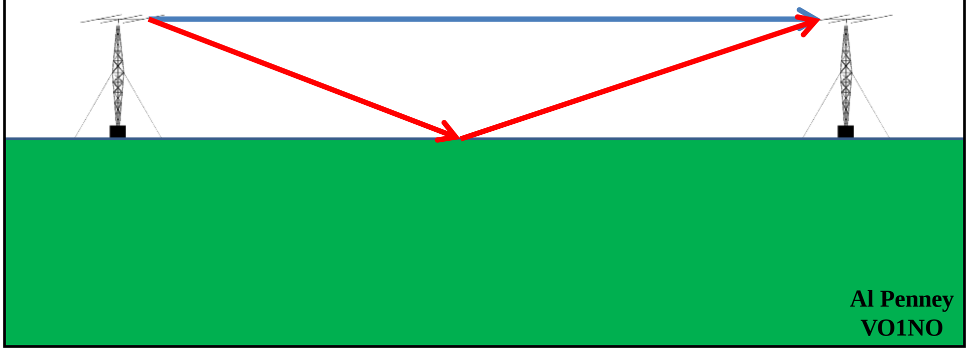
This effect has practically no influence in HF because waves arrive usually to the receiver by many other means such as refraction or reflection in the upper atmosphere, including

sometimes ground waves if the transmitter is not too far (say 150-200 km away). Note that if you live near the bottom of a valley, there are some chance that you had a hill or

a montain range just behind your house. If the relief is high and the landscape very close, in HF and upper bands this direction will be simply blocked up for Yagi's. You are "condemned" in using a high-end vertical antenna that, thanks to its omnidirectional pattern and vertical polarization will help you in jumping over this obstacle.

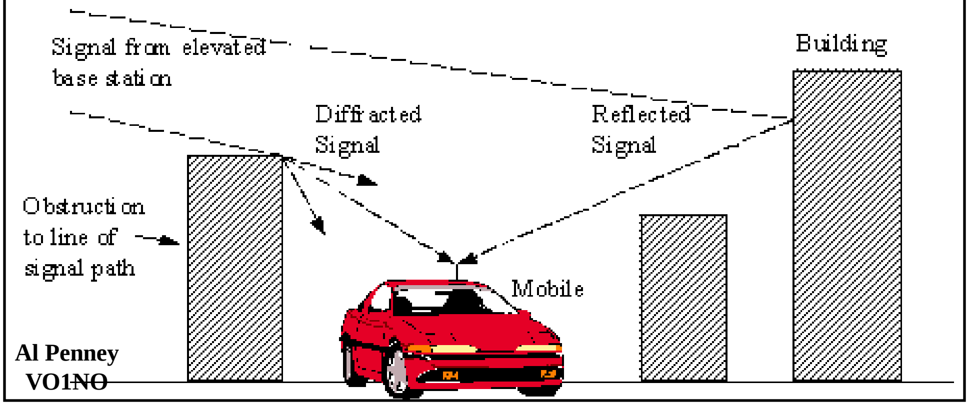
Interfering together, all these effects tend to replace the fine straight path followed by radio waves by a sort of large undulating and curved beam that widen as the distance and frequency increase and scatters in the atmosphere just like the light. This is even all benefit for radio amateurs that can receive by these means signals under conditions as unexpected as behind hills or thanks to atmospheric ducting or auroral events, other modes of traffic that we will review on the next pages.

Flat Terrain



Even flat terrain can result in multipath propagation that can cause fading.

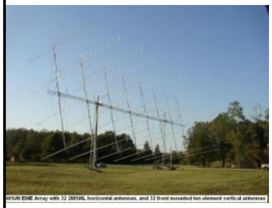
Concrete Jungle

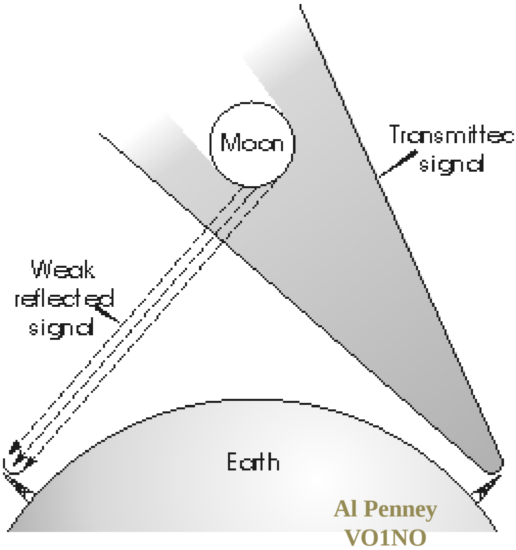


**Al Penney
VO1NO**

Reflection, diffraction and shadowing occurs frequently in cities, and its effect and extent is not readily predictable.

Moonbounce / EME


W5UN EME Array with 32 2M5WL horizontal antennas, and 32 front mounted ten element vertical antennas



Al Penney
VO1NO

Earth–Moon–Earth communication (**EME**), also known as **Moon bounce**, is a radio communications technique that relies on the propagation of radio waves from an Earth-based transmitter directed via reflection from the surface of the Moon back to an Earth-based receiver.

Amateur radio (ham) operators utilize EME for two-way communications. EME presents significant challenges to amateur operators interested in weak signal communication. EME provides the longest communications path any two stations on Earth can use.

Amateur frequency bands from 50 MHz to 47 GHz have been used successfully, but most EME communications are on the 2 meter, 70-centimeter or 23-centimeter bands. Common modulation modes are continuous wave with Morse code, digital (JT65) and when the link budgets allow, voice.

Recent advances in digital signal processing have allowed EME contacts, admittedly with low data rate, to take place with powers in the order of 100 Watts and a single Yagi–Uda antenna.

Echo delay and time spread

Radio waves propagate in vacuum at the speed of light *c*, exactly 299,792,458 m/s. Propagation time to the Moon and back ranges from 2.4 to 2.7 seconds, with an average of 2.56 seconds (distance from Earth to the Moon is 384,400 km).

The Moon is nearly spherical, and its radius corresponds to about 5.8 milliseconds of wave travel time. The trailing parts of an echo, reflected from irregular surface features near the edge of the lunar disk, are delayed from the leading edge by as much as twice this value.

Most of the Moon's surface appears relatively smooth at the typical microwave wavelengths used for amateur EME. Most amateurs do EME contacts below 6 GHz, and differences in the moon's reflectivity are somewhat hard to discern above 1 GHz.

Lunar reflections are by nature quasi-specular (like those from a shiny ball bearing). The power useful for communication is mostly reflected from a small region near the center of the disk. The effective time spread of an echo amounts to no more than 0.1 ms.

Antenna polarization for EME stations must consider that reflection from a smooth surface preserves linear polarization but reverses the sense of circular polarizations.

At shorter wavelengths the lunar surface appears increasingly rough, so reflections at 10 GHz and above contain a significant diffuse component as well as a quasi-specular component. The diffuse component is depolarized, and can be viewed as a source of low level system noise. Significant portions of the diffused component arise from regions farther out toward the lunar rim. The median time spread can then be as much as several milliseconds. In all practical cases, however, time spreading is small enough that it does not cause significant smearing of CW keying or intersymbol interference in the slowly keyed modulations commonly used for digital EME. The diffused component may appear as significant noise at higher message data rates.

EME time spreading does have one very significant effect. Signal components reflected from different parts of the lunar surface travel different distances and arrive at Earth with random phase relationships. As the relative geometry of the transmitting station, receiving station and reflecting lunar surface changes, signal components may sometimes add and sometimes cancel.

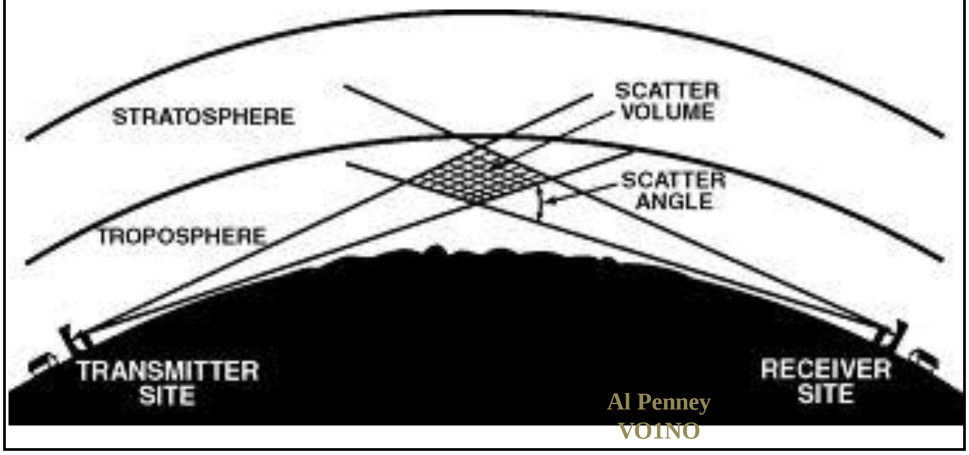
The dynamic addition and cancellation will create large amplitude fluctuations. These amplitude variations are referred to as "libration fading". These amplitude variations will be well correlated over the coherence bandwidth (typically a few kHz). The libration fading components are related to the time spread of reflected signals.

Other factors influencing EME communications

Doppler effect at 144 MHz band is 300 Hz at moonrise or moonset. The doppler offset goes to around zero when the Moon is overhead. At other frequencies other doppler offsets will exist. At moonrise, returned signals will be shifted approximately 300 Hz higher in frequency. As the Moon traverses the sky to a point due south, the Doppler effect approaches zero. By Moonset, they are shifted 300 Hz lower. Doppler effects cause many problems when tuning into, and locking onto, signals from the Moon.

Polarization effects can reduce the strength of received signals. One component is the geometrical alignment of the transmitting and receiving antennas. Many antennas produce a preferred plane of polarization. Transmitting and receiving station antennas may not be aligned from the perspective of an observer on the moon. This component is fixed by the alignment of the antennas and stations may include a facility to rotate antennas to adjust polarization. Another component is Faraday rotation on the Earth-Moon-Earth path. The plane of polarization of radio waves rotates as they pass through ionized layers of the Earth's atmosphere. This effect is more pronounced at lower VHF frequencies and becomes less significant at 1296 MHz and above. Some of the polarization mismatch loss can be reduced by using a larger antenna array (more Yagi elements or a larger dish)

Tropospheric Scatter



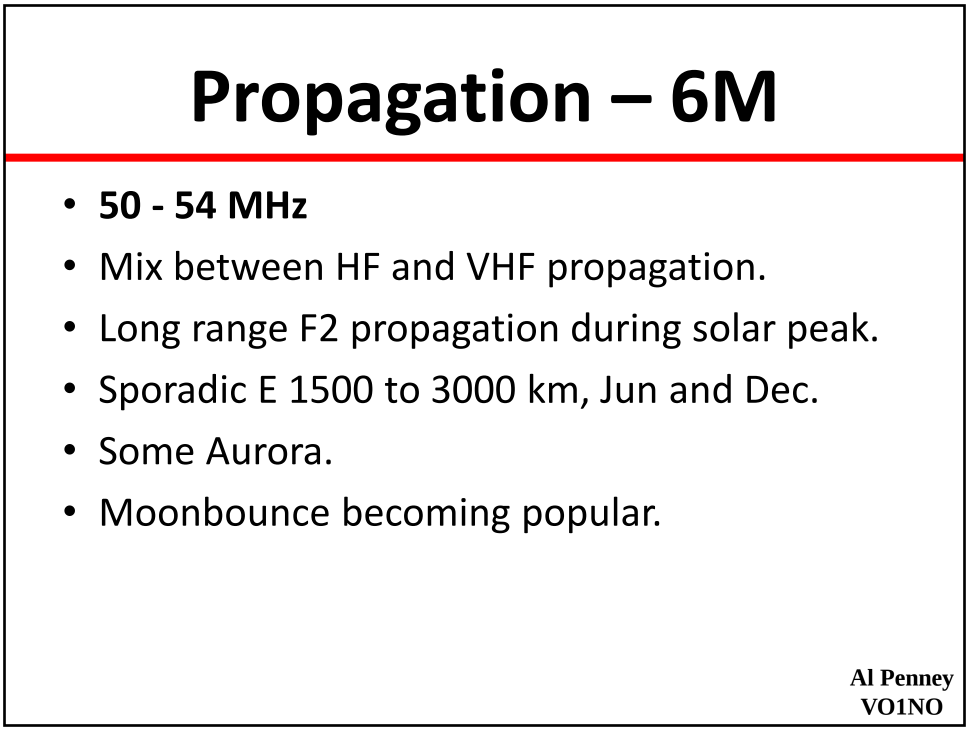
Al Penney
VO1NO

Tropospheric scatter (also known as **troposcatter**) is a method of communicating with **microwave radio signals over considerable distances – often up to 300 kilometres (190 mi), and further depending on terrain and climate factors.** This method of propagation uses the tropospheric scatter phenomenon, where radio waves at UHF and SHF frequencies are randomly scattered as they pass through the upper layers of the troposphere. Radio signals are transmitted in a narrow beam aimed just above the horizon in the direction of the receiver station. As the signals pass through the troposphere, some of the energy is scattered back toward the Earth, allowing the receiver station to pick up the signal.

Normally, signals in the microwave frequency range travel in straight lines, and so are limited to *line of sight* applications, in which the receiver can be 'seen' by the transmitter. Communication distances are limited by the visual horizon to around 30–40 miles (48–64 km). Troposcatter allows microwave communication beyond the horizon. It was developed in the 1950s and used for military communications until communications satellites largely replaced it in the 1970s.

Because the troposphere is turbulent and has a high proportion of moisture the tropospheric scatter radio signals are refracted and consequently only a tiny proportion of the radio energy is collected by the receiving antennas. **Frequencies of transmission around 2 GHz are best suited for tropospheric scatter** systems as at this frequency the wavelength of the signal interacts well with the moist, turbulent areas of the troposphere, improving signal to noise ratios.

The basic mechanism of tropospheric scatter is shown in Figure 1. The antennas of the two stations at the ends of the path cannot "see" each other, but they can each "see" a common volume of the atmosphere, labeled in the figure as the "scattering volume." Signals from one station are scattered by atmospheric inhomogeneities in this region, and some of the scattering is in the direction of the second station. The region of the atmosphere involved is called the troposphere and it extends from the ground up to a height of about 15 km. It's the region in which all weather phenomena occurs, air- planes fly, and is the region in which the "air" is found. Although this region looks clear and uniform to the eye, it really contains a lot of turbulence and stratification. Anyone who has had a bumpy ride in an aircraft has felt this first hand, just as anyone who has seen a star twinkle has directly observed the optical effects of atmospheric turbulence.



Propagation – 6M

- **50 - 54 MHz**
- Mix between HF and VHF propagation.
- Long range F2 propagation during solar peak.
- Sporadic E 1500 to 3000 km, Jun and Dec.
- Some Aurora.
- Moonbounce becoming popular.

Al Penney
VO1NO

The **6-meter band** is the lowest portion of the very high frequency (VHF) radio spectrum allocated to amateur radio use. The term refers to the average signal wavelength of 6 meters.

Although located in the lower portion of the VHF band, it nonetheless occasionally displays propagation mechanisms characteristic of the high frequency (HF) bands. This normally occurs close to sunspot maximum, when solar activity increases ionization levels in the upper atmosphere. During the last sunspot peak of 2005, worldwide 6-meter propagation occurred making 6-meter communications as good as or in some instances and locations, better than HF frequencies. The prevalence of HF characteristics on this VHF band has inspired amateur operators to dub it the "**magic band**".

In the northern hemisphere, activity peaks from May through early August, when regular sporadic E propagation enables long-distance contacts spanning up to 2,500 kilometres (1,600 mi) for single-hop propagation. Multiple-hop sporadic E propagation allows intercontinental communications at distances of up to 10,000 kilometres (6,200 mi). In the southern hemisphere, sporadic E propagation is most common from November through early February.

Also known as 6 Meters or The Magic Band. Good VHF ground wave coverage up to several hundred miles on SSB. 1200 miles or more on openings such as Sporadic-E, F2 layer skip, meteor scatter, aurora, inversions and some EME (**E**arth **M**oon Earth). Operators have worked the world with fairly modest stations. Some FM and repeater activity.

Propagation – 2M

- **144 –148 MHz**
- Most popular Amateur band.
- FM and repeaters very common.
- Tropospheric ducting to several hundred km.
- Sporadic E not common, but possible.
- Meteor Scatter out to 1500 km or more.
- Most popular Moonbounce band.
- Also used for Amateur satellites.
- Aurora also possible.

Al Penney
VO1NO

Repeaters and FM

Much of 2-meter FM operation uses a radio repeater, a radio receiver and transmitter that instantly retransmits a received signal on a separate frequency. Repeaters are normally located in high locations such as a tall building or a hill top overlooking expanses of territory. On VHF frequencies such as 2-meters, antenna height greatly influences how far one can talk. Typical reliable repeater range is about 25 miles (40 km). Some repeaters in unusually high locations, such as skyscrapers or mountain tops, can be usable as far out as 75 miles (121 km). Reliable range is very dependent on the height of the repeater antenna and also on the height and surroundings of the handheld or mobile unit attempting to access to the repeater. Line of sight would be the ultimate in reliability. The typical hand held two meter FM transceiver produces about 5 watts of transmit power. Stations in a car or home provide higher power, 25 to 75 watts, and may use a simple vertical antenna mounted on a pole or on the rooftop of a house or a vehicle.

However, even without repeaters available, the 2-meter band provides reliable crosstown communications throughout smaller towns, making it ideal for emergency communications. Antennas for repeater work are almost always vertically polarized since 2-meter antennas on cars are usually vertically polarized. Matching polarization allows for maximum signal coupling which equates to stronger signals in both directions. Simple radios for FM repeater operation have become plentiful and inexpensive in recent years.

Communications beyond 50 miles

While the 2 meter band is best known as a local band using the FM mode, there are many opportunities for long distance (DX) communications using other modes. A well-placed antenna and high-power equipment can achieve distances of up to a few hundred miles, and fortuitous propagation conditions called "signal enhancements" can on occasion reach across oceans.

A set of two long Yagi antennas for the 2 meter band fed in phase to obtain more gain and narrow main lobe of radiation (station WA6PY)

The typical 2 meter station using CW (Morse code) or SSB (single side band) modes consists of a radio driving a power amplifier generating about 200–500 Watts of RF power. This extra power is usually fed to a multi-element, compound antenna, usually a Yagi-Uda or *Yagi*, which can beam most of the signal power towards the intended receiving station. "Beam antennas" provide substantial increase in signal directivity over ordinary dipole or vertical antennas. Antennas used for distance work are usually horizontally polarized instead of the vertical polarization customarily used for local contacts.

Stations that have antennas located in relatively high locations with views (from the antenna) clear to the horizon have a big advantage over other stations. Such stations are able to communicate 100–300 miles (160–480 km) consistently. It is usual for them to be heard at distances far beyond line of sight on a daily basis without help from signal enhancements. *Signal enhancements* are unusual circumstances in the atmosphere and ionosphere that bend the signal path into an arc that better follows the curve of the Earth, instead of the radio waves traveling in the usual straight line off into space. The best known of these are:

- tropospheric ducting
- sporadic E
- meteor scatter

These and other well-known forms of VHF signal enhancement that allow trans-oceanic and trans-continental contacts on 2 meters are described in the subsections that follow within this section.

With the exception of sporadic E, directional antennas such as Yagis or log periodic antennas are almost essential to take advantage of signal enhancements. When a well-equipped station with its antenna well-located "high and in the clear" is operating during a signal enhancement, astonishing distances can be bridged, momentarily approaching what is regularly possible on shortwave and mediumwave.

Tropospheric ducting

Occasionally, signal bending in the atmosphere's troposphere known as tropospheric ducting can allow 2 meter signals to carry hundreds or even thousands of miles as evidenced by the occasional 2 meter contact between the west coast of the United States and the Hawaiian Islands, the northeast region to the Florida coast and across the Gulf of Mexico. These "Openings" as they are known, are generally first spotted by amateurs operating SSB (Single Side Band) and CW (Continuous Wave) modes since amateurs using these modes typically are attempting distance contacts (DX) and alert for signal enhancement events.

Completion of contacts using these weak signal modes involves the exchange of signal level reports and location by grid square which is known as the Maidenhead Locator System. Two way ducting contacts can have very strong signals and are often made with moderate power, small antennas and other types of modes. Long distance ducting contacts do occur using FM modes as well but for the most part go unnoticed by many FM operators.

Sporadic E

Another form of VHF propagation is called Sporadic E propagation. This is a phenomenon whereby radio signals are reflected back towards Earth by highly ionized segments of the ionosphere which can facilitate contacts in excess of 1,000 miles (1,600 km) with very strong signals received by both parties.

Unlike some other long distance modes, high power and large antennas are often not required to make contact with distant stations via a sporadic E event. A two-way conversation can take place over a distance of several hundred miles or more, often using low levels of RF power. Sporadic E is a rare and completely random propagation phenomenon lasting anywhere from a matter of minutes to several hours.

Satellite communications

Satellites are basically repeater stations in orbit. The 2 meter band is also used in conjunction with the 70-centimeter band, or the 10-meter band and various microwave bands via orbiting amateur radio satellites. This is known as cross band repeating. On-board software defines what mode or band is in use at any particular time and this is determined by amateurs at so-called earth stations who control or instruct the satellite behavior. Amateurs know what mode is in use via published internet schedules.

For instance, a favorite mode is Mode "B" or "V/U" which simply indicates the uplink and downlink frequencies or bands the satellite is currently using. In this example, V/U means VHF/UHF or VHF uplink with UHF downlink. Most amateur satellites are Low Earth Orbit satellites, or LEO's as they are affectionately known, and generally are about 450 miles high (700 km). At that height amateurs can expect reception distances of up to around 3,000 miles (4,800 km).

There are a few amateur satellites that have very high elliptical orbits. These satellites can reach altitudes of 30,000 miles (50,000 km) above the earth where an entire hemisphere is visible providing outstanding communications capabilities from any two points on the earth within line of sight of the satellite; distances that are far beyond the reach of the LEO's.

Transequatorial propagation

Transequatorial propagation also known as (TEP) is a regular daytime occurrence on the 2 meter band over the equatorial regions and is common in the temperate latitudes in late spring, early summer and, to a lesser degree, in early winter. For receiving stations located within ± 10 degrees of the geomagnetic equator, equatorial E-skip can be expected on most days throughout the year, peaking around midday local time.

Meteor burst

By speeding up Morse code using analog tape or digital modes such as JT6M or FSK441, very short high-speed bursts of digital data can be bounced off the ionized gas trail of meteor showers. The speed required to confirm a two way contact via a short lived ionized meteor trail can only be performed by fast computers on both ends with very little human interaction.

One computer will send a request for contact and if successfully received by a distant station, a reply will be sent by the receiving stations computer usually via the same ionized meteor trail to confirm the contact. If nothing is received after the request, a new request is transmitted. This continues until a reply is received to confirm the contact or until no contact can be made and no new requests are sent. Using this high speed digital mode, a full two way contact, can be completed in one second or less and can only be validated using a computer. Depending on the intensity of the ionized meteor trail, multiple contacts from multiple stations can be made off the same trail until it dissipates and can no longer reflect VHF signals with sufficient strength. This mode is often called burst transmission and can yield communication distances similar to sporadic E as described above.

Auroral propagation

Another phenomenon that produces upper atmosphere ionization suitable for 2-meter DXing are the auroras. Since the ionization persists much longer than meteor trails, voice modulated radio signals may sometimes be used, but the constant movement of the ionized gas leads to heavy distortion of the signals causing the audio to sound "ghostly" and whispered. In most instances using auroral reflections on 2 meters, audio or voice is totally unintelligible and ham operators wishing to make contacts via aurora, must resort to CW (Morse code).

CW signals returning from an auroral reflection have no distinct sound or tone but simply sound like a swishing or whooshing noise. An exception to this phenomenon would be the 6 meter band which is significantly lower in frequency than the 2 meter band by 94 MHz. In many instances 6 meter voice modes are readable but with varying degrees of difficulty when reflected off an aurora. Therefore, when using an auroral event as a radio signal reflector, the reflected signal strength and signal intelligibility decreases with increasing transmitting frequency.

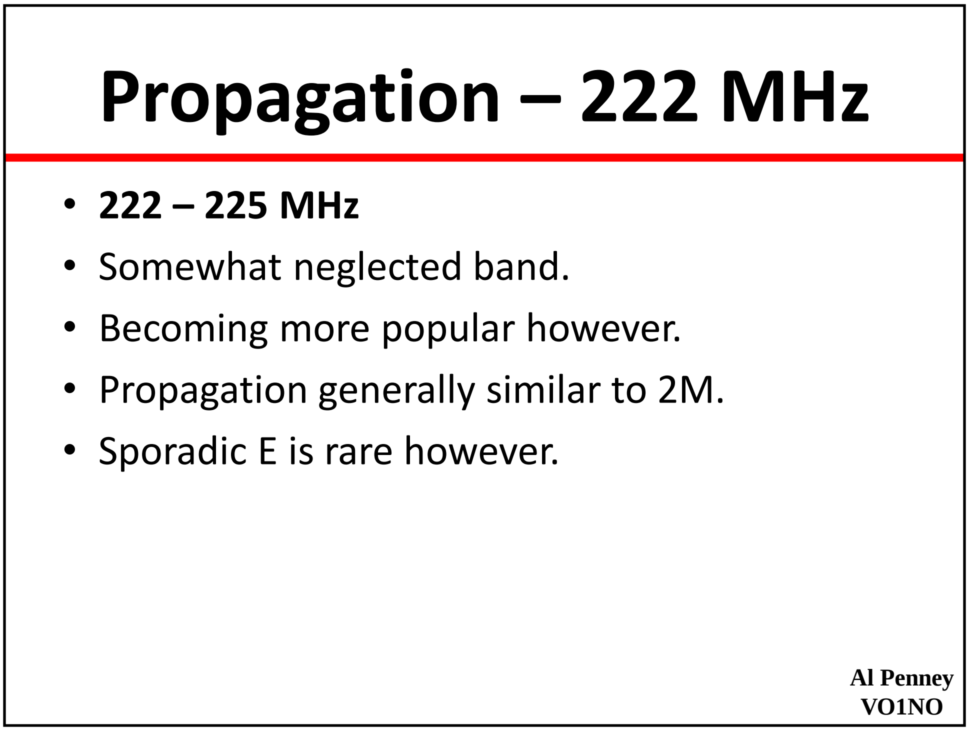
Moonbounce (EME)

To communicate over the longest distances, hams use moon bounce. VHF signals normally escape the Earth's atmosphere, so using the moon as a target is quite practical. Due to the distance involved and the very high path loss getting a readable signal bounced off the moon involves high power ~1,000 Watts and steerable high gain antennas. Receiving these very weak return signals, again involves the use of high gain antennas (usually the same ones used to transmit the signal) and a very low-noise front end RF amplifier and a frequency stable receiver.

However, new and recent technological advances in weak signal detection has allowed the successful reception of signals off the moon using much smaller or less well equipped stations allowing reception of signals that are "in the noise" and not audible to the human ear. One of these modes is JT65 which is a digital mode. Due to the delay of the signal traveling to the moon and back (travel time approx. 2.5 seconds), a person transmitting may hear the end of their own transmission returning.

144-148 MHz

The popular 2 meter band. Generally shorter groundwave distances of around 200 miles can be expected on this band with a modest SSB or CW station. Good mobile FM band. Lots of local FM communications on repeaters with up to 150 miles on some "machines". Lots of repeaters are linked together for even greater coverage. The IRLP (Internet Radio Linking Project) is very popular on repeaters linking to the internet all over the world! Also a good band for packet radio. There is also lots of satellite activity, EME and terrestrial DX for hams doing weak signal work (QRP). You can expect many of the same kinds of openings on 2 meters as you will experience on 6 meters.



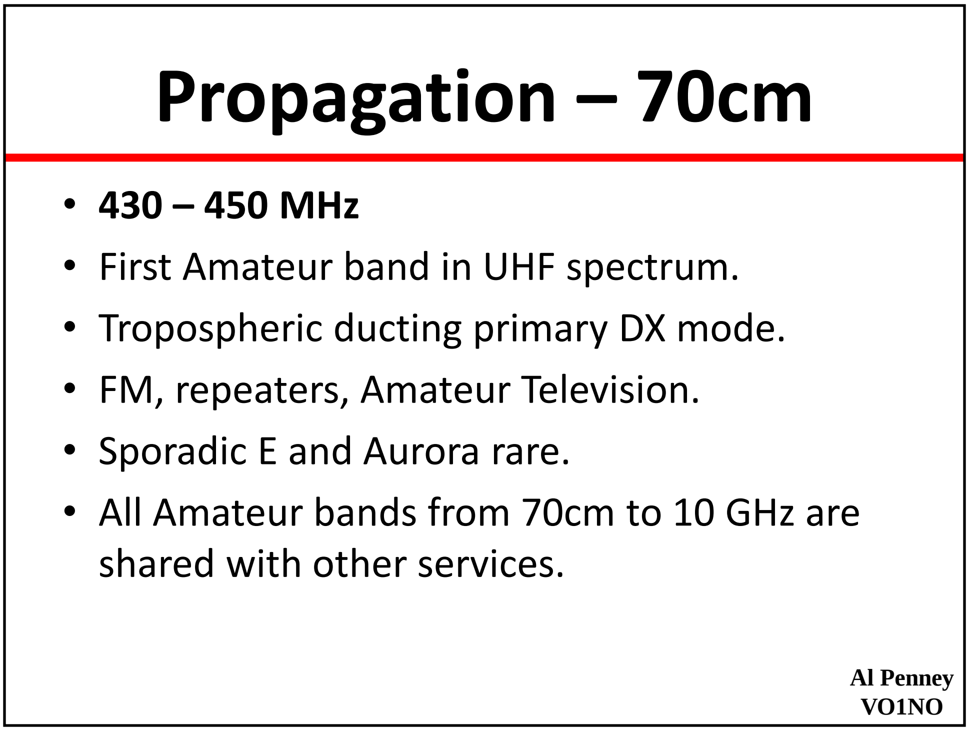
Propagation – 222 MHz

- **222 – 225 MHz**
- Somewhat neglected band.
- Becoming more popular however.
- Propagation generally similar to 2M.
- Sporadic E is rare however.

Al Penney
VO1NO

222-225 MHz 1-1/4 Meters.

Not as much activity as 2 meters and no satellite activity.
This band is not available in many countries other than Canada and the USA.



Propagation – 70cm

- **430 – 450 MHz**
- First Amateur band in UHF spectrum.
- Tropospheric ducting primary DX mode.
- FM, repeaters, Amateur Television.
- Sporadic E and Aurora rare.
- All Amateur bands from 70cm to 10 GHz are shared with other services.

Al Penney
VO1NO

70-centimeter propagation characteristics lie midway between 2-meter and 33-centimeter (~900 MHz) bands. Above 200 MHz, as frequency increases, building penetration is reduced.[6] However, smaller obstacles may also block or reflect the signal. Higher frequencies also present a lower noise floor, making it easier to overcome both natural and artificial interference, especially prevalent in urban environments.

Atmospheric thermal ducting is often more intense at UHF, because shorter wavelengths have much greater refraction angles than longer ones. However, a much stronger thermal inversion is often required than is needed for ducting in the 2-meter band.

UHF 420-450MHz

Also known as 70 centimeters (cm). This is the lowest frequency amateur **UHF** band. Groundwave coverage is quite limited compared to 2 meters due to high absorption. Satellite, EME and terrestrial DXing are popular on this band. Fast scan TV has also found a home on 430 MHz. Lots of FM activity between 440-450 MHz. Lots of machines are linked to 2 meters! The longest Element of a beam for this band is about 12 to 13 inches on the low end!

902 - 928MHz

Not much activity on this band so far due to a lack of suitable equipment.
Also this is a shared band with other services.

1200-1300MHz

1.2 GHz is a HUGE band with lots of room for experimenters. EME and satellite are popular up here and in some parts of the US there are very active FM repeaters. Antennas are VERY small! Not a lot of terrestrial DXing but during contests there is some activity. Antennas for small signal work are quite impressive with lots of elements on short booms. Dishes are practical on this band.

GETTING CLOSER TO LIGHT!

Above 1300 MHz Amateur radio has allocations all the way from here to light and all kinds of room for experimentation with microwaves and frequencies approaching light. Lasers anyone?

Questions?

Al Penney
VO1NO

Review Question 1

What is the best method to tell if a band is “open” for communication with a particular distant location?

- Ask others on your local 2 metre FM repeater
- Telephone an experienced local amateur
- Look at the propagation forecasts in an amateur radio magazine
- Listen for signals from that area from an amateur beacon station or a foreign broadcast or television station on a nearby frequency

Al Penney
VO1NO

Review Question 1

What is the best method to tell if a band is “open” for communication with a particular distant location?

- Ask others on your local 2 metre FM repeater
- Telephone an experienced local amateur
- Look at the propagation forecasts in an amateur radio magazine
- Listen for signals from that area from an amateur beacon station or a foreign broadcast or television station on a nearby frequency

< Listen for signals from that area from an amateur beacon station or a foreign broadcast or television station on a nearby frequency >

Al Penney
VO1NO

Review Question 2

What type of propagation usually occurs from one hand-held VHF transceiver to another nearby?

- Auroral propagation
- Line-of-sight propagation
- Tunnel propagation
- Sky-wave propagation

Al Penney
VO1NO

Review Question 2

What type of propagation usually occurs from one hand-held VHF transceiver to another nearby?

- Auroral propagation
- Line-of-sight propagation
- Tunnel propagation
- Sky-wave propagation

< Line-of-sight propagation >

Al Penney
VO1NO

Review Question 3

How does the range of sky-wave propagation compare to ground-wave propagation?

- It is much longer
- It is much shorter
- It is about the same
- It depends on the weather

Review Question 3

How does the range of sky-wave propagation compare to ground-wave propagation?

- It is much longer
- It is much shorter
- It is about the same
- It depends on the weather

< It is much longer >

Review Question 4

When a signal is returned to Earth by the ionosphere, what is this called?

- Tropospheric propagation
- Ground-wave propagation
- Earth-Moon-Earth propagation
- Sky-wave propagation

Al Penney
VO1NO

Review Question 4

When a signal is returned to Earth by the ionosphere, what is this called?

- Tropospheric propagation
- Ground-wave propagation
- Earth-Moon-Earth propagation
- Sky-wave propagation

< Sky-wave propagation >

Al Penney
VO1NO

Review Question 5

How are VHF signals propagated within the range of the visible horizon?

- By direct wave
- By sky-wave
- By plane wave
- By geometric wave

Review Question 5

How are VHF signals propagated within the range of the visible horizon?

- By direct wave
- By sky-wave
- By plane wave
- By geometric wave

< By direct wave >

Al Penney
VO1NO

Review Question 6

Sky-wave is another name for:

- inverted wave
- ionospheric wave
- tropospheric wave
- ground wave

Al Penney
VO1NO

Review Question 6

Sky-wave is another name for:

- inverted wave
- ionospheric wave
- tropospheric wave
- ground wave

< ionospheric wave >

Al Penney
VO1NO

Review Question 7

What two sub-regions of ionosphere exist only in the daytime?

- Electrostatic and electromagnetic
- D and E
- F1 and F2
- Troposphere and stratosphere

Al Penney
VO1NO

Review Question 7

What two sub-regions of ionosphere exist only in the daytime?

- Electrostatic and electromagnetic
- D and E
- F1 and F2
- Troposphere and stratosphere

< F1 and F2>

Review Question 8

At lower HF frequencies, radiocommunication out to 200 km is made possible by:

- troposphere
- skip wave
- ionosphere
- ground wave

Al Penney
VO1NO

Review Question 8

At lower HF frequencies, radiocommunication out to 200 km is made possible by:

- troposphere
- skip wave
- ionosphere
- ground wave

< ground wave >

Al Penney
VO1NO

Review Question 9

The distance travelled by ground waves:

- is more at higher frequencies
- is the same for all frequencies
- is less at higher frequencies
- depends on the maximum usable frequency

Al Penney
VO1NO

Review Question 9

The distance travelled by ground waves:

- is more at higher frequencies
- is the same for all frequencies
- is less at higher frequencies
- depends on the maximum usable frequency

< is less at higher frequencies >

Al Penney
VO1NO

Review Question 10

What causes the ionosphere to form?

- Lightning ionizing the outer atmosphere
- Release of fluorocarbons into the atmosphere
- Temperature changes ionizing the outer atmosphere
- Solar radiation ionizing the outer atmosphere

Al Penney
VO1NO

Review Question 10

What causes the ionosphere to form?

- Lightning ionizing the outer atmosphere
- Release of fluorocarbons into the atmosphere
- Temperature changes ionizing the outer atmosphere
- Solar radiation ionizing the outer atmosphere

< Solar radiation ionizing the outer atmosphere >

Al Penney
VO1NO

Review Question 11

Reception of high frequency (HF) radio waves beyond 4000 km is generally made possible by:

- ground wave
- skip wave
- surface wave
- ionospheric wave

Review Question 11

Reception of high frequency (HF) radio waves beyond 4000 km is generally made possible by:

- ground wave
- skip wave
- surface wave
- ionospheric wave

< ionospheric wave >

Al Penney
VO1NO

Review Question 12

When is the ionosphere least ionized?

- Shortly before midnight
- Shortly before dawn
- Just after noon
- Just after dusk

Al Penney
VO1NO

Review Question 12

When is the ionosphere least ionized?

- Shortly before midnight
- Shortly before dawn
- Just after noon
- Just after dusk

< Shortly before dawn >

Al Penney
VO1NO

Review Question 13

Why is the F2 region mainly responsible for the longest distance radio-wave propagation?

- Because it is the lowest ionospheric region
- Because it does not absorb radio waves as much as other ionospheric regions
- Because it is the highest ionospheric region
- Because it exists only at night

Al Penney
VO1NO

Review Question 13

Why is the F2 region mainly responsible for the longest distance radio-wave propagation?

- Because it is the lowest ionospheric region
- Because it does not absorb radio waves as much as other ionospheric regions
- Because it is the highest ionospheric region
- Because it exists only at night

< Because it is the highest ionospheric region >

Al Penney
VO1NO

Review Question 14

What is the main reason the 160, 80 and 40 metre amateur bands tend to be useful only for short-distance communications during daylight hours?

- Because of magnetic flux
- Because of a lack of activity
- Because of D-region absorption
- Because of auroral propagation

Al Penney
VO1NO

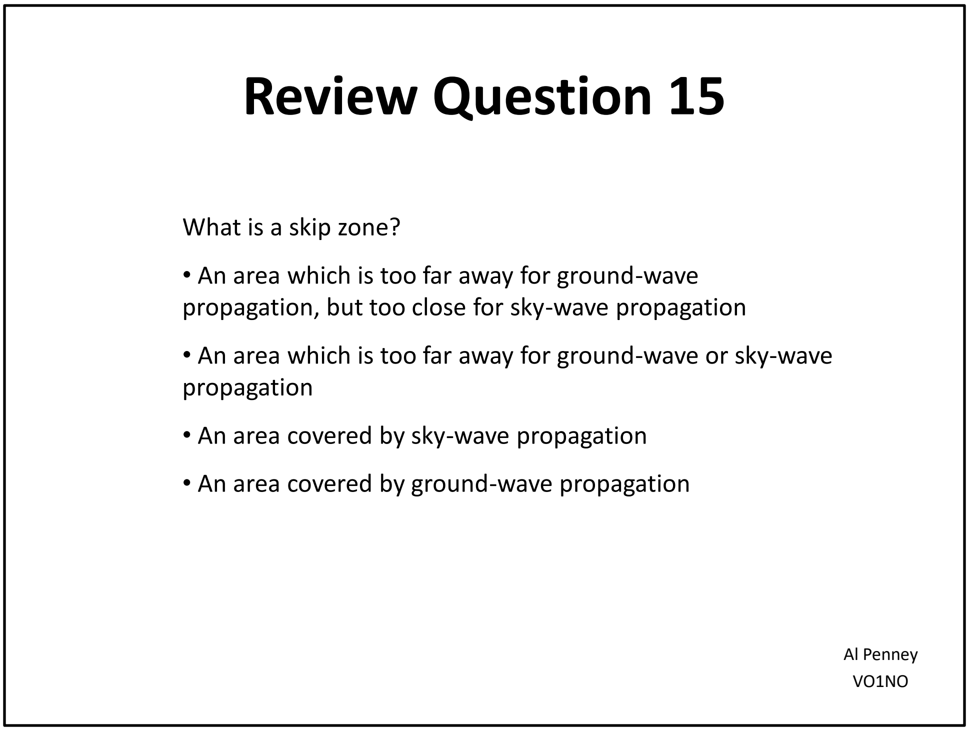
Review Question 14

What is the main reason the 160, 80 and 40 metre amateur bands tend to be useful only for short-distance communications during daylight hours?

- Because of magnetic flux
- Because of a lack of activity
- Because of D-region absorption
- Because of auroral propagation

< Because of D-region absorption >

Al Penney
VO1NO

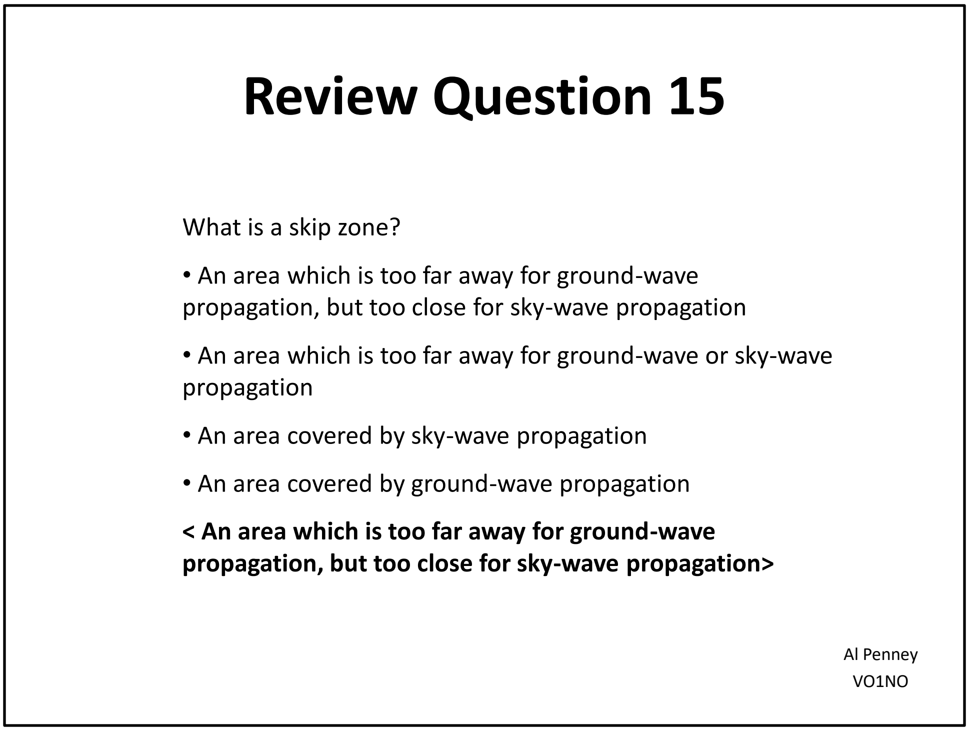


Review Question 15

What is a skip zone?

- An area which is too far away for ground-wave propagation, but too close for sky-wave propagation
- An area which is too far away for ground-wave or sky-wave propagation
- An area covered by sky-wave propagation
- An area covered by ground-wave propagation

Al Penney
VO1NO



Review Question 15

What is a skip zone?

- An area which is too far away for ground-wave propagation, but too close for sky-wave propagation
- An area which is too far away for ground-wave or sky-wave propagation
- An area covered by sky-wave propagation
- An area covered by ground-wave propagation

< An area which is too far away for ground-wave propagation, but too close for sky-wave propagation>

Al Penney
VO1NO

Review Question 16

What is the maximum distance along the Earth’s surface that is normally covered in one hop using the F2 region?

- 4000 km (2500 miles)
- None; the F2 region does not support radio-wave propagation
- 2000 km (1250 miles)
- 300 km (190 miles)

Al Penney
VO1NO

Review Question 16

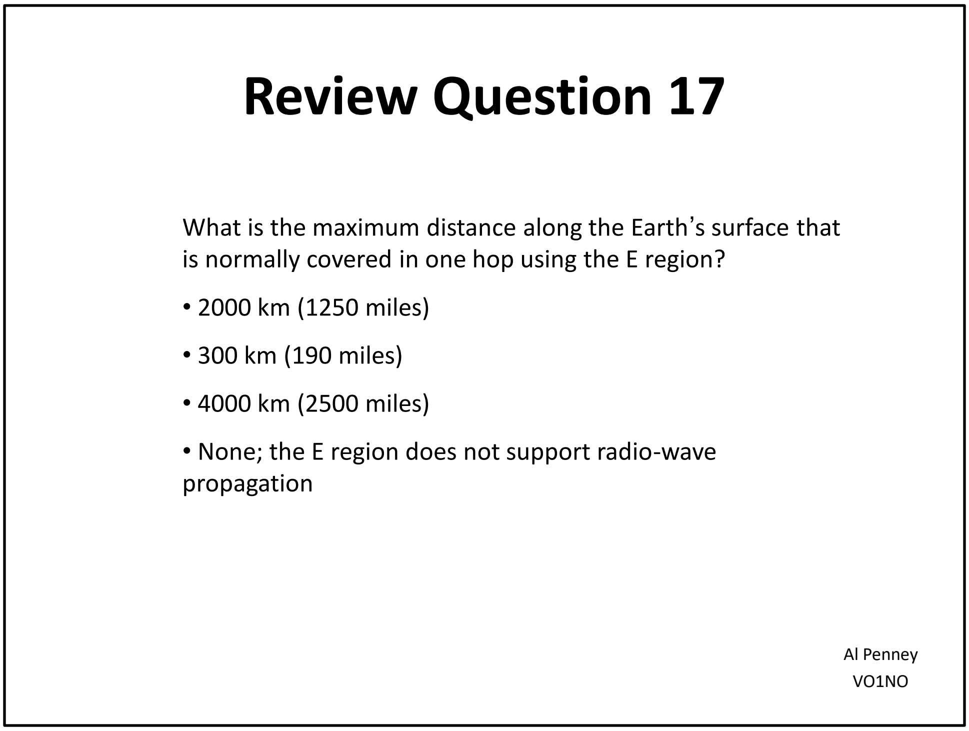
What is the maximum distance along the Earth’s surface that is normally covered in one hop using the F2 region?

- 4000 km (2500 miles)
- None; the F2 region does not support radio-wave propagation
- 2000 km (1250 miles)
- 300 km (190 miles)

< 4000 km (2500 miles) >

Actually this value can be as high as 4800 km! But remember the answer ISED wants.

Al Penney
VO1NO



Review Question 17

What is the maximum distance along the Earth’s surface that is normally covered in one hop using the E region?

- 2000 km (1250 miles)
- 300 km (190 miles)
- 4000 km (2500 miles)
- None; the E region does not support radio-wave propagation

Al Penney
VO1NO

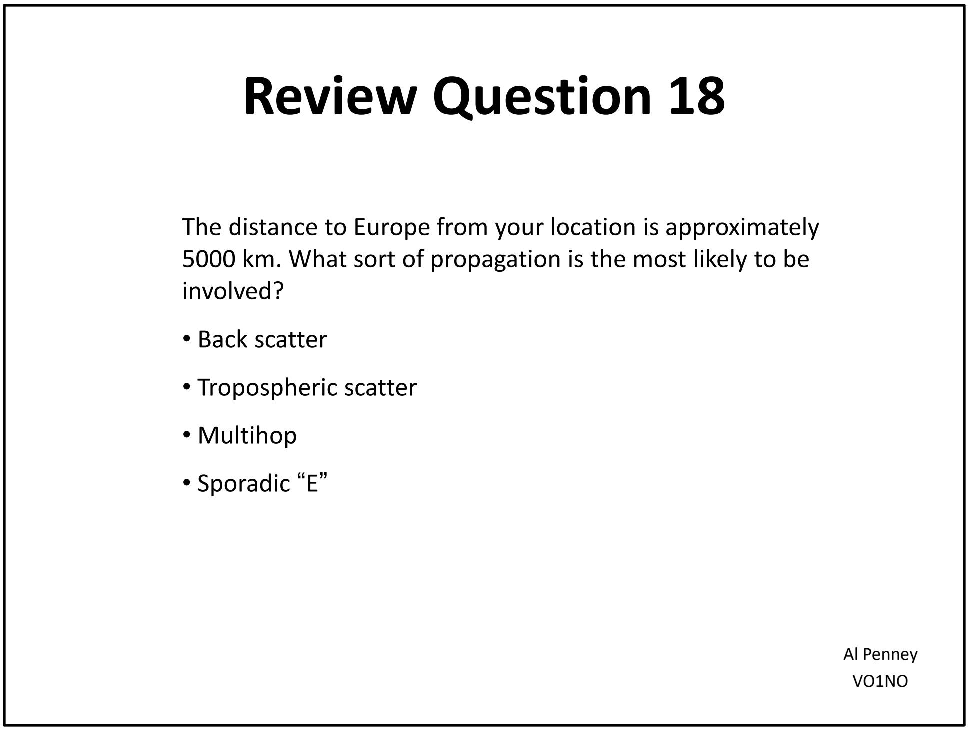
Review Question 17

What is the maximum distance along the Earth’s surface that is normally covered in one hop using the E region?

- 2000 km (1250 miles)
- 300 km (190 miles)
- 4000 km (2500 miles)
- None; the E region does not support radio-wave propagation

< 2000 km (1250 miles) >

Al Penney
VO1NO



Review Question 18

The distance to Europe from your location is approximately 5000 km. What sort of propagation is the most likely to be involved?

- Back scatter
- Tropospheric scatter
- Multihop
- Sporadic “E”

Al Penney
VO1NO

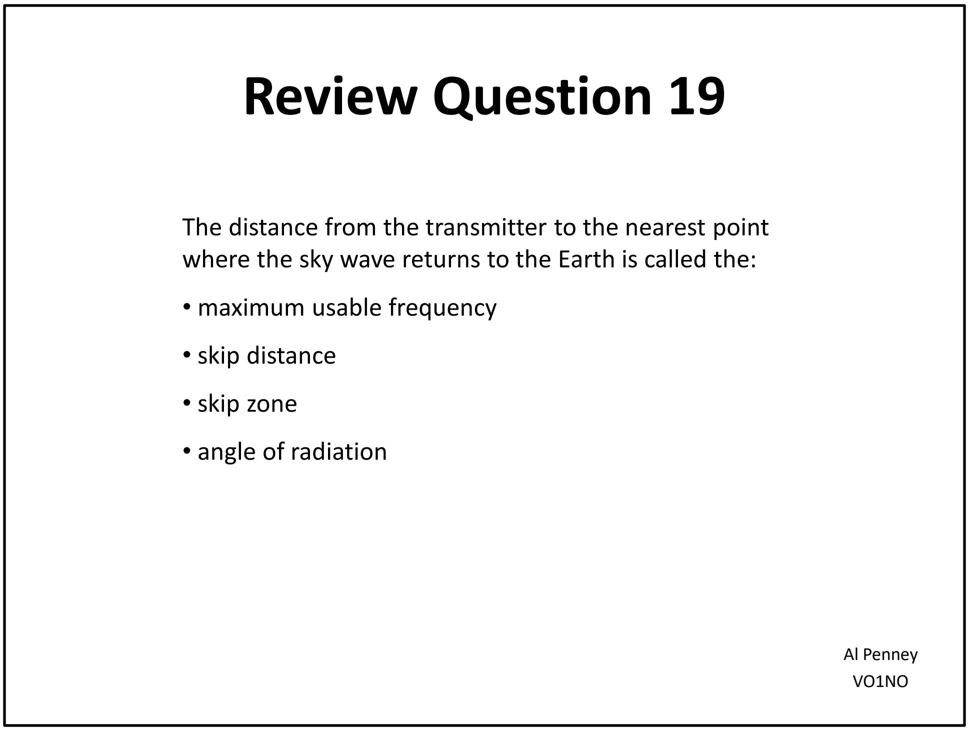
Review Question 18

The distance to Europe from your location is approximately 5000 km. What sort of propagation is the most likely to be involved?

- Back scatter
- Tropospheric scatter
- Multihop
- Sporadic “E”

< Multihop >

Al Penney
VO1NO



Review Question 19

The distance from the transmitter to the nearest point where the sky wave returns to the Earth is called the:

- maximum usable frequency
- skip distance
- skip zone
- angle of radiation

Al Penney
VO1NO

Review Question 19

The distance from the transmitter to the nearest point where the sky wave returns to the Earth is called the:

- maximum usable frequency
- skip distance
- skip zone
- angle of radiation

< skip distance >

Al Penney
VO1NO

Review Question 20

The skip distance of a sky wave will be greatest when the:

- polarization is vertical
- ionosphere is most densely ionized
- signal given out is strongest
- angle between ground and radiation is smallest

Al Penney
VO1NO

Review Question 20

The skip distance of a sky wave will be greatest when the:

- polarization is vertical
- ionosphere is most densely ionized
- signal given out is strongest
- angle between ground and radiation is smallest

< angle between ground and radiation is smallest >

Al Penney
VO1NO

Review Question 21

What effect does the D region of the ionosphere have on lower frequency HF signals in the daytime?

- It refracts the radio waves back to Earth
- It has little or no effect on 80-metre radio waves
- It absorbs the signals
- It bends the radio waves out into space

Al Penney
VO1NO

Review Question 21

What effect does the D region of the ionosphere have on lower frequency HF signals in the daytime?

- It refracts the radio waves back to Earth
- It has little or no effect on 80-metre radio waves
- It absorbs the signals
- It bends the radio waves out into space

< It absorbs the signals >

Al Penney
VO1NO

Review Question 22

Two or more parts of the radio wave follow different paths during propagation and this may result in phase differences at the receiver. This “change” at the receiver is called:

- absorption
- skip
- fading
- baffling

Al Penney
VO1NO

Review Question 22

Two or more parts of the radio wave follow different paths during propagation and this may result in phase differences at the receiver. This “change” at the receiver is called:

- absorption
- skip
- fading
- baffling

< fading >

Al Penney
VO1NO

Review Question 23

The usual effect of ionospheric storms is to:

- increase the maximum usable frequency
- cause a fade-out of sky-wave signals
- produce extreme weather changes
- prevent communications by ground wave

Al Penney
VO1NO

Review Question 23

The usual effect of ionospheric storms is to:

- increase the maximum usable frequency
- cause a fade-out of sky-wave signals
- produce extreme weather changes
- prevent communications by ground wave

< cause a fade-out of sky-wave signals >

Al Penney
VO1NO

Review Question 24

On the VHF and UHF bands, polarization of the receiving antenna is very important in relation to the transmitting antenna, yet on HF bands it is relatively unimportant. Why is that so?

- Greater selectivity is possible with HF receivers making changes in polarization redundant
- The ionosphere can change the polarization of the signal from moment to moment
- The ground wave and the sky wave continually shift the polarization
- Anomalies in the Earth’s magnetic field produce a profound effect on HF polarization but not on VHF & UHF frequencies

Al Penney
VO1NO

Review Question 24

On the VHF and UHF bands, polarization of the receiving antenna is very important in relation to the transmitting antenna, yet on HF bands it is relatively unimportant. Why is that so?

- Greater selectivity is possible with HF receivers making changes in polarization redundant
- The ionosphere can change the polarization of the signal from moment to moment
- The ground wave and the sky wave continually shift the polarization
- Anomalies in the Earth’s magnetic field produce a profound effect on HF polarization but not on VHF & UHF frequencies

< The ionosphere can change the polarization of the signal from moment to moment >

Al Penney
VO1NO

Review Question 25

How does the bandwidth of a transmitted signal affect selective fading?

- It is the same for both wide and narrow bandwidths
- Only the receiver bandwidth determines the selective fading effect
- It is more pronounced at narrow bandwidths
- It is more pronounced at wide bandwidths

Review Question 25

How does the bandwidth of a transmitted signal affect selective fading?

- It is the same for both wide and narrow bandwidths
- Only the receiver bandwidth determines the selective fading effect
- It is more pronounced at narrow bandwidths
- It is more pronounced at wide bandwidths

< It is more pronounced at wide bandwidths >

Al Penney
VO1NO

Review Question 26

How do sunspots change the ionization of the atmosphere?

- The more sunspots there are, the greater the ionization
- The more sunspots there are, the less the ionization
- Unless there are sunspots, the ionization is zero
- They have no effect

Al Penney
VO1NO

Review Question 26

How do sunspots change the ionization of the atmosphere?

- The more sunspots there are, the greater the ionization
- The more sunspots there are, the less the ionization
- Unless there are sunspots, the ionization is zero
- They have no effect

< The more sunspots there are, the greater the ionization >

Al Penney
VO1NO

Review Question 27

What influences all radio communication beyond ground-wave or line-of-sight ranges?

- The F2 region of the ionosphere
- The F1 region of the ionosphere
- Lunar tidal effects
- Solar radiation

Review Question 27

What influences all radio communication beyond ground-wave or line-of-sight ranges?

- The F2 region of the ionosphere
- The F1 region of the ionosphere
- Lunar tidal effects
- Solar radiation

< Solar radiation >

Al Penney
VO1NO

Review Question 28

The ability of the ionosphere to reflect high frequency radio signals depends on:

- the receiver sensitivity
- upper atmosphere weather conditions
- the amount of solar radiation
- the power of the transmitted signal

Al Penney
VO1NO

Review Question 28

The ability of the ionosphere to reflect high frequency radio signals depends on:

- the receiver sensitivity
- upper atmosphere weather conditions
- the amount of solar radiation
- the power of the transmitted signal

< the amount of solar radiation >

Al Penney
VO1NO

Review Question 29

What does maximum usable frequency mean?

- The lowest frequency signal that will reach its intended destination
- The highest frequency signal that is most absorbed by the ionosphere
- The lowest frequency signal that is most absorbed by the ionosphere
- The highest frequency signal that will reach its intended destination

Al Penney
VO1NO

Review Question 29

What does maximum usable frequency mean?

- The lowest frequency signal that will reach its intended destination
- The highest frequency signal that is most absorbed by the ionosphere
- The lowest frequency signal that is most absorbed by the ionosphere
- The highest frequency signal that will reach its intended destination

< The highest frequency signal that will reach its intended destination >

Al Penney
VO1NO

Review Question 30

At what point in the solar cycle does the 20-metre band usually support worldwide propagation during daylight hours?

- Only at the maximum point of the solar cycle
- At the summer solstice
- At any point in the solar cycle
- Only at the minimum point of the solar cycle

Al Penney
VO1NO

Review Question 30

At what point in the solar cycle does the 20-metre band usually support worldwide propagation during daylight hours?

- Only at the maximum point of the solar cycle
- At the summer solstice
- At any point in the solar cycle
- Only at the minimum point of the solar cycle

< At any point in the solar cycle >

Al Penney
VO1NO

Review Question 31

During summer daytime, which bands are the most difficult for communications beyond ground wave?

- 20 metres
- 160 and 80 metres
- 40 metres
- 30 metres

Al Penney
VO1NO

Review Question 31

During summer daytime, which bands are the most difficult for communications beyond ground wave?

- 20 metres
- 160 and 80 metres
- 40 metres
- 30 metres

<160 and 80 metres >

Al Penney
VO1NO

Review Question 32

What causes tropospheric ducting of radio waves?

- A temperature inversion
- Lightning between the transmitting and receiving stations
- An aurora to the north
- A very low pressure area

Al Penney
VO1NO

Review Question 32

What causes tropospheric ducting of radio waves?

- A temperature inversion
- Lightning between the transmitting and receiving stations
- An aurora to the north
- A very low pressure area

< A temperature inversion >

Al Penney
VO1NO

Review Question 33

Where in the ionosphere does auroral activity occur?

- At D-region height
- At E-region height
- At F-region height
- In the equatorial band

Al Penney
VO1NO

Review Question 33

Where in the ionosphere does auroral activity occur?

- At D-region height
- At E-region height
- At F-region height
- In the equatorial band

< At E-region height >

Al Penney
VO1NO

Review Question 34

Excluding enhanced propagation modes, what is the approximate range of normal VHF tropospheric propagation?

- 1600 km (1000 miles)
- 800 km (500 miles)
- 2400 km (1500 miles)
- 3200 km (2000 miles)

Al Penney
VO1NO

Review Question 34

Excluding enhanced propagation modes, what is the approximate range of normal VHF tropospheric propagation?

- 1600 km (1000 miles)
- 800 km (500 miles)
- 2400 km (1500 miles)
- 3200 km (2000 miles)

< 800 km (500 miles) >

Al Penney
VO1NO

Review Question 35

What kind of unusual HF propagation allows weak signals from the skip zone to be heard occasionally?

- Sky-wave with low radiation angle
- Ducting
- Ground-wave
- Scatter-mode

Al Penney
VO1NO

Review Question 35

What kind of unusual HF propagation allows weak signals from the skip zone to be heard occasionally?

- Sky-wave with low radiation angle
- Ducting
- Ground-wave
- Scatter-mode

< Scatter-mode >

Al Penney
VO1NO

Review Question 36

Which of the following IS NOT a scatter mode?

- Tropospheric scatter
- Ionospheric scatter
- Absorption scatter
- Meteor scatter

Al Penney
VO1NO

Review Question 36

Which of the following IS NOT a scatter mode?

- Tropospheric scatter
- Ionospheric scatter
- Absorption scatter
- Meteor scatter

< Absorption scatter >

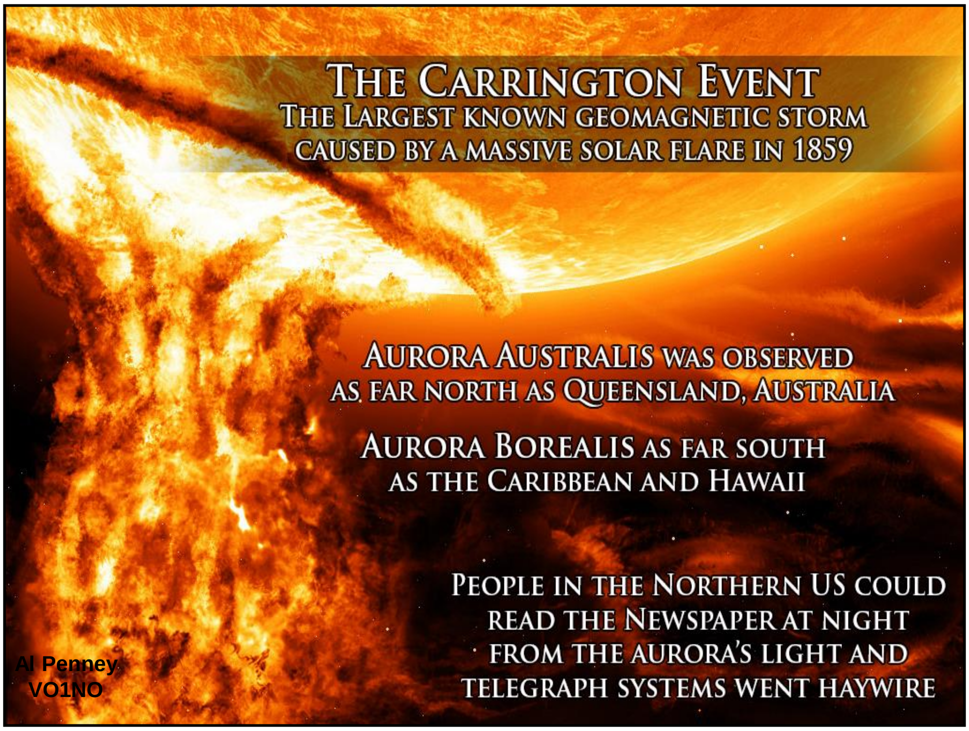
Al Penney
VO1NO

For Next Class:

- Review Chapter 6 of Basic Study Guide;
- Read Chapter 7 of Basic Study Guide;
- Read the Question Bank – there are lots more questions on propagation; and
- Read RIC-9: https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf02102.html

Questions?

Al Penney
VO1NO



The **Carrington Event** was the most intense geomagnetic storm in recorded history, peaking from 1 to 2 September 1859 during solar cycle 10. It created strong auroral displays that were reported globally[1] and caused sparking and fires in multiple telegraph stations. The geomagnetic storm was most likely the result of a coronal mass ejection (CME) from the Sun colliding with Earth's magnetosphere.[2]

A very bright solar flare associated with the geomagnetic storm was observed and recorded independently by British astronomers Richard Carrington and Richard Hodgson on 1 September 1859. This was the first recorded solar flare.

A geomagnetic storm of this magnitude occurring today would cause widespread electrical disruptions, blackouts, and damage due to extended outages of the electrical grid.

Geomagnetic storm

The solar storm of 2012, as photographed by STEREO, was a CME of comparable strength to the one which is thought to have struck the Earth during the 1859 Carrington Event.

On 1–2 September 1859, one of the largest geomagnetic storms (as recorded by ground-based magnetometers) occurred.[6] Estimates of the storm strength (Dst) range from −0.80 to −1.75 μT.[7]

The geomagnetic storm is thought to have been initiated by a major coronal mass ejection (CME) that traveled directly toward Earth, taking 17.6 hours to make the 150 million kilometer (93 million mile) journey. Typical CMEs take several days to arrive at Earth, but it is believed that the relatively high speed of this CME was made possible by a prior CME, perhaps the cause of the large aurora event on 29 August that "cleared the way" of ambient solar wind plasma for the Carrington Event.[8]

Associated solar flare[edit]

Just before noon on 1 September, the English amateur astronomers Richard Christopher Carrington and Richard Hodgson independently recorded the earliest observations of a solar flare.[8] Carrington and Hodgson compiled independent reports which were published side by side in the *Monthly Notices of the Royal Astronomical Society*, and exhibited their drawings of the event at the November 1859 meeting of the Royal Astronomical Society.[9][10]

Because of a geomagnetic solar flare effect (a "magnetic crochet")[11] observed in the Kew Observatory magnetometer record by Scottish physicist Balfour Stewart, and a geomagnetic storm observed the following day, Carrington suspected a solar-terrestrial connection.[12] Worldwide reports on the effects of the geomagnetic storm of 1859 were compiled and published by American mathematician Elias Loomis, which support the observations of Carrington and Stewart.

Auroras[edit]

Aurora during a geomagnetic storm that was most likely caused by a coronal mass ejection from the Sun on 24 May 2010, taken from the ISS

Auroras were seen around the world, those in the northern hemisphere as far south as the Caribbean; those over the Rocky Mountains in the U.S. were so bright that the glow woke gold miners, who began preparing breakfast because they thought it was morning.[8] People in the northeastern United States could read a newspaper by the aurora's light.[14] The aurora was visible from the poles to low latitude areas such as south-central Mexico,[15][16] Queensland, Cuba, Hawaii,[17] southern Japan and China,[18] and even at lower latitudes very close to the equator, such as in Colombia

Telegraphs[edit]

Telegraph systems all over Europe and North America failed, in some cases giving telegraph operators electric shocks.[22] Telegraph pylons threw sparks.[23] Some telegraph operators could continue to send and receive messages despite having disconnected their power supplies.

Al Penney
VO1NO

Many telegraph lines across North America were rendered inoperable on the night of August 28 as the first of two successive solar storms struck. E.W. Culgan, a telegraph manager in Pittsburgh, reported that the resulting currents flowing through the wires were so powerful that platinum contacts were in danger of melting and “streams of fire” were pouring forth from the circuits. In Washington, D.C., telegraph operator Frederick W. Royce was severely shocked as his forehead grazed a ground wire. According to a witness, an arc of fire jumped from Royce’s head to the telegraphic equipment. Some telegraph stations that used chemicals to mark sheets reported that powerful surges caused telegraph paper to combust.

On the morning of September 2, the magnetic mayhem resulting from the second storm created even more chaos for telegraph operators. When American Telegraph Company employees arrived at their Boston office at 8 a.m., they discovered it was impossible to transmit or receive dispatches. The atmosphere was so charged, however, that operators made an incredible discovery: They could unplug their batteries and still transmit messages to Portland, Maine, at 30- to 90-second intervals using only the auroral current. Messages still couldn’t be sent as seamlessly as under normal conditions, but it was a useful workaround. By 10 a.m. the magnetic disturbance abated enough that stations reconnected their batteries, but transmissions were still affected for the rest of the morning.

Sky on Fire

When telegraphs did come back on line, many were filled with vivid accounts of the celestial light show that had been witnessed the night before. Newspapers from France to Australia featured glowing descriptions of brilliant auroras that had turned night into day. One eyewitness account from a woman on Sullivan’s Island in South Carolina ran in the Charleston Mercury: “The eastern sky appeared of a blood red color. It seemed brightest exactly in the east, as though the full moon, or rather the sun, were about to rise. It extended almost to the zenith. The whole island was illuminated. The sea reflected the phenomenon, and no one could look at it without thinking of the passage in the Bible which says, ‘the sea was turned to blood.’ The shells on the beach, reflecting light, resembled coals of fire.”

The sky was so crimson that many who saw it believed that neighboring locales were on fire. Americans in the South were particularly startled by the northern lights, which migrated so close to the equator that they were seen in Cuba and Jamaica. Elsewhere, however, there appeared to be genuine confusion. In Abbeville, South Carolina, masons awoke and began to lay bricks at their job site until they realized the hour and returned to bed. In Bealeton, Virginia, larks were stirred from their sleep at 1 a.m. and began to warble. (Unfortunately for them, a conductor on the Orange & Alexandria Railroad was also awake and shot three of them dead.) In cities across America, people stood in the streets and gazed up at the heavenly pyrotechnics. In Boston, some even caught up on their reading, taking advantage of the celestial fire to peruse the local newspapers.

Al Penney
VO1NO

Humanity is far more technologically dependent than it was in 1859. A Carrington-like event today could wreak havoc on power grids, satellites and wireless communication. In 1972, a solar flare knocked out long-distance telephone lines in Illinois, for example. In 1989, a flare blacked out most of Quebec province, cutting power to roughly 6 million people for up to nine hours. In 2005, a solar storm disrupted GPS satellites for 10 minutes.

If this type of solar geomagnetic storm occurred today, it would cost an estimated one to two TRILLION dollars in damage. It would certainly cause extensive economic and social disruptions across the planet.

Coming shortly after the 2012 near miss, researchers from Lloyd's of London and the Atmospheric and Environmental Research agency in the United States estimated that a Carrington-class event impacting Earth today would cause between $0.6 and $2.6 trillion in damages to the United States alone and would cause widespread — if not global — electrical disruptions, blackouts, and damages to electrical grids.

Cascading failures of electrical grids, especially in New England in the United States, are also particularly likely during a Carrington-class event. Power restoration estimates range anywhere from a week to the least affected areas to more than a year to the hardest-hit regions.

Electronic payment systems at grocery stores and gas stations would likely crash, electric vehicle charging stations — that rely on the power grid — would likely be unusable for some time, as would ATMs which rely on internet and/or satellite link to verify account and cash disbursement information.

Television signals from satellites would be majorly disrupted, and satellites, too, would experience disruptions to radio frequency communication, crippling GPS navigation.

Planes flying over the oceans would likely experience navigation errors and communications blackouts as a result of the disrupted satellite network.

Astronauts onboard space stations would either seek shelter in a radiation-hardened modul or, if enough time permitted and the CME event was significant enough, enter their return spacecraft and come home.

The question of exactly how to best protect astronauts on the Moon or at destinations farther out in the solar system is an on-going discussion/effort.

The best prevention is prediction. Knowing that a coronal mass ejection is on its way could give operators time to safely reconfigure or shut down equipment to prevent it from being destroyed.

Building in extra resiliency could help as well. For the power grid, that could include adding in redundancy or devices that can drain off excess charge. Federal agencies could have a stock of mobile power transformers standing by, ready to deploy to areas where existing transformers — which have been known to melt in previous solar storms — have been knocked out. In space, satellites could be put into a safe mode while they wait out the storm.

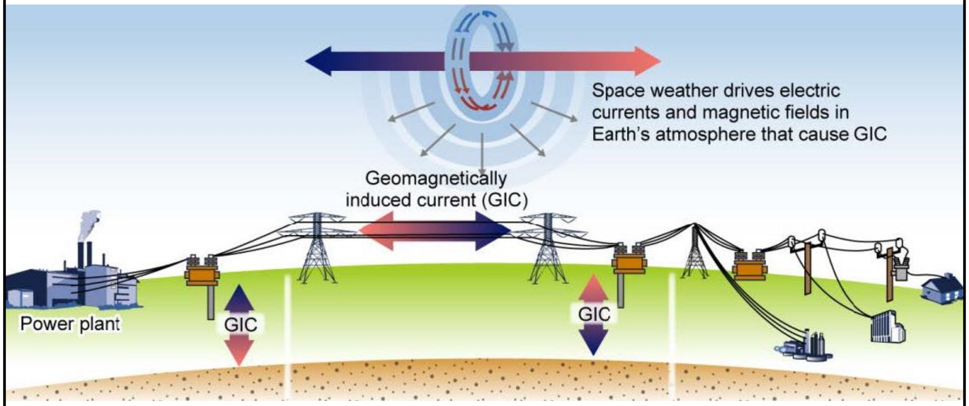
That 1989 event finally got the attention of infrastructure planners. "Those are the kinds of things that we have really learned our lesson from," Halford says. Power companies began building safety measures, such as tripwires, into the electricity grid to stop cascading failure. If power increases too quickly, these tripwires are programmed to switch off so that damage is limited and transformers don't burn out as they did in 1989.

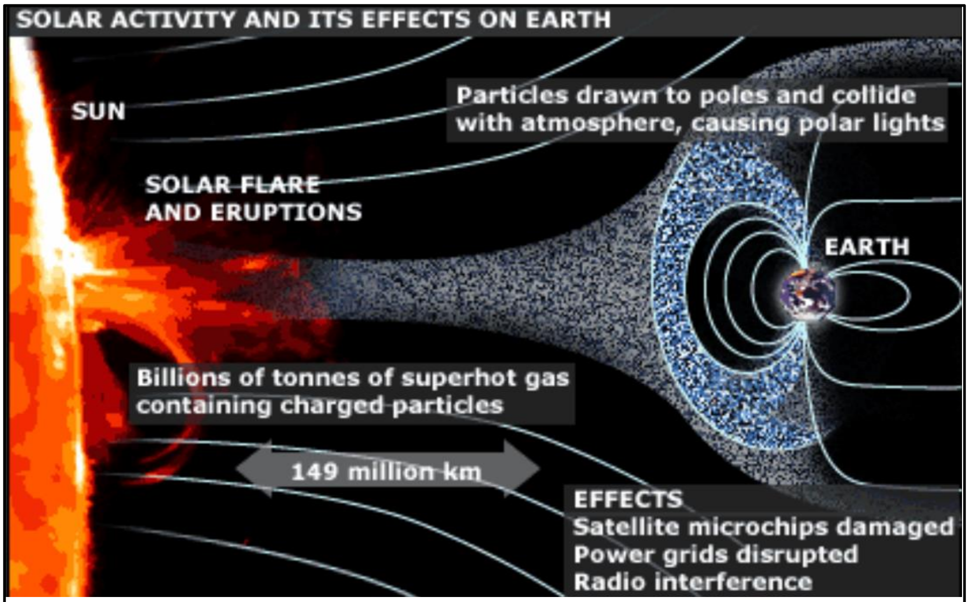
Geomagnetic storms can also cause bit flips, surface charging or internal charging to satellites orbiting our planet — all things that occurred **this October** when a solar flare produced a coronal mass ejection and a geomagnetic storm that hit Earth. Satellites are particularly susceptible because they don't benefit from the relative protection of our atmosphere. But most of the satellites launched in the past two decades have been built robustly enough that they are resistant to overcharging.

Not all impacts of a large solar flare would necessarily be negative. When these events occur, they thicken the density of Earth's upper atmosphere. In effect, the atmosphere rises in altitude for a short period. This can impact the orbits of satellites, potentially causing problems, but it can also affect the orbits of space debris floating around up there. The extra drag could cause this junk to fall into orbit and burn up.

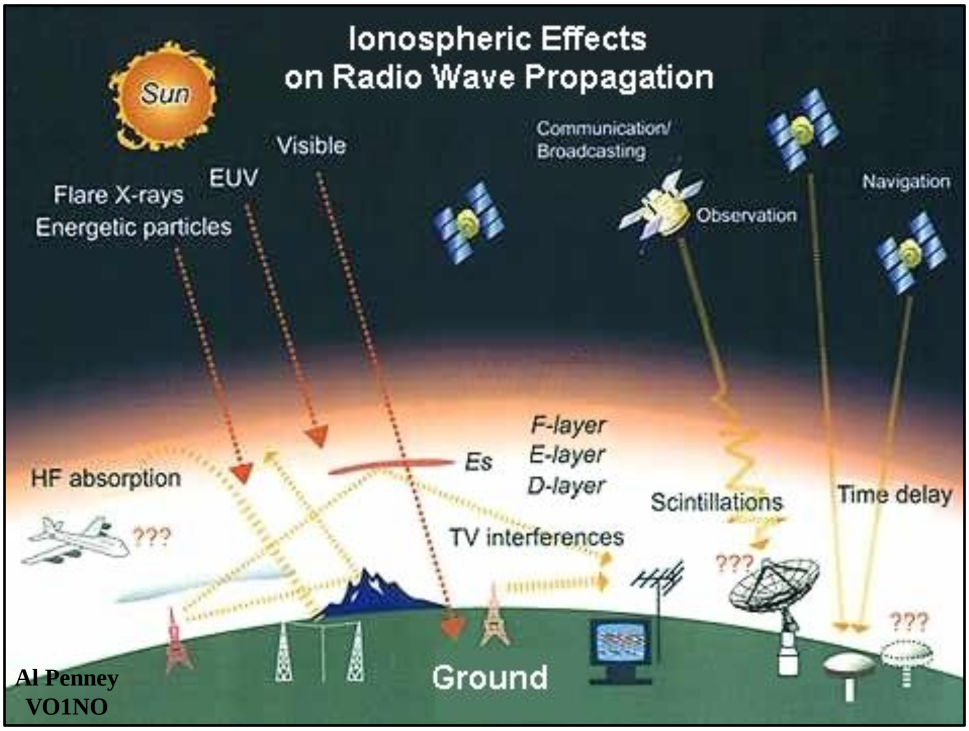
Al Penney
VO1NO

[redacted]

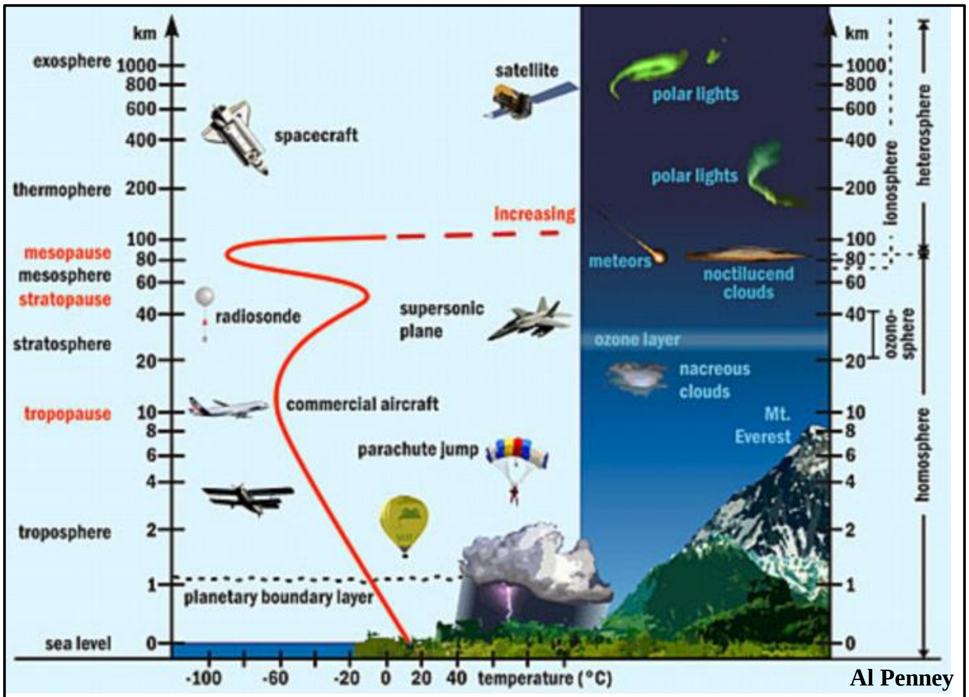

Space weather drives electric currents and magnetic fields in Earth's atmosphere that cause GIC
Geomagnetically induced current (GIC)
Power plant
GIC
GIC



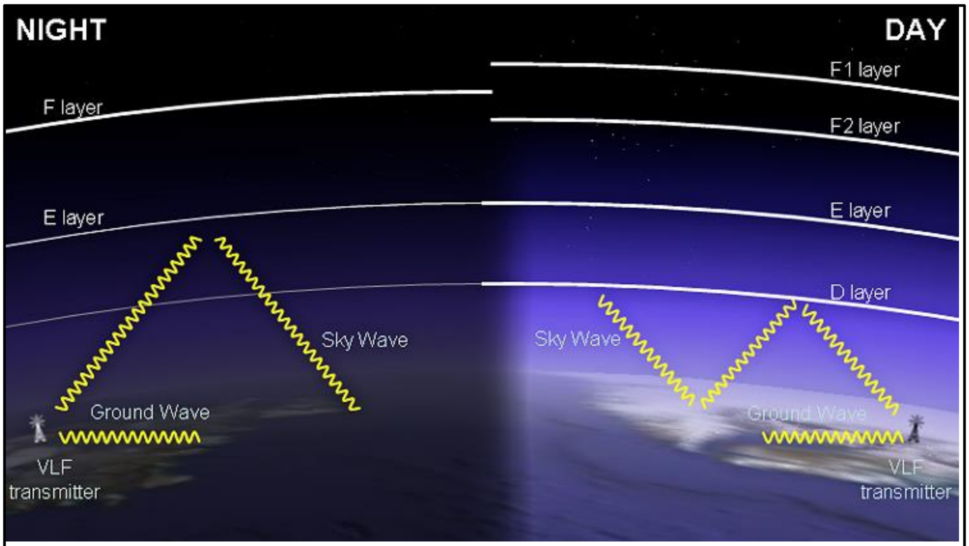
Al Penney
VO1NO



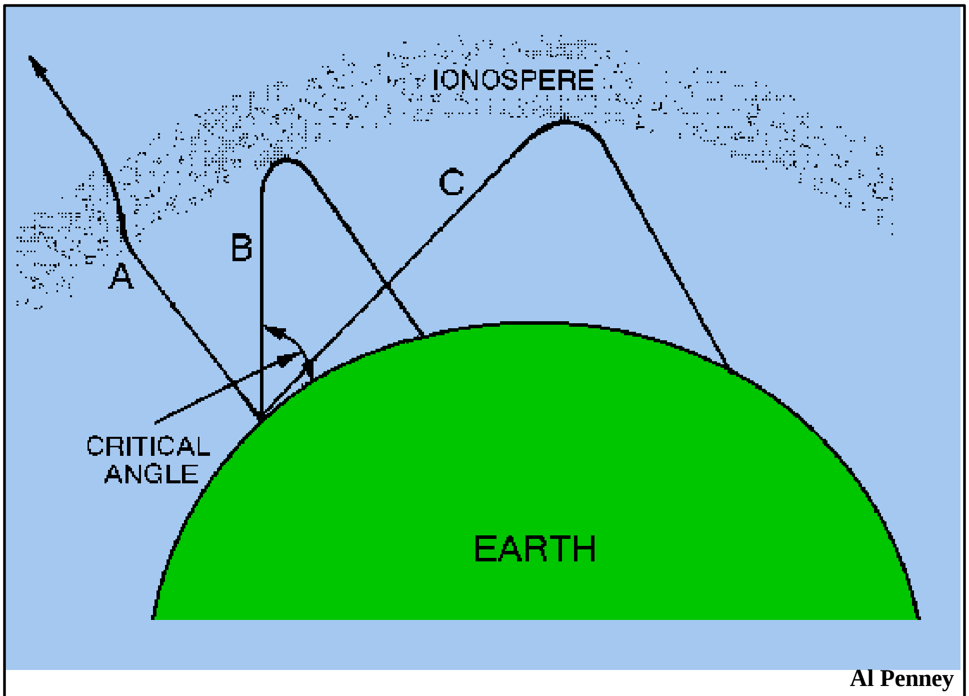
Al Penney
VO1NO



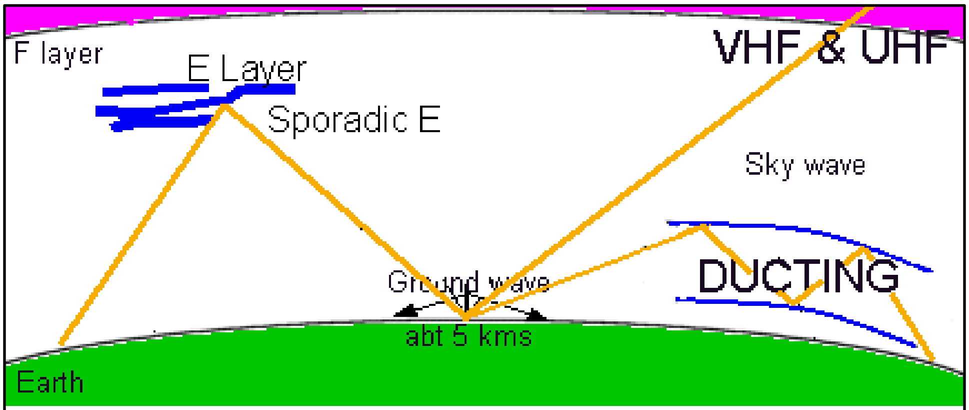
Al Penney
VO1NO



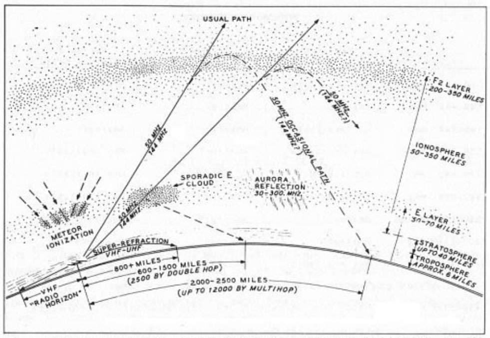
Al Penney
VO1NO



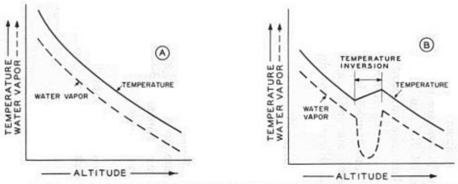
Al Penney
VO1NO



Al Penney
VO1NO

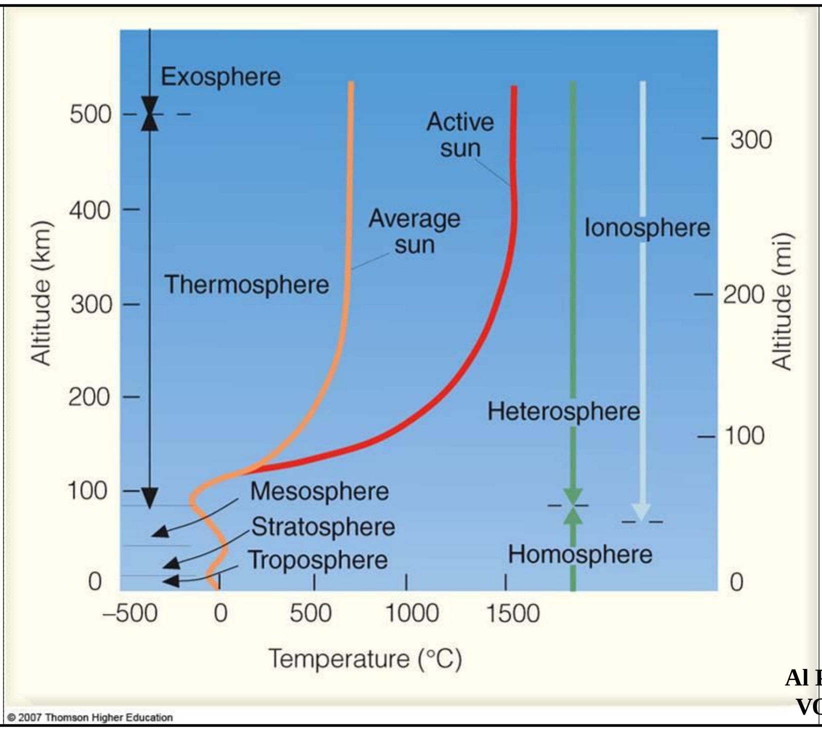


ATMOSPHERE OF THE EARTH is concentrated in a thin layer about 300 miles thick. The ionized layers of air within this span have the ability to reflect electromagnetic energy of certain frequencies. The atmosphere is divided into strata named the troposphere, the stratosphere and the ionosphere. It is in the latter region that radio reflection at the higher frequencies takes place.

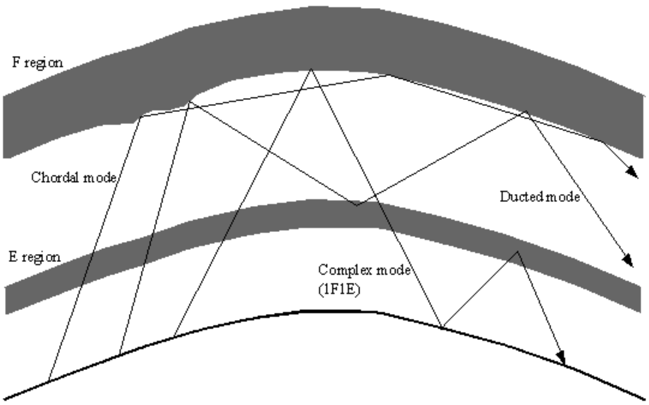


LONG DISTANCE TROPOSPHERIC PROPAGATION takes place because of temperature inversion. Normal temperature and water vapor content of air decrease with altitude (A). Refractive index of the atmosphere can produce inversion area (B), showing an abrupt break in water vapor content. If the inversion is pronounced, the resulting bending of the radio wave will follow the curvature of the earth. Atmospheric ducts have propagated VHF signals over distances in excess of 2500 miles.

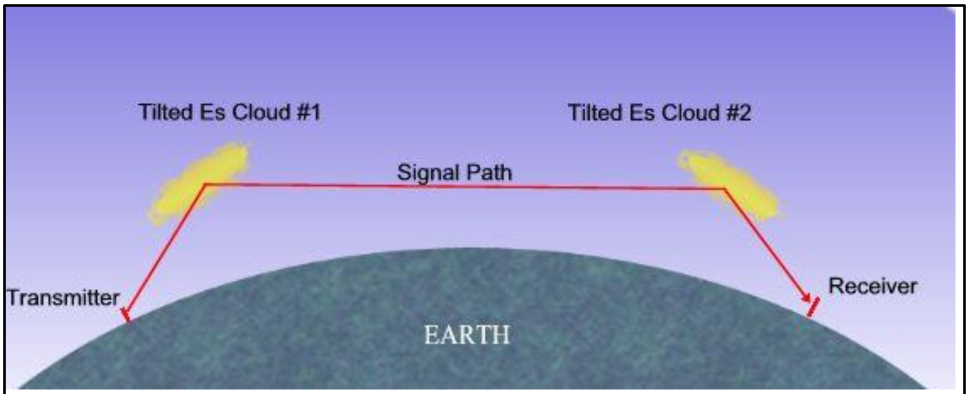
Al Penney
VO1NO



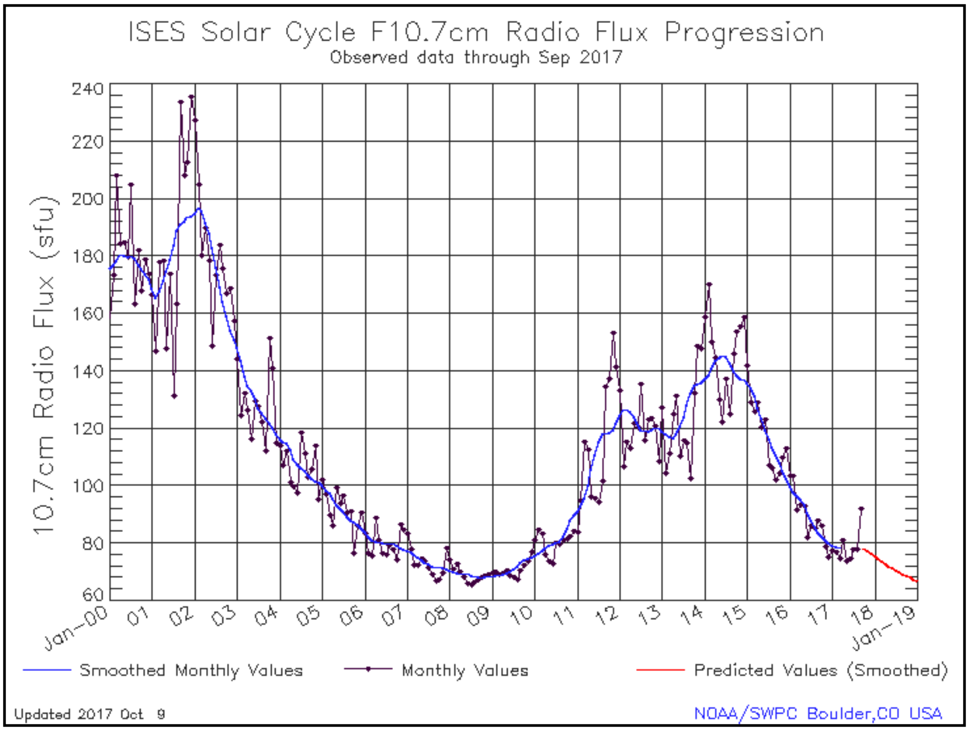
Al Penney
VO1NO



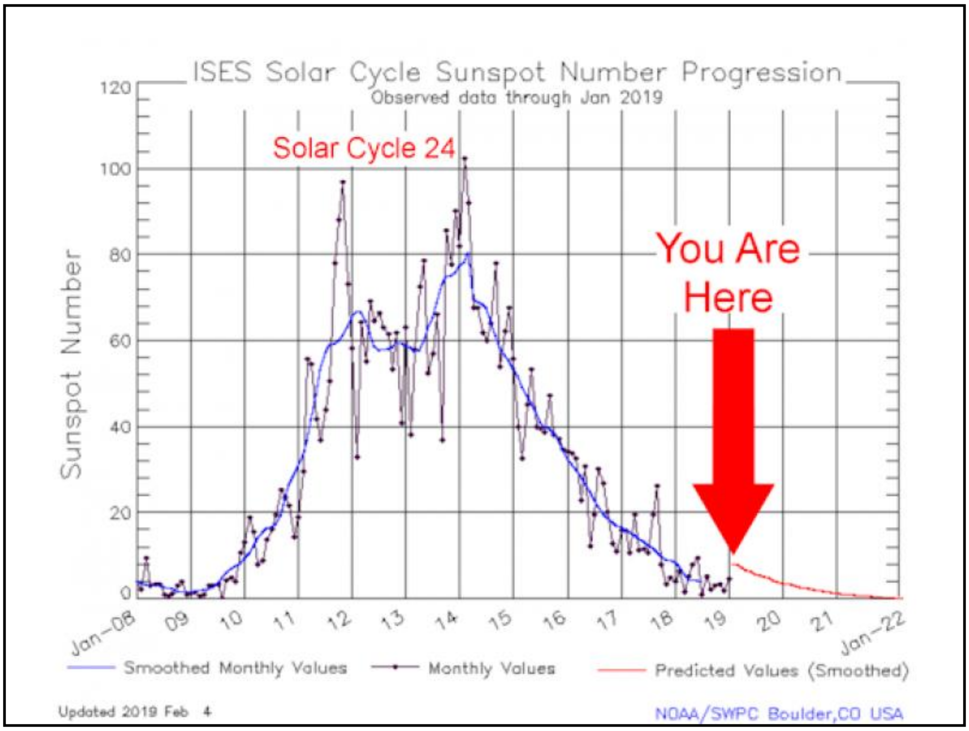
Al Penney
VO1NO



Al Penney
VO1NO



International Space Environment Services



Solar Cycle 24 has been one of the quietest, weakest cycles in a century. (The prior cycle 23 also had an extended period of very few sunspots.)

SOLAR CYCLE 25 PREDICTIONS

According to NOAA/NASA experts: "Cycle 25 will be similar in size to cycle 24, preceded by a long, deep minimum. Solar Cycle 25 may have a slow start, but is anticipated to peak with solar maximum occurring between 2023 and 2026, and a sunspot range of 95 to 130. This is well below the average number of sunspots, which typically ranges from 140 to 220 sunspots per solar cycle."

In other words, Solar Cycle