Chapter 20

Low and High Latitude Communication Problems

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20 Low and High Latitude Communication Problems

The Earth's magnetic field exerts a considerable influence over the ionosphere, separating the ionosphere into three broad regions.

- Low-latitude equatorial,
- Mid-latitude, and
- High-latitude polar region

Of the three, the mid-latitude region is the most studied and well understood.

The problems that occur at mid-latitudes including E mode screening, sporadic E, noise, and the multitude of fading problems also occur at both the low and high latitudes. In addition, the low and high latitudes each have problems that are unique to their particular regions. Consequently, the high-latitude polar ionosphere bears little resemblance to the low-latitude equatorial region, and both are considerably different from the mid-latitude ionosphere.

20.1 Problems at Low Latitudes

Earth's equatorial region is the zone between the Tropic of Cancer and the Tropic of Capricorn, 23.5 degrees either side of the equator (Figure 1).

Earth's magnetic field throughout the equatorial region is predominately horizontal (parallel to the Earth's surface) as illustrated in Figure 2. Energetic electrically charged particles from the magnetosphere and solar wind cannot cross these magnetic field lines. Instead, the particles spiral along the field lines parallel to Earth's surface before plunging vertically into Earth's polar region atmosphere. The high energy particles heavily ionize the ionosphere's D layer adversely affecting transpolar propagation, for example from a transmitting station (Tx) in California to a receiving station (Rx) in Europe. As illustrated in Figure 2, the signals are heavily absorbed in the D layer as they enter the ionosphere. What remains of the signals refract from the F2 region and then are absorbed again in the D layer as they travel to the receiving station. If the energy of the particles is high enough, a Polar Cap Absorption (PCA) event may be triggered preventing all transpolar communications. The equatorial region, however, does not have these problems. The horizontal magnetic field above the equator shields Earth's low latitude regions from energetic particles.

The equatorial ionosphere is unique in that it is thicker than elsewhere. In addition, the Sun is nearly over head every day throughout the year resulting in extensive solar photo-ionization with little seasonal variations between summer and winter. Consequently, critical frequencies are higher in the tropics than anywhere else on Earth. Based on these characteristics we would expect the low latitude region to be particularly conducive to HF communications. To an extent our assumptions are correct.

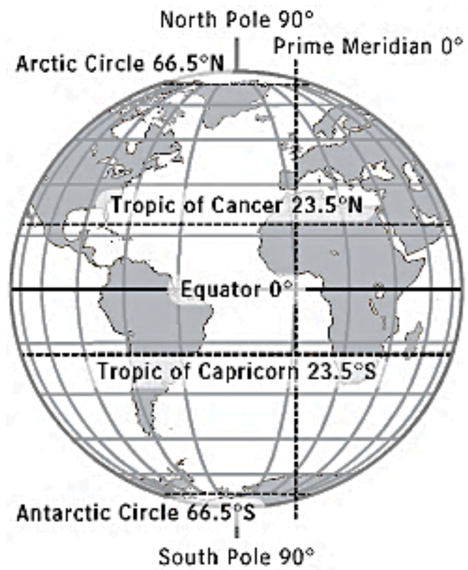

Figure 1 Regions of the Earth (source: google)

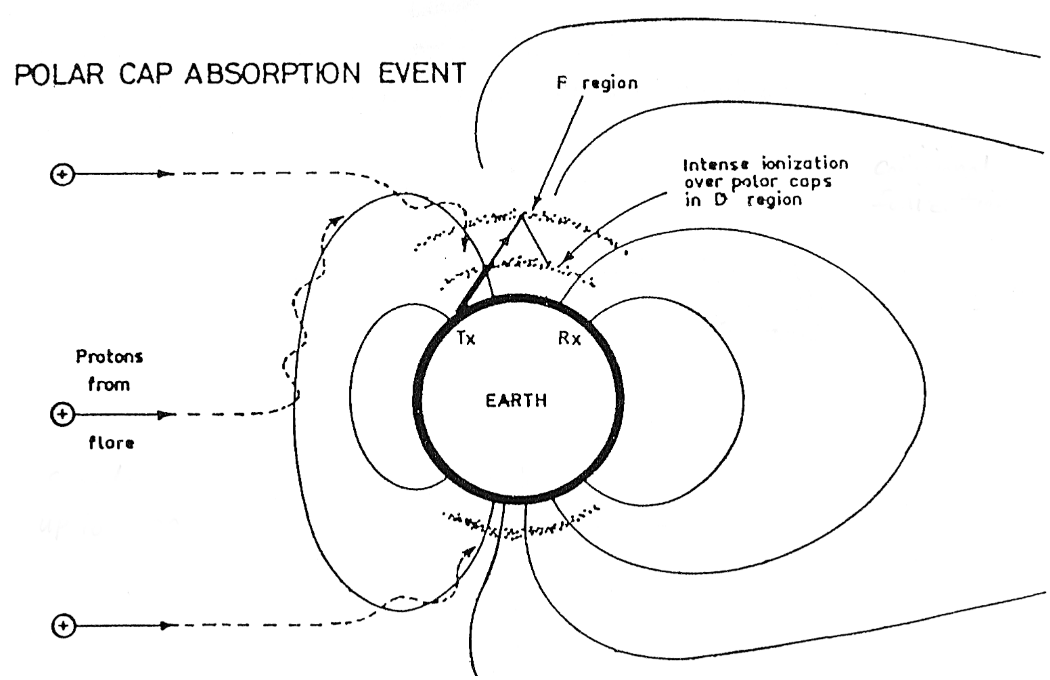

Figure 2 Charged particles cannot cross Earth's magnetic field (source: McNamara)

However, strong electromagnetic forces are present in the equatorial zone. These forces result from:

- The Earth's horizontal north-south magnetic field over the geomagnetic equator,
- High concentrations of free electrons resulting from extensive photo-ionization, and
- A horizontal west to east electric field also over the geomagnetic equator.

20.1.1 Low Latitude Equatorial Electrojet

During the day, as the Sun warms Earth's equatorial atmosphere, temperature and pressure differences develop creating atmospheric winds blowing eastward in the ionosphere's E region. The electron and ion densities are very high at an altitude of roughly 90 to 130 km due to intense solar ionization. In addition, Earth's magnetic field is horizontal (parallel to Earth's surface) and pointed northward along the magnetic equator. This set of conditions combine to produce a very strong eastward electrical current flowing within the equatorial E region. This electrical current is known as the Equatorial Electrojet illustrated in Figure 3.

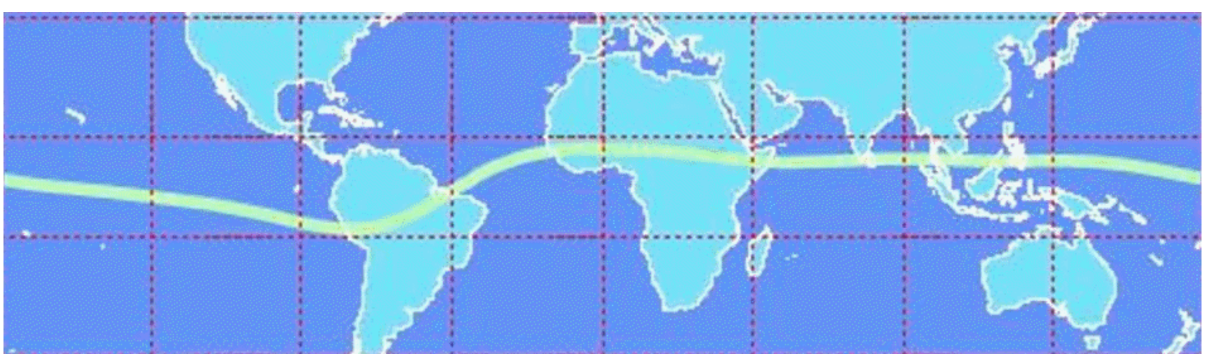

Figure 3 Low latitude electrojet (source: gfz-potsdam.de)

20.1.2 Low Latitude Sporadic E Patches

At low latitudes, ionization irregularities resulting from the electrojet are believed to be responsible for creating equatorial sporadic E zones. These particularly strong sporadic E patches are essentially a daytime phenomenon, occurring nearly every day with little seasonal variation.

20.1.3 Spread F Irregularities

Signal scattering due to field-aligned irregularities in electron density result in an F region phenomena known as spread F. Spread F causes an HF signal to be reflected from various heights within the F layer, as illustrated in Figure 4, stretching out and garbling the transmitted signal. Digital data is particularly vulnerable limiting the data rate of signals that can be successfully transmitted. In addition, spread F produces rapid fading. Spread F is often noticed in the echoes of ionogram pulses. In some cases, the echoed pulse is up to 10 times wider than the transmitted pulse. This type of distortion is known as **range spread**. In other cases, **frequency spread** distorts critical frequencies so that they are no longer single frequencies but instead bands of frequencies.

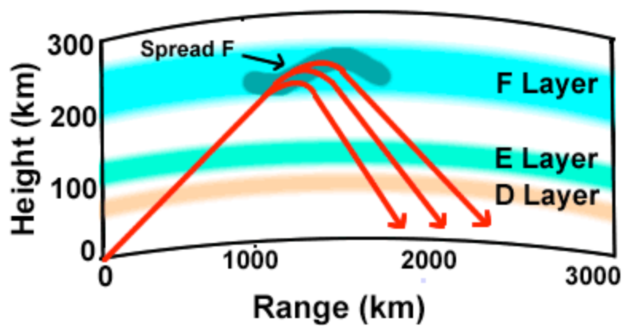

Figure 4 Spread F irregularity (source: www.met.nps.edu)

The field aligned irregularities producing spread F are highly variable in size. They can range from roughly a 100 km to several thousand kilometers wide and about a kilometer thick

In the equatorial region spread F irregularities appear mainly at night, during magnetically quiet days, in a zone straddling the geomagnetic equator from approximately 20º south to 20º north latitude. They begin appearing near sunset, in conjunction with the nightly upward drifting F region, peak around midnight, and then gradually disappear. Spread F can occur at any time but tends to be more intense and occur more often during solar maximum, during the equinoxes, and on most nights from November through January. Equatorial spread F disappears with the onset of a magnetic storm.

20.1.4 Equatorial Plasma Fountain

Collisions occur infrequently in the rarified atmosphere of the equatorial F region. At this altitude both ions and electrons are mobile drifting upward during the day across geomagnetic field lines at a velocity of

$$\overrightarrow{v_d} = \frac{\overrightarrow{E_{eq}} \times \overrightarrow{B_0}}{|B_0|^2}$$

due to the force exerted by horizontal crossed electric $\overrightarrow{E_{eq}}$ and magnetic fields $\overrightarrow{B_0}$. The electric field gradually weakens and finally disappears at an altitude of around 800 km. With the electric field no longer present, charged particles, both ions and electrons, travel under the influence of gravity and pressure gradients along magnetic field lines curving back to Earth as illustrated in Figure 5. The charged particles eventually reenter the mid part of the F region approximately 15 to 20 degrees either side of the magnetic dip equator (see the chapter on "Earth's Magnetic Field"). Charged particles transported from the equator combine with those already in the region creating a peak or crest in electron concentrations 15 to 20º north and south of the magnetic equator. The outflow of particles reduces the electron density along the dip equator producing an equatorial trough. This phenomena is known as the Equatorial Plasma Fountain.

The plasma fountain is usually not symmetric about the magnetic equator. High altitude winds tend to push plasma from the summer to the winter hemisphere. Consequently, the largest electron peaks generally occur in the winter hemisphere. Also, the declination of Earth's magnetic field causes the characteristics of electron peaks to change with geographic longitude.

The plasma fountain crests are most pronounced during solar maximum. However, the average latitudinal locations of the crests vary by only 2 to 3 degrees from solar minimum to solar maximum.

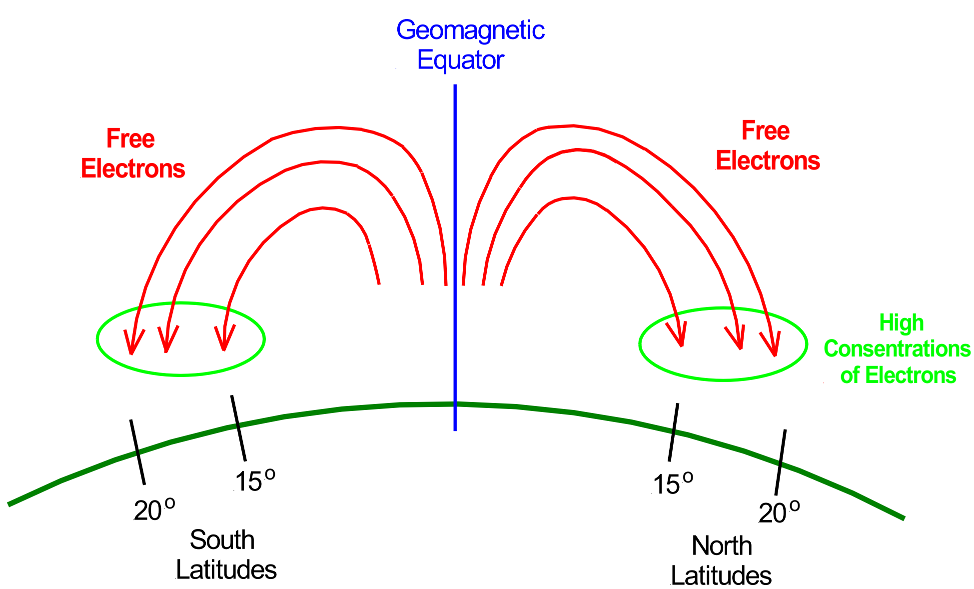

Figure 5 Equatorial plasma fountain (source: author)

20.1.5 Appleton Equatorial Anomaly

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

The fountain effect is clearly visible in the F2 winter (December) ionospheric map shown in Figure 6. The black line sloping through South America is the magnetic dip equator. The crests in electron concentrations are the bright pink zones on both sides of the magnetic equator.

The crests usually form in the late afternoon and early evening. While the crests vary from day-to-day and seasonally, they are most pronounced during solar maximum. Notice in Figure 6 that the largest electron peaks (two of them) occur in the winter hemisphere.

F2 critical frequencies within the crests can often reach 15 MHz or higher during solar maximum. In contrast, critical frequencies along the magnetic equatorial trough will typically be several MHz less.

The altitude at which the F2 peak electron density occurs is also different between the equator and the crests, however, in this case the difference is reversed. The peak F2 electron density along the equator is higher in altitude than the corresponding peak in the crests.

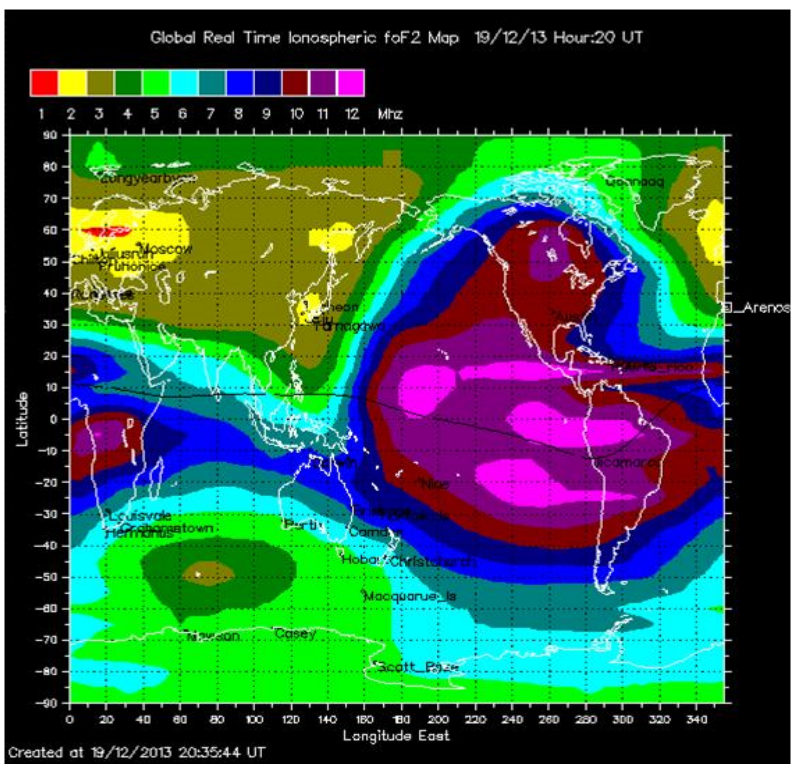

Figure 6 Ionospheric map showing fountain crests (source: Australian Space Weather Services)

The fountain effect distorts the general form of the ionosphere throughout the low latitude equatorial region leading to the interesting transequatorial HF propagation phenomena illustrated in Figure 7. Typically, a radio signal transmitted from one hemisphere to the other requires multiple hops through the ionosphere to reach its destination, with signal attenuations occurring with each hop. Instead, a radio signal experiencing transequatorial propagation reflects off one anomaly crest, travels across the equator to the second crest, and then refracts back to Earth. Transequatorial propagation allows a radio signal to traverse the distance from transmitter to receiver in one hop minimizing signal loss. Transequatorial propagation is most pronounced for signals in the 6 meter frequency band.

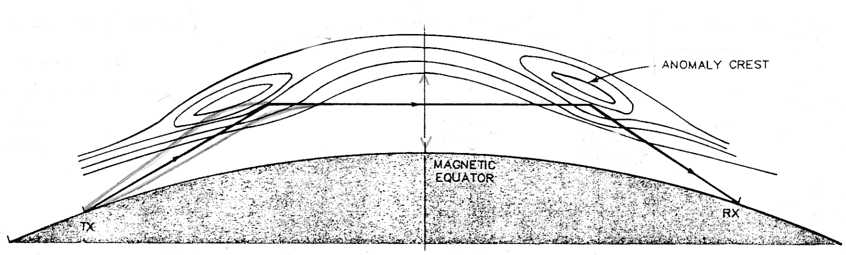

Figure 7 Transequatorial propagation (source: McNamara)

20.1.6 Rapidly Changing Critical Frequencies

At mid and high latitudes sunrise occurs gradually because the Sun is relatively low in the sky. However, in equatorial regions the Sun is nearly over head every day throughout the year. This causes sunrise, and the transition from night to day time critical frequencies, to occur very quickly in the tropics. Critical frequencies can change from 6 to 12 MHz in less than an hour making it difficult to select an appropriate operating frequency. Multi-hop west to east transmissions are particularly a problem during sunrise since critical frequencies along the transmission path change rapidly over distances of only a few hundred kilometers. Critical frequencies stabilize following the sunrise transition period. Sunset also occurs quickly. However, ionosphere electron densities and critical frequencies decline more slowly during sunset creating less of a problem.

20.2 Problems at High Latitudes

As we know, solar wind emanating from the Sun severely distorts Earth's magnetic field forming the magnetosphere shown in Figure 8. Earth's magnetic field shields the Earth from the ravages of the solar wind by defecting the wind past the Earth and in the process making life on Earth possible.

Solar wind particles (mostly electrons, protons [H^+], and some α-particles [He^{2+}]) impact Earth's magnetic field in the region of the magnetopause around 11 Earth radii (11 R_E) from the sunlight side of the Earth. (1 R_E = 6,370 km = 3,959 mi). In general, the electrically charged solar wind particles cannot cross magnetic field lines into the magnetosphere and so are forced to travel around the magnetosphere outer edge creating a bow shock about 15 R_E from closest approach to the Earth. The force exerted by the solar wind on Earth's magnetic field compresses the magnetosphere on the dayside and stretches it out on the nightside forming a long comet like magnetic tail that extends out past the Moon (Figure 9). Notice that during a full moon the moon is within the magnetic tail. However, during a new moon the moon, at a distance of 384,400 km (238,900 mi ~ 60 R_E), is outside the magnetosphere subjecting it to the ravages of the solar wind.

The magnetosphere is fixed relative to the Sun while the Earth itself rotates within the stationary magnetosphere. That is, the nose of Earth's comet shaped magnetosphere always points toward the Sun while the tail points down stream away from the Sun.

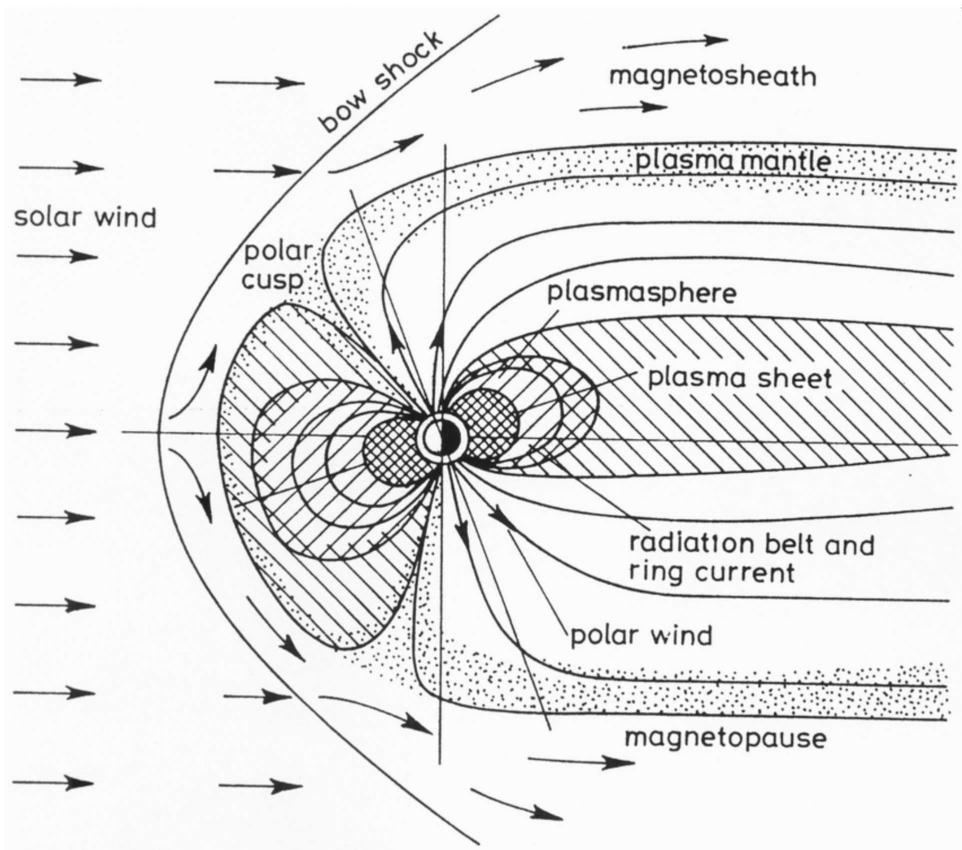

Figure 8 Earth's Magnetosphere (source: Davies)

As we have noted, moving charged particles can travel along magnetic field lines but cannot cross them. As a result, solar wind particles emanating from violent activity on the Sun are prevented from entering the atmosphere in Earth's equatorial region where the magnetic field is parallel to Earth's surface. However, the situation is different at high latitudes. Here the magnetic field lines are nearly vertical allowing solar wind particles to spiral downward along magnetic lines directly into the polar atmosphere, as illustrated in Figure 10.

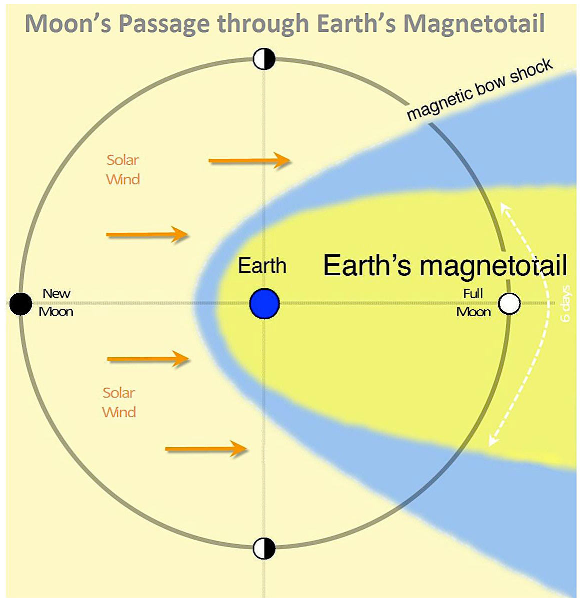

Figure 9 Earth's magnetic field tail stretches out past the moon (source: Time-Price-Research)

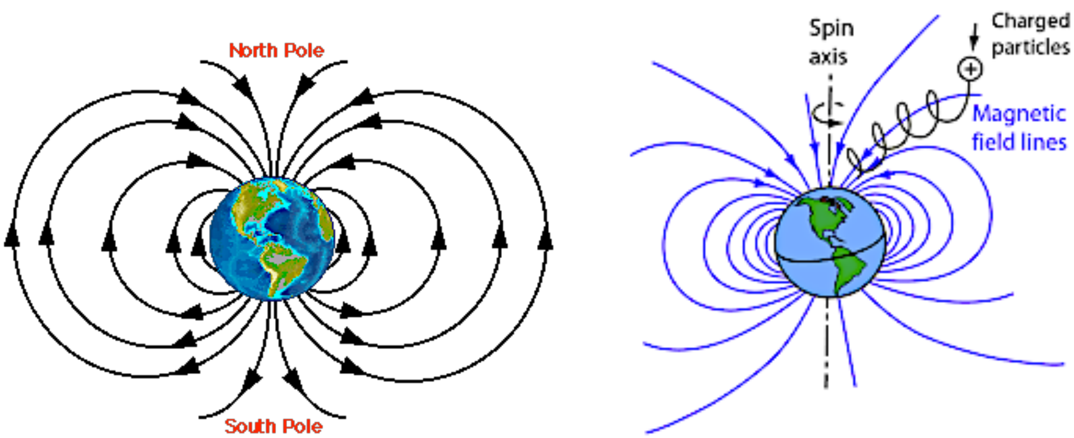

Figure 10 Earth's vertical magnetic field at the poles (source: The Ocean Web and hyperphysics)

There are two neutral zones in the magnetosphere, one in each hemisphere, where the total magnetic field is nearly zero. These neutral zones are known as the Polar Cusps. As shown in Figure 8, the polar cusps form the gap between the day side magnetic field extending out in front of the Earth and the nightside field forming the magnetotail.

The polar cusps are extremely important since they are the only locations where charged particles can enter the magnetosphere without crossing magnetic field lines.

Each polar cusp extends downward through the magnetosphere forming a band about 5^o wide at Earth's surface centered around 77^o magnetic latitude. Within the cusps solar wind particles stream down directly into Earth's upper atmosphere, unimpeded, significantly affecting the high latitude ionosphere. These particles include solar energetic particles (SEPs) ejected during solar flares and traveling at nearly the speed of light.

The high latitude (Figure 11) ionosphere is extremely complex compared to the rather benign mid and equatorial ionospheres. Most of the magnetosphere regions shown in Figure 8 originate or terminate in the high latitudes, resulting in very complex high latitude field aligned electrical currents, hall currents, and electrojets as illustrated in Figure 12. In addition, hundreds of tons of charged particles flow into and out of the high latitude regions. It is no wonder that transmitting HF radio signals through the polar area is challenging.

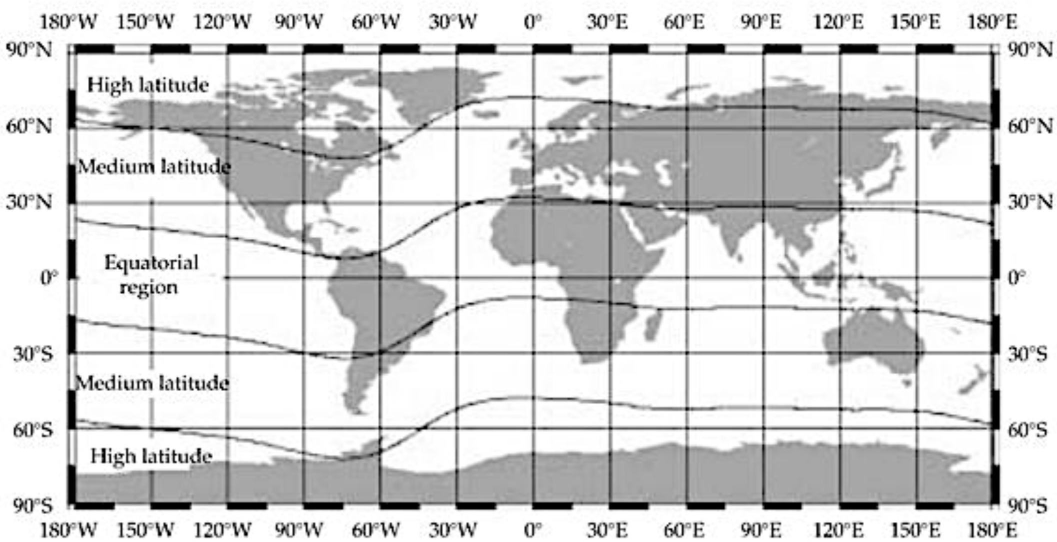

Figure 11 Regions of Earth's Ionosphere (source: ResourceGate.net)

In a sense, the north and south polar regions are Earth's garbage pits for all of the junk, hundreds of tons of it, arriving at Earth from turbulent events occurring on the Sun. The junk consists mainly of electrons, protons, and alpha particles; the remains of hydrogen and helium atoms ionized by the intense heat from violent solar activity. Hydrogen and helium are, of course, the primary constituents of the Sun.

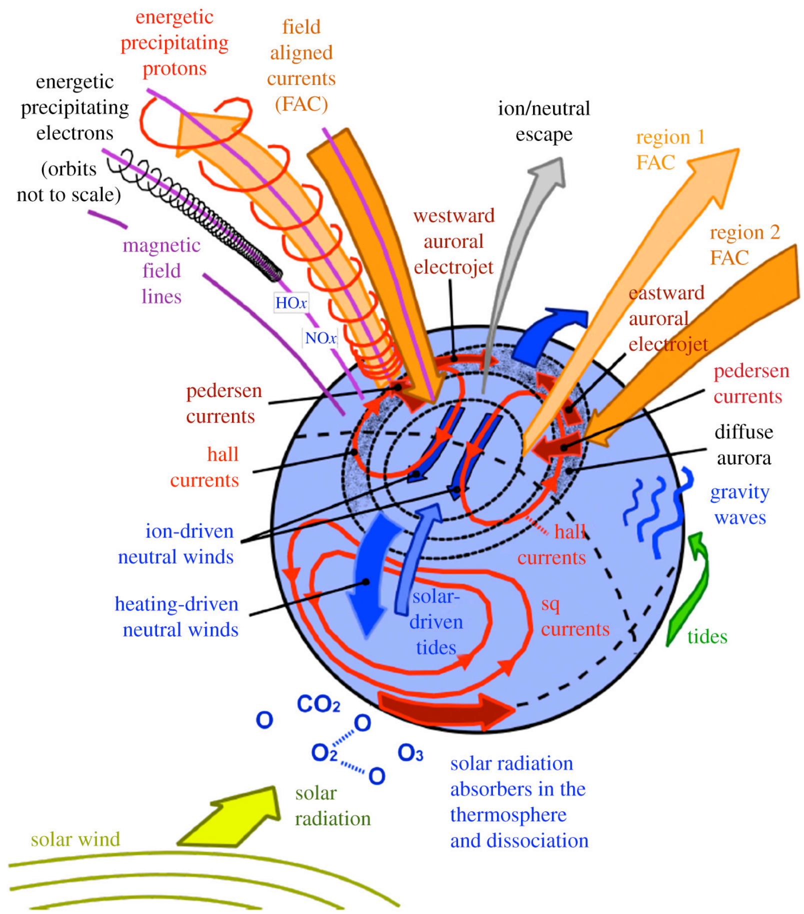

Figure 12 Polar region electrical currents and particle flows (source: royalsocietypublishing.org)

Yet, in all of this chaos there is beauty in the polar region aurora light displays and in the auroral ovals (Figure 13). The polar regions are like no other place on Earth. Within this environment, and because of it, exists the very complex high latitude ionosphere.

Figure 13 Auroral Display and Oval (source: sciencephoto.net)

20.2.1 F Region of the High Latitude Ionosphere

Problems occurring in the high latitude F region include:

- The polar cusps directly exposing the high latitude F region to violent disturbances on the Sun,
- Charged partials spiraling along magnetic field lines down into the ionosphere,
- The polar wind transporting tons of charged particles out of the ionosphere,
- Troughs of depleted electron density,
- High latitude spread F,
- High density electron patches and blobs in constant motion, and
- Traveling ionospheric disturbances.

The equatorial and mid-latitude regions of the ionosphere do not encounter these problems.

F region plasma in the equatorial and mid-latitude regions is driven by high altitude neutral winds. However, at high latitudes, the plasma is driven more by changing electric and magnetic fields than by the neutral winds. The cross-polar electric field coupled with the vertical magnetic field produce plasma speeds of 200 to 1,000 meters per second in accordance with

$$\vec{v} = \frac{\vec{E} \times \vec{B}}{|B|^2}$$

where v is the plasma speed and E and B are the electric and magnetic fields respectively. The direction of the plasma flow is directly over the pole from the polar cap midnight to noon sectors, with a return flow through the auroral oval back to the night sector. This flow is perpendicular to both the polar cap electric field and vertical magnetic field, forming two hall current convection cells as illustrated in Figure 12 and Figure 14. Variations in the solar wind and interplanetary magnetic field (IMF) distorts this basic flow pattern.

20.2.1.1 F Layer in the Polar Cap

The high latitude Polar Cap (yellow) and Auroral Oval (green) regions are illustrated in Figure 15.

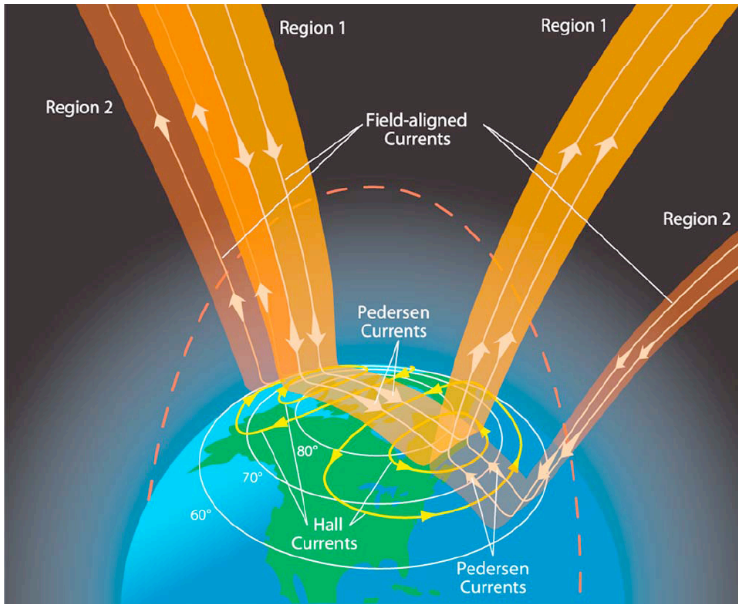

Figure 14 Field Aligned Currents (source: Wikipedia)

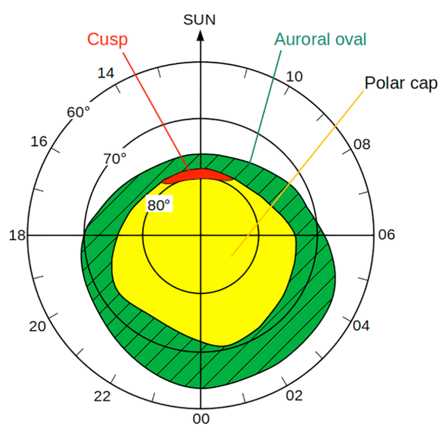

Figure 15 High Latitude Polar Cap and Auroral Regions (source: ResearchGate)

Ionization of the polar cap F regions is the result of:

- EUV radiation from the Sun as usual – Plus
- Solar wind energetic particles spiraling down along field lines into the polar cap.

At times, energetic particles streaming in from the solar wind and magnetosphere are the primary source of polar cap ionization.

Loss of electrons in the polar cap F region is the result of:

- Electron–ion recombination as usual – Plus

- Polar wind transporting tons of charged particles from the upper ionosphere into the magnetosphere. The charged particles are primarily electrons and oxygen ions.

Polar wind is the second most important mechanism responsible for removing electrons from the polar ionosphere, second only to recombination. Consequently, the polar wind decreases electron densities in the polar cap region beyond that normally encountered through recombination.

Variations in the polar cap F region are greatest during the winter when the polar cap is darkest. Critical frequencies of 2 – 3 MHz are common in the winter and occasionally as low as 1 MHz. At times the polar cap F1 region can be stronger than the F2 region.

20.2.1.2 F Region in the Auroral Oval

The auroral oval F region (green area in Figure 15) is similar to the F region at mid latitudes including diurnal and seasonal variations, the winter anomaly, variations with the solar cycle, etc. However, electron densities on the poleward side of the oval, and extending a few degrees into the polar cap, are often enhanced by electrons flowing in along magnetic field lines from the solar wind and outer magnetosphere. The enhancements are generally not uniform. Large variations in electron densities can occur over relatively short distances due to irregularities in the influx of electrons. Inflow of solar wind and magnetosphere ions is particularly strong in the cusp region, highlighted by the red band in Figure 15. The inflow results in collisional ionization as the high speed in coming ions collide with neutral high altitude atoms and molecules. Collisional ionization further increases electron densities. In addition, transport of plasma from the aurora's day to night side contributes significantly to late night ionization levels within the auroral oval. On the far side of the oval, toward the equator, extended night time depletions in electron and ion densities form F region ionospheric troughs, including the main trough described in the next section.

These factors cause critical frequencies in the auroral oval region to be erratic disrupting the propagation of HF radio signals through the area.

20.2.1.3 High Latitude F Region Irregularities

Irregularities in the high latitude F region include:

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

Increased geomagnetic activity dramatically increases the appearances of those irregularities highlighted in red.

20.2.1.3.1 F Region Ionospheric Troughs

An ionospheric trough is a relatively narrow strip of depleted ionization in the high latitude F region of the ionosphere. Within a trough electron densities and O^+ ion concentrations are relatively low compared to regions outside the trough.

A number of troughs exist. The largest and most pronounced trough is the F Region Main Trough. It is a narrow ribbon of depleted ionization that stretches east to west near 60° latitude along the equatorial edge of the auroral oval. The main trough is shown as the shaded band below the auroral oval in Figure 16. It is primarily a night time phenomenon, appearing at dusk and extending through the night to dawn. Typically, the main trough is around 15° wide in latitude. Originally the main trough was called the mid-latitude trough. Today the term main trough is generally used since there are a number of smaller troughs in both the northern and southern auroral zones.

The main trough is generally considered the boundary between mid and high latitude regions of the ionosphere. However, the main trough is not stationary. It expands and contracts both northward and toward the equator. During the night the trough often drifts to lower latitudes. It can also drift toward lower latitudes during geomagnetic storms.

The main trough occurs most often in the winter and during the equinoxes. The trough rarely appears in summer. When a summer trough does occur it usually appears only around midnight.

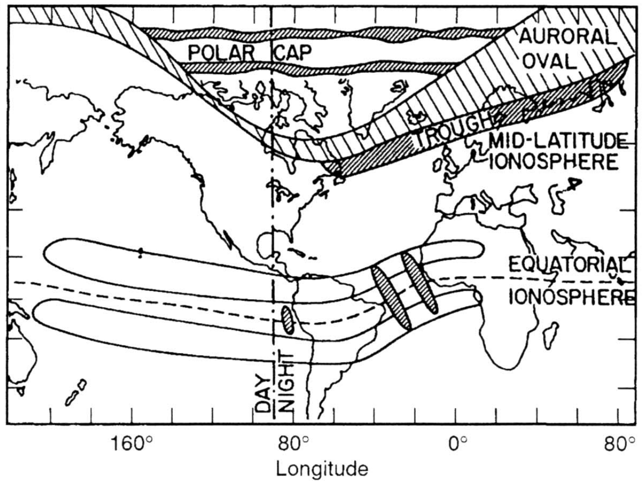

Figure 16 Location of main trough (source: Goodman)

It is generally believed that trough formation is the result of high latitude F region plasma flowing from east to west in the opposite direction of Earth's rotation. The westward flow extends the amount of time that the plasma is in darkness, allowing more time for electron-ion recombination to occur before solar photo-ionization resumes at sunrise. The extended period of darkness results in lower concentrations of electrons and ions in a trough.

F region troughs that appear in the southern hemisphere are much different from those in the north. Southern hemisphere troughs appear throughout the year and at all times of the day. They tend to occur more often during the day than at night and during the equinoxes and in the summer, the opposite of northern hemisphere troughs. The considerable difference between northern and southern hemisphere troughs is believed to be due to differences in hemispheric polar circulations.

Other high latitude troughs occur in the auroral oval. These troughs are typically between 5° to 9° wide and are generally found above 65° latitude. They typically last 4 to 8 hours. Low concentrations of H^+, O^+, and N^+ ions occur in these troughs while, surprisingly, molecular NO^+ and O_2^+ concentrations increase.

Depletions that are not elongated are classified as holes.

A polar hole is a distinct feature of the Antarctic polar cap. The hole is a long term depletion in ion and electron concentrations that occurs in the winter during solar minimum. It hardly ever appears in the summer. The hole develops shortly after midnight at latitudes near 80°. Electron densities within the hole at an altitude of 300 km are around 1×10^2 per cm^3 compared to 10^5 per cm^3 elsewhere in the polar cap. For unknown reasons, a polar hole does not occur in the Artic.

The problem with low electron density in a trough is that it disrupts radio circuits passing through the trough area. Figure 17 illustrates the problem. A signal that would normally propagate through the region without any problem (the red trace in Figure 17) is instead lost to outer space (the black trace) due to the low ionization levels in the trough. The only way to rectify the problem is to switch to a lower operating frequency compatible with the night time critical frequency within the trough. For example, switching from 40 meters down to 80 meters. Knowledge of trough appearances and locations are thus important for high latitude and transpolar radio communications.

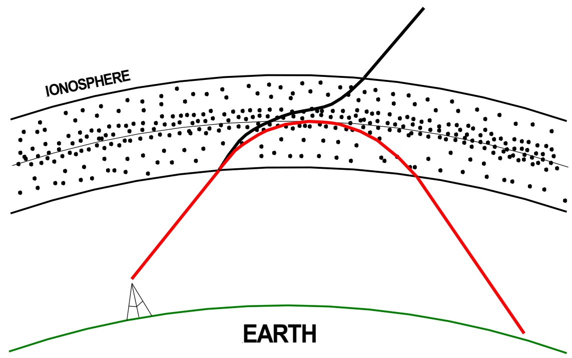

Figure 17 Signal lost to outer space (source: author)

20.2.1.3.2 High Latitude Spread F

As discussed earlier, signal scattering due to field-aligned irregularities results in spread F conditions. Spread F causes an HF signal to be reflected from various heights within the F layer, as illustrated in Figure 18, stretching out and garbling the transmitted signal. Digital data is particularly vulnerable limiting the data rate of signals that can be successfully transmitted. In addition, spread F produces rapid fading.

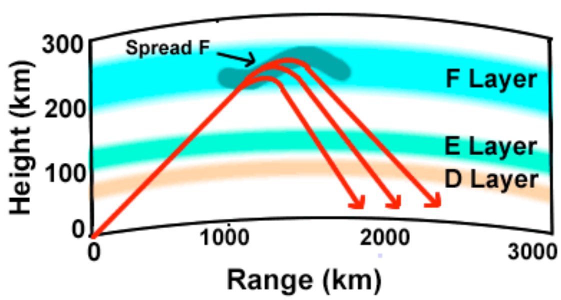

Figure 18 Spread F (source: www.met.nps.edu)

The field aligned irregularities producing spread F are highly variable in size. They can range in length from roughly a 100 km to several thousand kilometers and are about a kilometer thick. These irregularities drift horizontally at speeds up to about 100 meters per second.

At high latitudes, spread F occurrences begin around 40º and becomes more pronounced with increasing latitude.

In both the auroral and polar cap zones increased geomagnetic activity dramatically increases the appearance and growth of spread F. In addition, spread F formations, with electron concentrations several orders of magnitude greater than normal, frequently drift into the polar cap from the auroral zones, particularly with elevated solar activity.

During the summer, near the magnetic dip poles, spread F occurs nearly every night and often during the day. In the winter spread F is nearly continuous, both day and night.

20.2.1.3.3 Polar Cap Patches

Patches are roughly circular areas of enhanced electron densities, 200 to 1000 km in size, that generally occur at night in the polar cap. Electron densities within a patch are typically 2 – 10 times higher than in the ambient polar cap ionosphere. For instance, a patch may have an electron density of 10^6 electrons per cm^3 compared to 10^5 per cm^3 in the surrounding ionosphere. Patches appear under disturbed ionospheric conditions when the Interplanetary Magnetic Field (IMF) is pointing southward. It is believed that a change in polar circulation, due to a sudden increase in solar wind or change in the IMF, can detach plasma from the dayside polar cap. Plasma drift in the polar cap rapidly transports the detached patch over the pole to the night sector. Patches can occur during all seasons of the year but are more frequent during the winter and tend to be stronger at solar maximum.

20.2.1.3.4 Auroral Zone Blobs

Electron density enhancements in the auroral zone are called blobs. Blobs vary considerably in size. They are smaller than patches, typically tens of kilometers in size instead of hundreds of kilometers. The cause of blobs is uncertain and may be formed by a number of different mechanisms. In some cases, blobs may be formed by solar wind particle inflow. It is also possible that some blobs are formed by patches drifting into the auroral zone from the polar cap and then breaking up into smaller blobs. Why this happens is unknown. In general, blobs seem to move with the auroral F region plasma drift.

20.2.1.3.5 Traveling Ionospheric Disturbances

Traveling ionospheric disturbances (TIDs), illustrated in Figure 19, are large scale wavelike disturbances with wave periods from a few minutes to more than an hour. They are typically 100 to 1000 km in size and travel at speeds from 50 to about 1000 meters per second. TIDs have long wave fronts that are tilted forward. Consequently, TIDs appear first at high altitudes and move downward as they pass. Vary large TIDs originate in the auroral zone and travel great distances. These disturbances are associated with magnetic storms.

HF radio signals encountering traveling ionospheric disturbances are seriously disrupted. Nearly all aspects of an HF signal are distorted including signal frequency, amplitude, phase, and polarization.

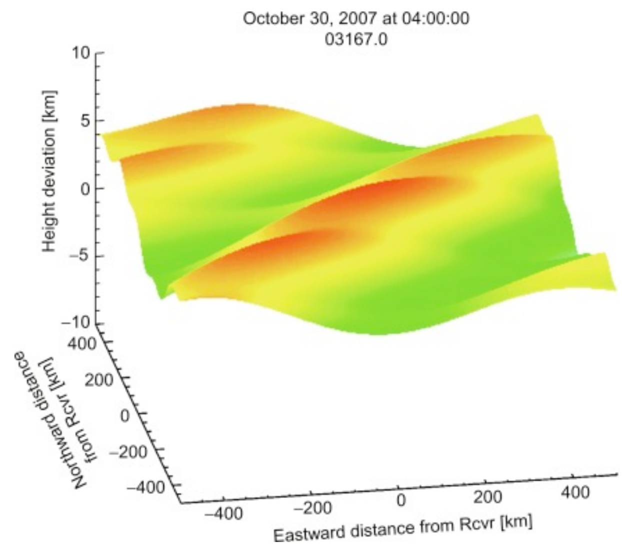

Figure 19 Traveling Ionospheric Disturbance (source: ScienceDirect.com)

20.2.2 High Latitude E Region

During geomagnetic quite times the high latitude E region is very much like the mid-latitude E region and subject to the same diurnal, seasonal, and solar cycle variations. The E region electron density builds up following sunrise, peaks at local noon, and declines later in the day. However, the Sun is above the horizon most of the time during summer in the high latitudes. For instance, in mid-July, sunrise occurs at 4 AM in Fairbanks, Alaska and sets a few minutes before midnight. Consequently, summer time E Region ionization levels remain relatively high well into the night. In the winter the high latitudes are in darkness a good part of the time leading to low E region ionization.

Geomagnetic storms are the main disturbances affecting the auroral E region. The auroral oval becomes more dynamic during a storm producing visual aurora as well as expanding in size both poleward and toward the equator. Figure 20 shows the aurora (the fuzzy blue area) embedded in the E region. Incoming high energy particles which create the visual aurora also enhance auroral E region ionization. The increased ionization levels are considerably beyond that which would normally occur through EUV radiation.

It is interesting to note that the E region over the polar cap remains pretty much the same as the mid-latitude E region, even during geomagnetic storms.

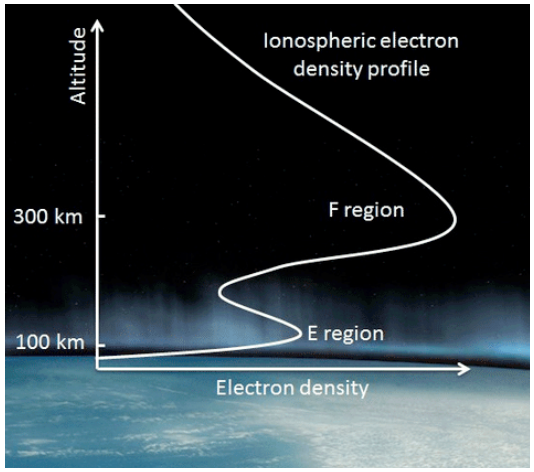

Figure 20 High latitude E region (source: researchgate.net)

20.2.2.1 Auroral Sporadic E

The appearance of auroral sporadic E zones, particularly at night, is one of the most conspicuous features of a disturbed E region. Auroral sporadic E is formed by energetic electrons streaming down into the auroral ionosphere during a storm, increasing ionization levels. Auroral sporadic E critical frequencies can be as high as 7 MHz.

20.2.2.2 Auroral E Region Electrojets

Ionization produced by incoming electrons increases E region conductivity permitting an intense electrical current, known as the auroral electrojet, to flow in the auroral E region. The electrojet disrupts the geomagnetic field in the auroral zone causing it to vary in synchronism with the visual auroral display. The electrojet is responsible for the magnetic aspects of an auroral storm while excited atoms and molecules are responsible for the visual part of the storm.

20.2.3 High Latitude D Region

The high latitude D region of the ionosphere is more complex than the E region above it due to higher atmospheric pressures at D region altitudes. The higher pressure inhibits plasma motion and electrical currents in addition to complicating photochemistry in the region. What the high latitude D and E regions have in common is the importance of incoming energetic charged particles in ionizing both regions. At times this ionization can be greater than that produced by solar EUV radiation.

There are two absorption phenomena that are unique to the high latitude D region:

- Polar Cap Absorption (PCA), and
- Auroral absorption (AA).

Polar cap absorption events are caused by high energy solar protons streaming into the polar cap region following large solar flares. The inflow heavily ionizes the ionosphere's D layer. PCAs are relatively infrequent with 8 – 10 occurring per year during solar maximum and only 1 or 2 during solar minimum. However, when a PCA event does occur, it heavily absorbs HF radio signals throughout the polar cap region often creating a transpolar radio blackout.

Auroral absorption is caused by sporadic influx of energetic electrons into the auroral zone enhancing D region ionization. The energetic electrons generally originate within the magnetosphere during magnetic storms. Auroral absorption is more common than PCA events but not as intense and more sporadic in time and location, often occurring as bursts of absorption within the auroral zone.

20.2.4 High Latitude HF Radio Communications

Long distance HF radio communications depends on a "smooth" ionosphere from which radio signals can refract back to Earth as illustrated in Figure 21. At high latitudes unstable levels of ionization, troughs, patches, and blobs are not conducive to a smooth polar ionosphere. Fortunately, these disruptions do not occur all the time. However, their occurrences are not always predictable. Thus, radio operators must look for propagation openings through the high latitude regions.

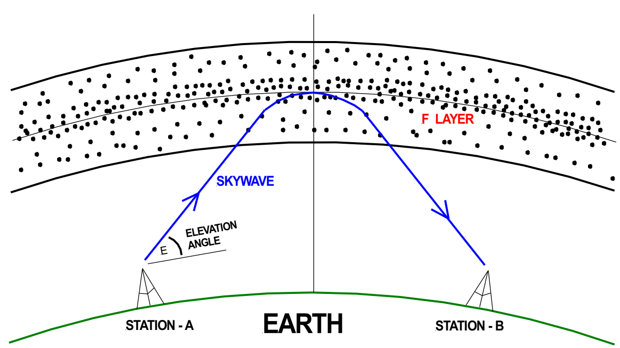

Figure 21 Ionospheric HF radio propagation (source: author)

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