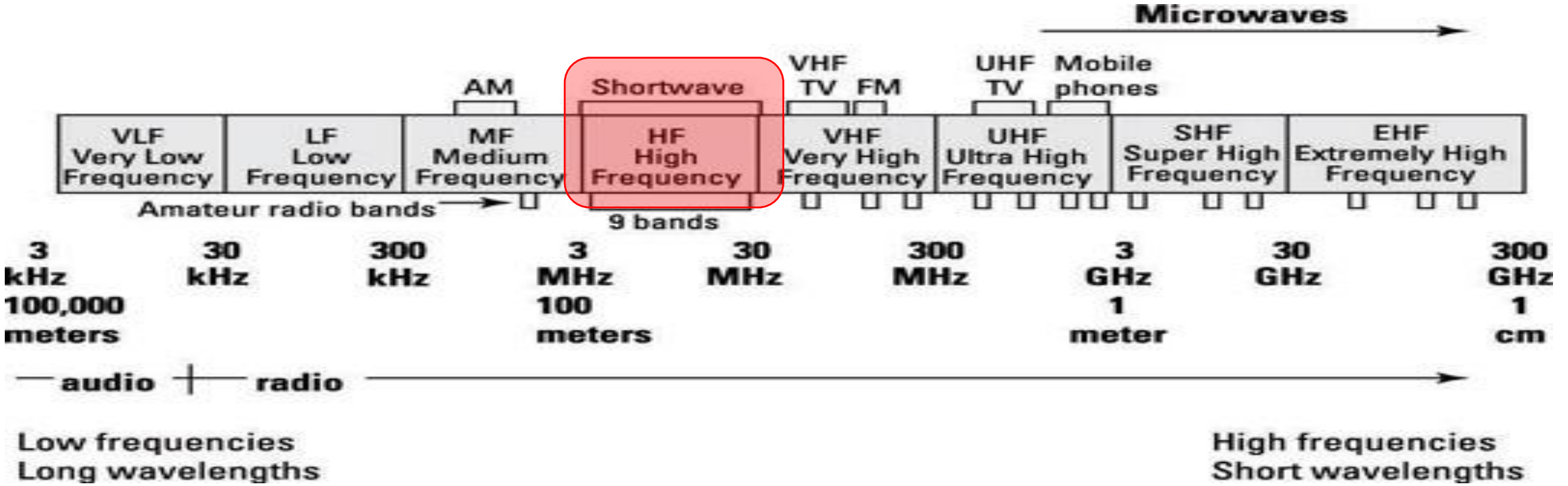
HF RADIOWAVE PROPAGATION

ECE 523E – ANTENNA & RADIOWAVE PROPAGATION

Tuesday, September 22, 2026

WHAT IF HIGH FREQUENCY (HF) BAND

- High frequency (HF) is the International Telecommunications Union (ITU) designation for the range of radio frequency **electromagnetic waves (radio waves) between 3 and 30 megahertz (MHz).**
- **HF band is also known as the decameter band** or decameter wave as its wavelengths range from one to ten decameters (ten to one hundred metres).



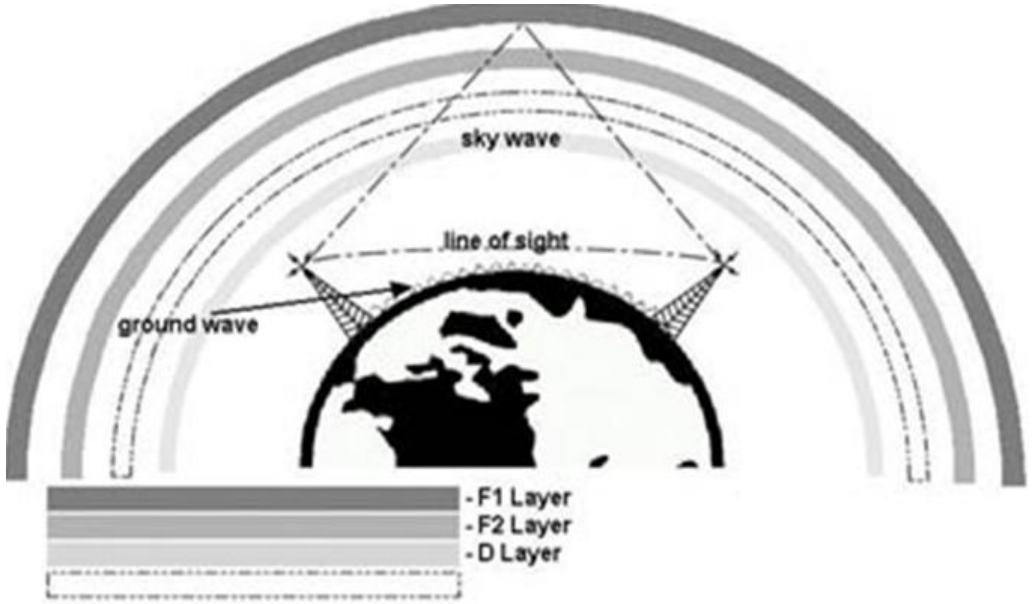
USES OF HF COMMUNICATION

HF radio wave propagation is used in the following areas:

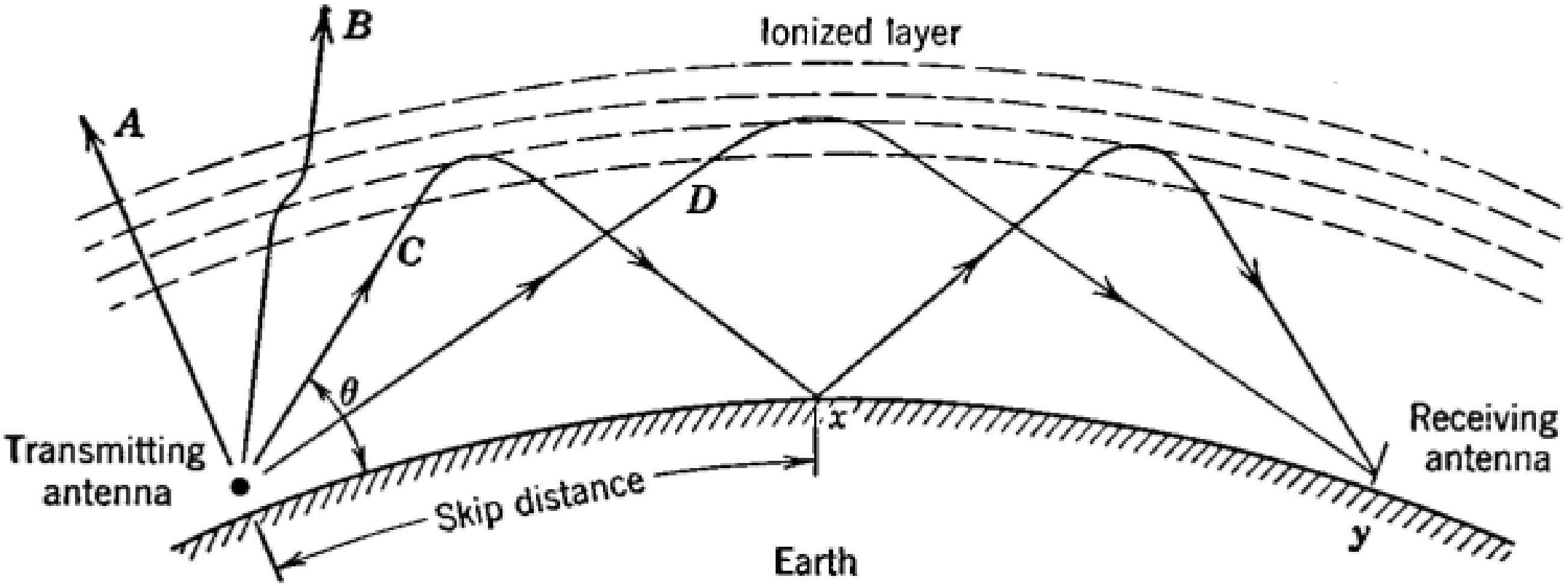
1. Aviation air-to-ground communications
2. Shortwave international and regional broadcasting
3. Amateur radio
4. Maritime sea-to-shore services
5. Over-the-horizon radar systems
6. Global Maritime Distress and Safety System (GMDSS) communication
7. Military and governmental communication systems

CHARACTERISTICS OF HF RADIO PROPAGATION

1. Propagation is possible over thousands of kilometres.
2. Propagation is highly variable. It has daily and seasonal variation, as well as a much longer 11-year cycle.
3. HF radio waves may travel by any of the following modes:
   a) Ground Wave
   b) Sky Wave
   c) Space Wave (line-of-sight)



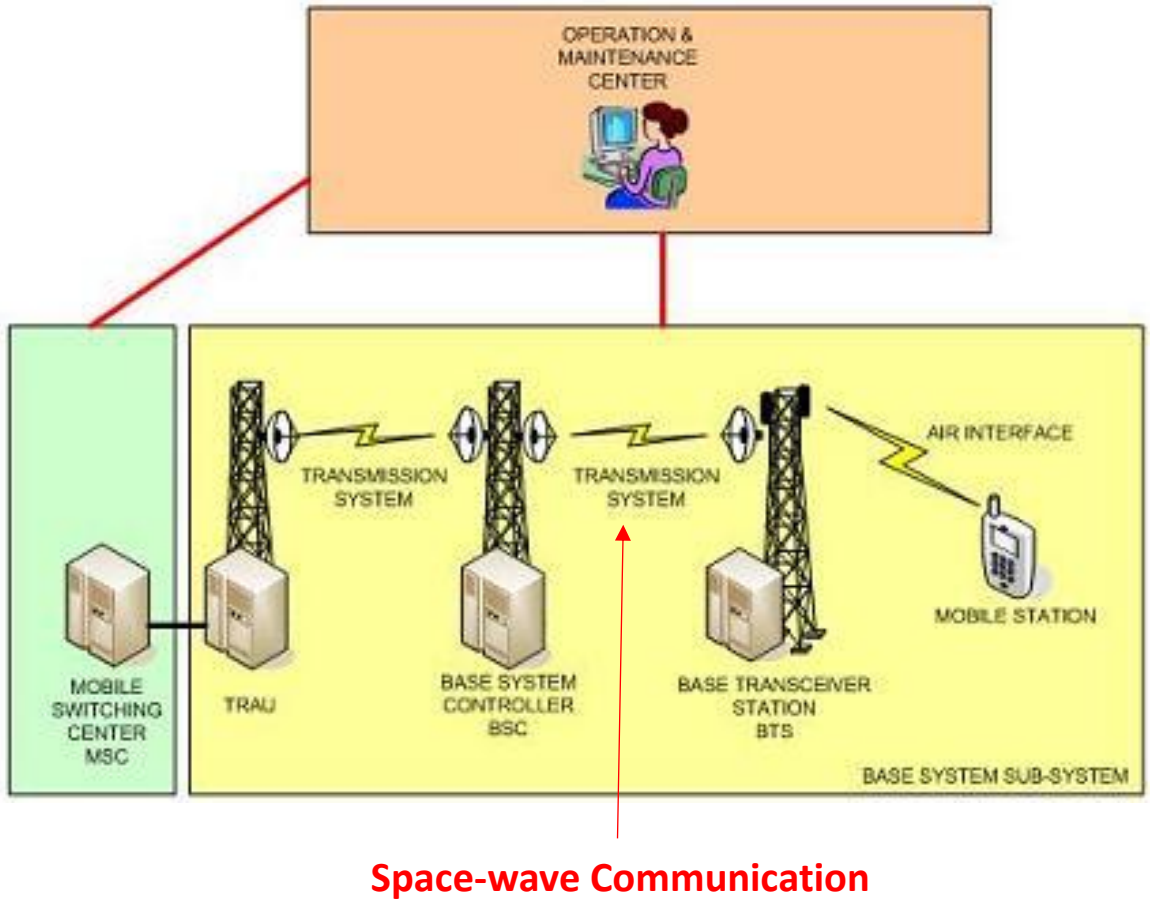
PRINCIPLE OF HF RADIO PROPAGATION



Radio waves of the same frequency, but radiated at different angles, behave somewhat as shown. The angle θ is the critical angle for the frequency used.

RECAP: SPACE WAVE

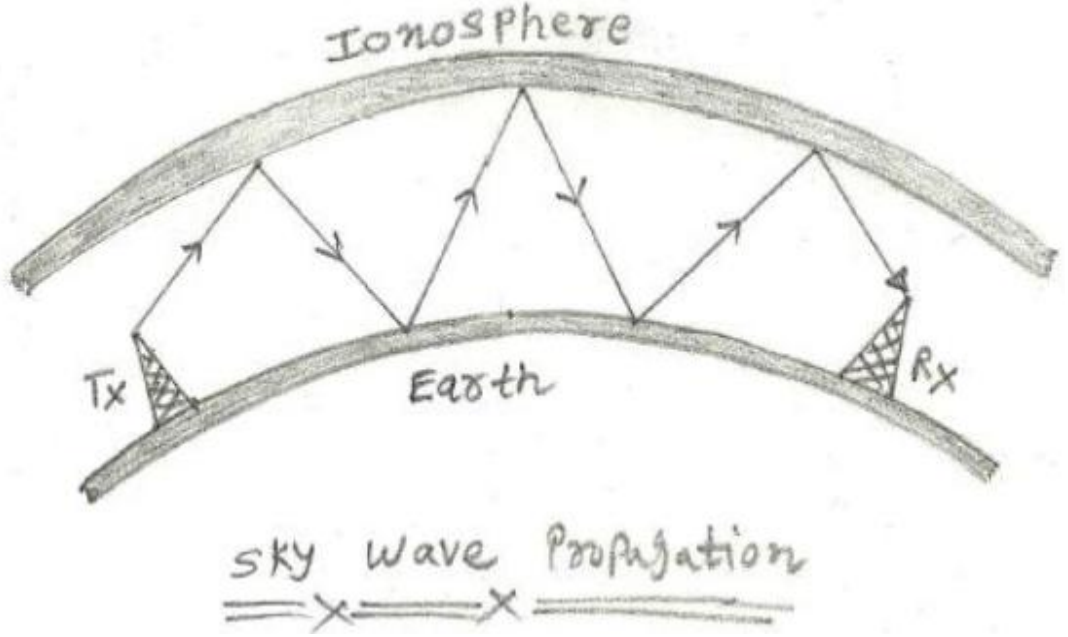
1. **Space wave** follow the line-of-sight path between transmitter and receiver.
2. In order for direct wave communication to occur, antennas at both ends of the path must have low beam-width.
3. This is difficult to do at the lower frequencies, and as a result, direct wave communication is normally used in UHF and microwave frequency bands.
4. Its range is determined by the height of both antennas and is generally less than 40 Kms.



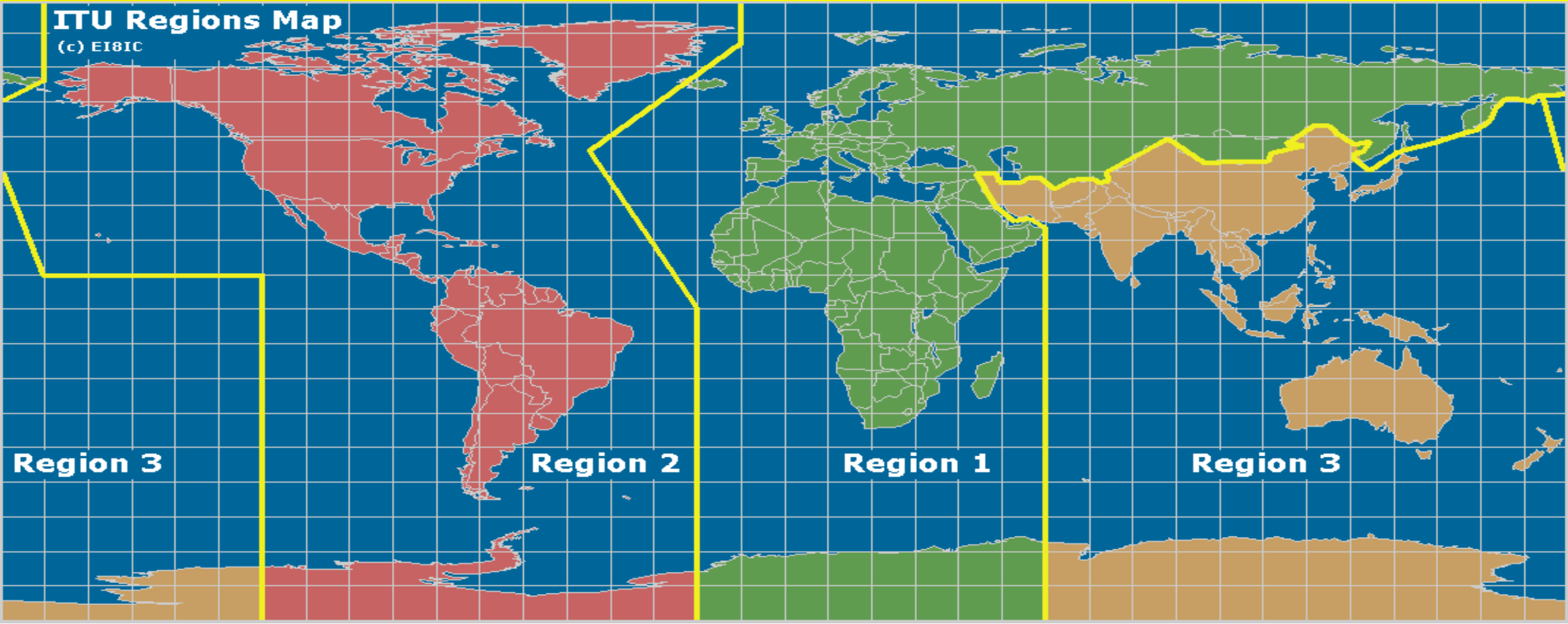
RECAP: SKY WAVES

1. **Sky waves** are waves that leave the transmitting antenna in a straight line and are returned to the earth at a considerable distance by an electrically charged layer known as the ionosphere.

2. **Sky Wave Communication** is possible throughout much of the day to almost anywhere in the world via sky wave.

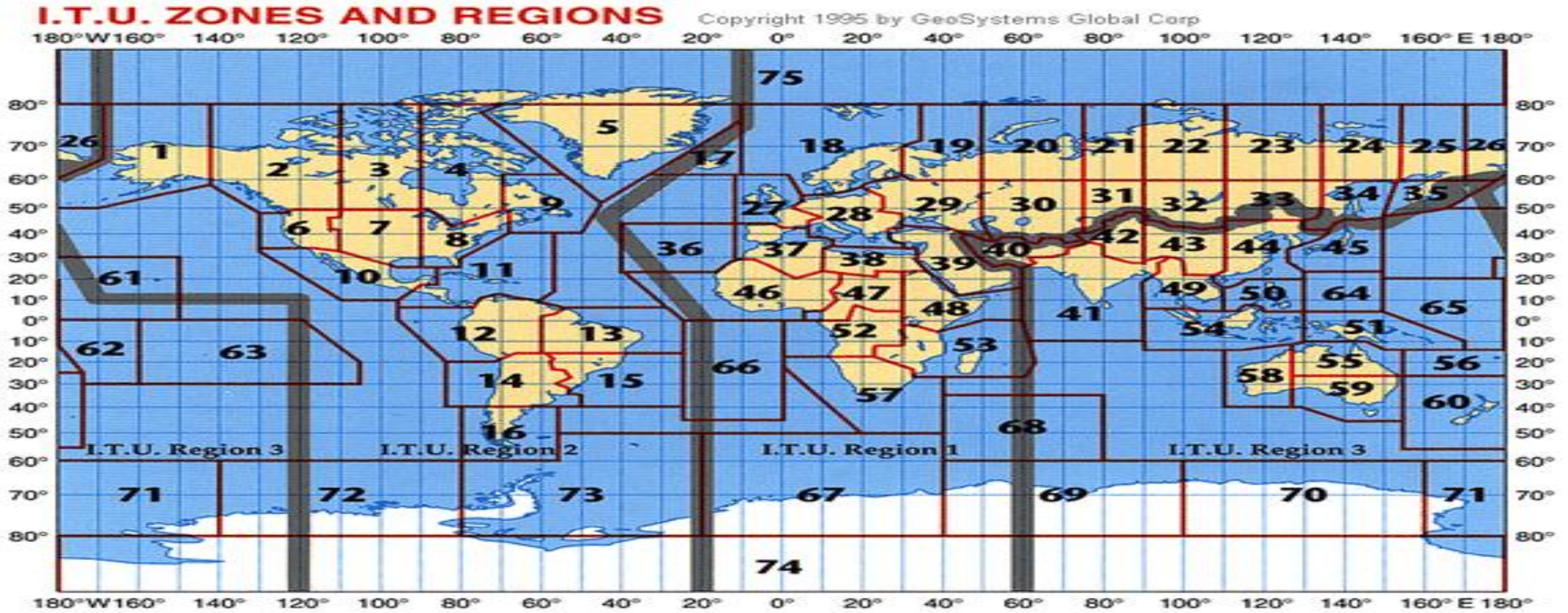


WORLD RADIO FREQUENCY PLANNING REGIONS

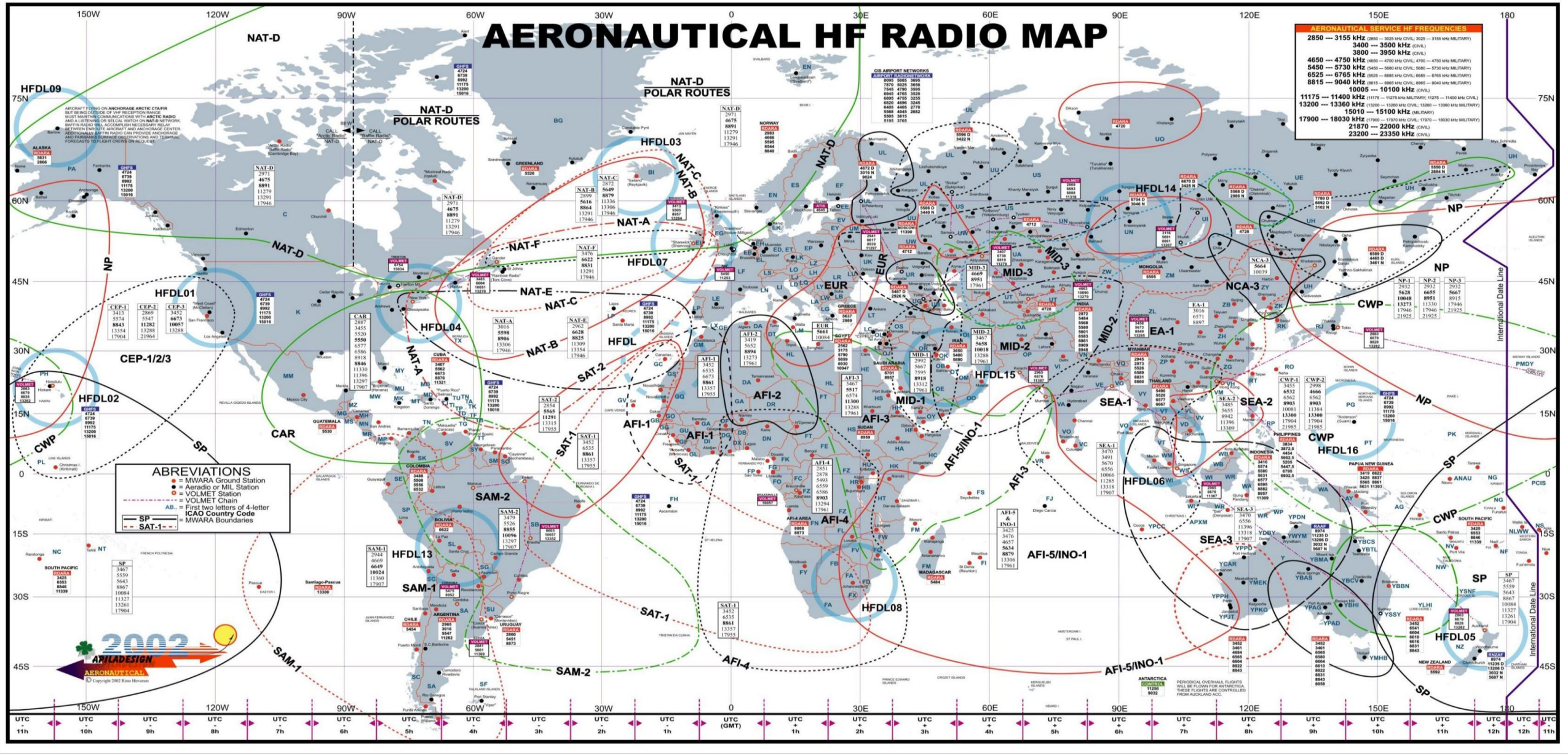


- The world is divided into three regions to make it easy for radio planning especially for Sky-wave radio propagation which cover large areas.

WORLD ARMATURE RADIO REGIONS



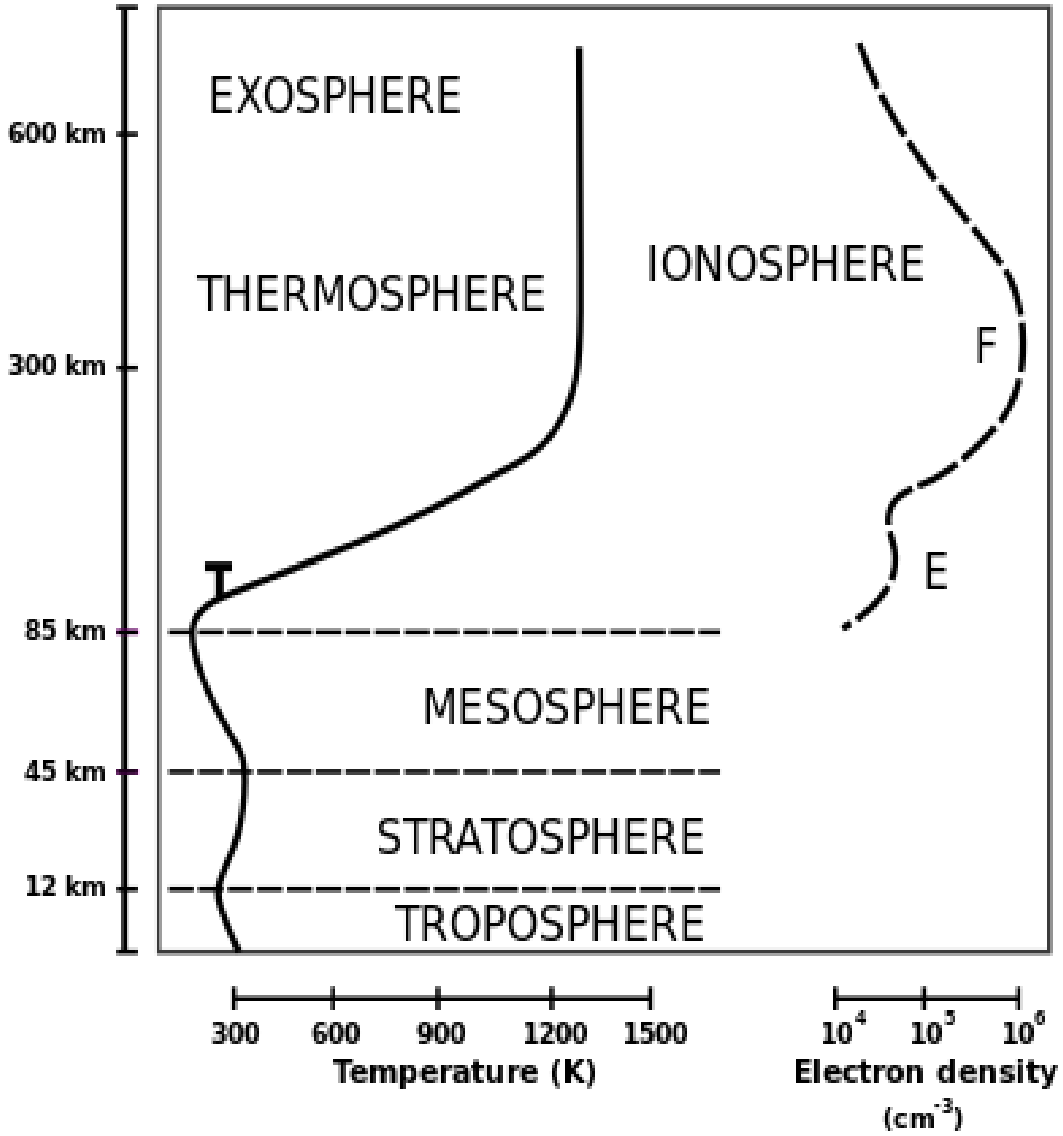
- Armature radio regions generally cover large regions because the predominantly use HF frequencies



- Aeronautical HF Radio Map gives the HF radio service frequencies for use by pilots

THE IONOSPHERE

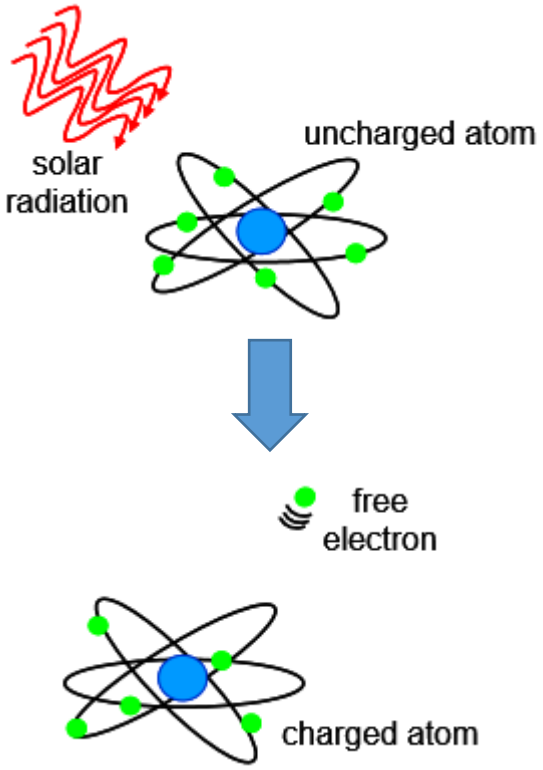
1. **The Ionosphere** extends from a height of about 50 km to over 500 km. Most of the molecules of this part of the atmosphere are ionised by radiation from the Sun.
2. Ionisation is the process in which electrons, which are negatively charged, are removed from neutral atoms or molecules to leave positively charged ions and free electrons.
3. It is the ions that give their name to the ionosphere, **but it is the much lighter and more freely moving electrons which are important in terms of HF (high frequency) radio propagation.**
4. **The free electrons in the ionosphere cause HF radio waves to be refracted (bent) and eventually reflected back to earth**.
5. The greater the density of electrons, the higher the frequencies that can be reflected.



PRODUCTION/LOSS OF ELECTRONS IN THE IONOSPHERE

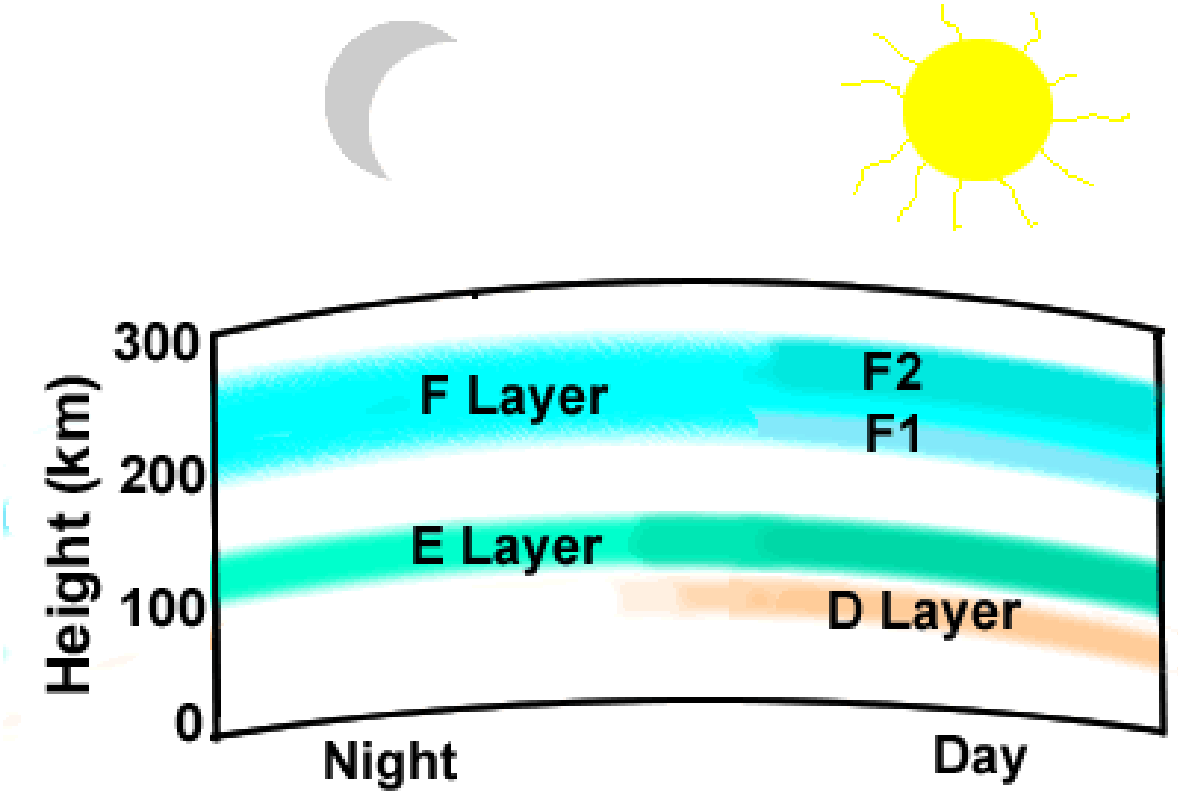
1. **Electrons are produced when solar radiation collides with uncharged atoms and molecules.** Since this process requires solar radiation, production of electrons only occurs in the daylight hemisphere of the ionosphere.

2. **Loss of free-electrons in the ionosphere occurs when a free electron combines with a charged ion to form a neutral particle.** Loss of electrons occurs continually, both day and night.

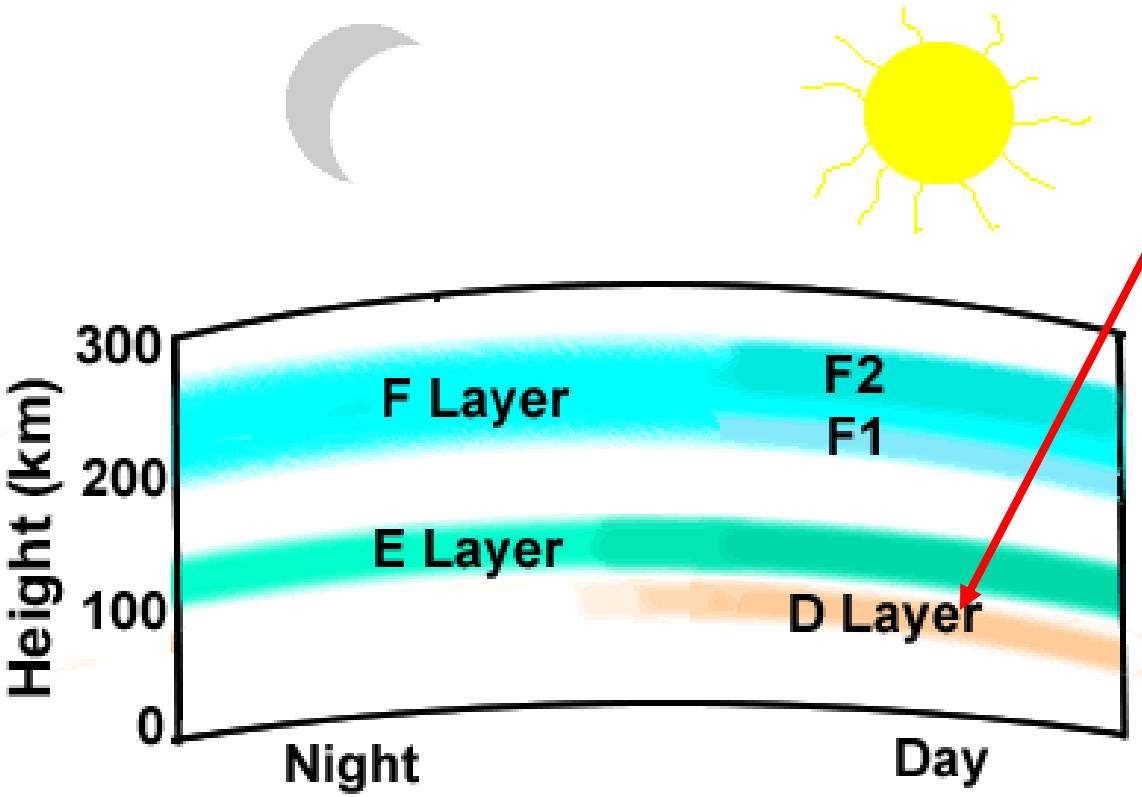


THE IONOSPHERE (2)

1. Although the ions in the ionosphere are created by solar radiation, the layer does not completely disappear shortly after sunset.
2. The D and E layers disappear very quickly after sunset due to increased loss of electrons.
3. The F1 and F2 layers do not disappear, but merge into a single F layer.
4. Ions recombine much faster at lower altitudes.

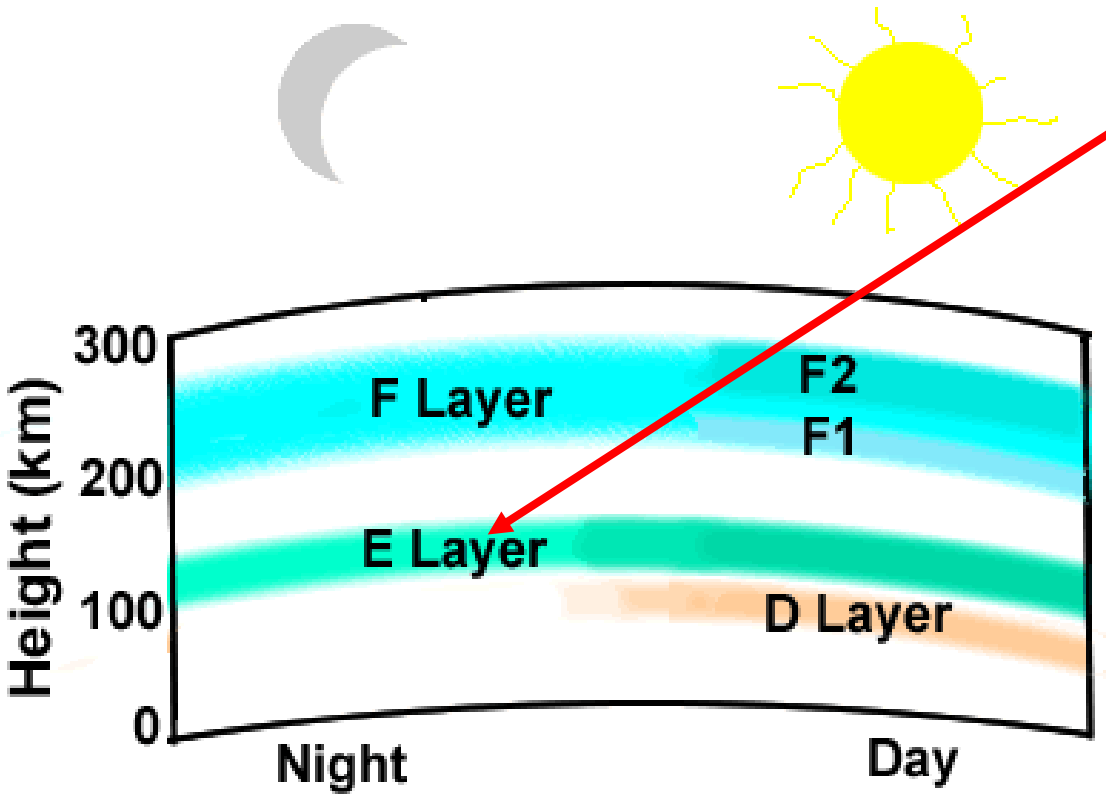


THE D-LAYER



1. **D-layer** is created at sunrise, reaches maximum density at noon, and disappears by sunset.
2. The D layer plays only a negative role in HF communications.
3. D layer acts as an attenuator, absorbing the radio signals, rather than returning them to earth.
4. The absorption is inversely proportional to the square of the frequency, severely restricting communications on the lower HF bands during daylight.

THE E-LAYER

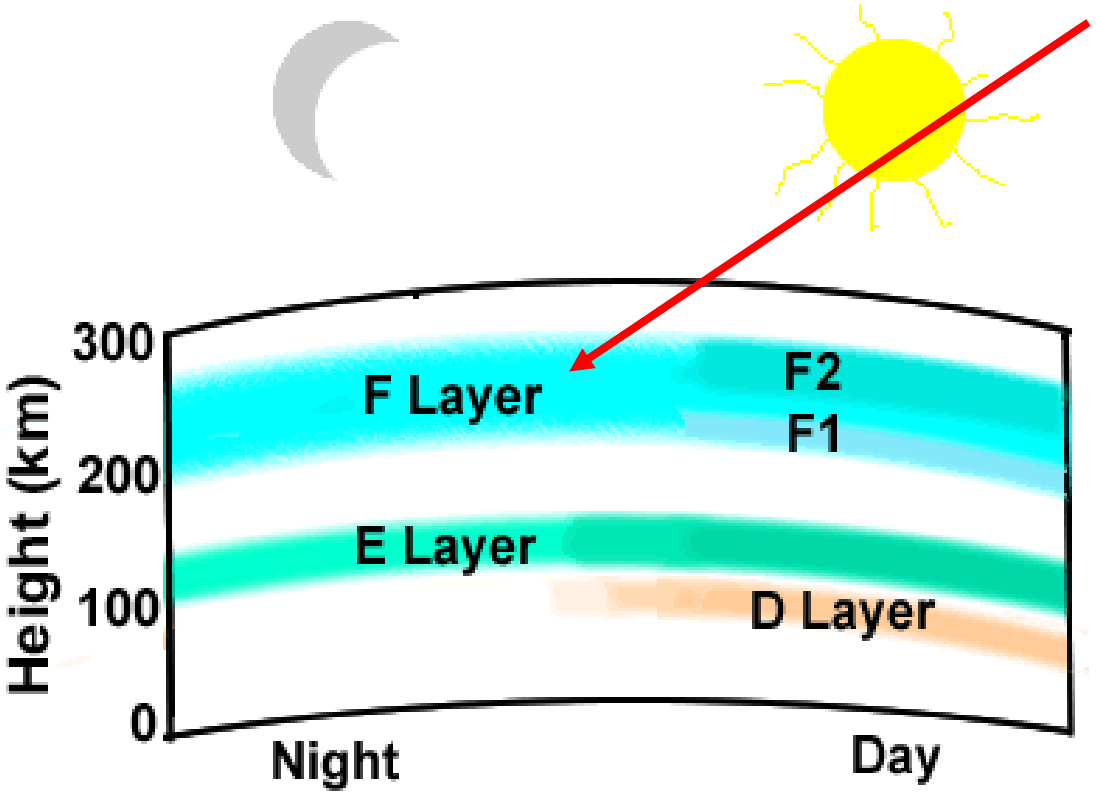


1. The E-layer is created at sunrise, reaches maximum density at noon, and starts fading at sunset.

2. It can return lower HF frequencies to the Earth, resulting in daytime short skip on the lower HF bands.

3. It has very little effect on higher frequency HF radio waves, other than to change slightly by refraction their direction of travel.

THE F-LAYER

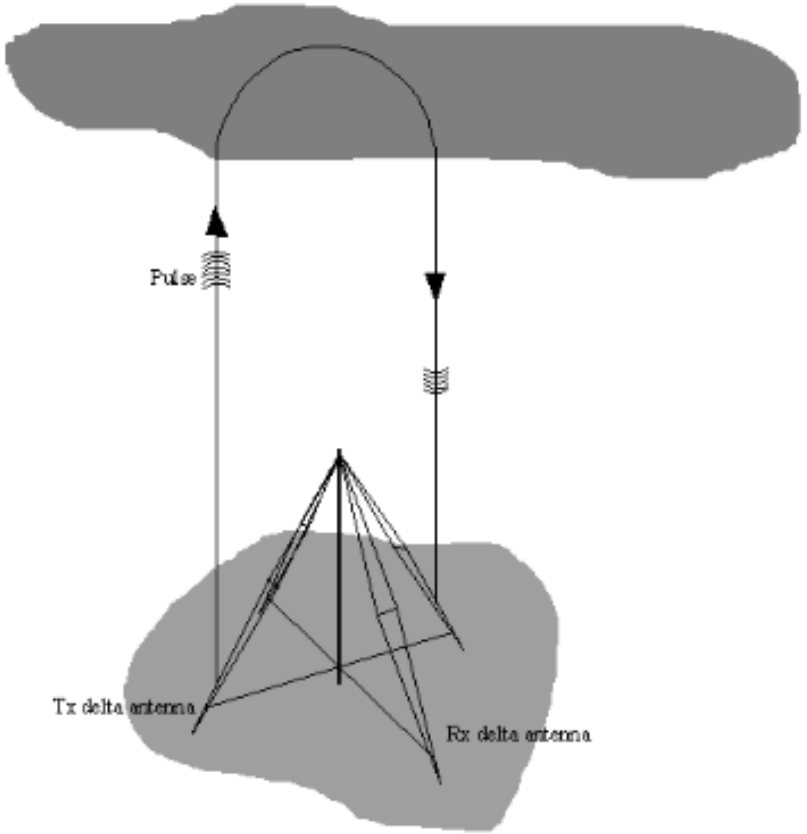


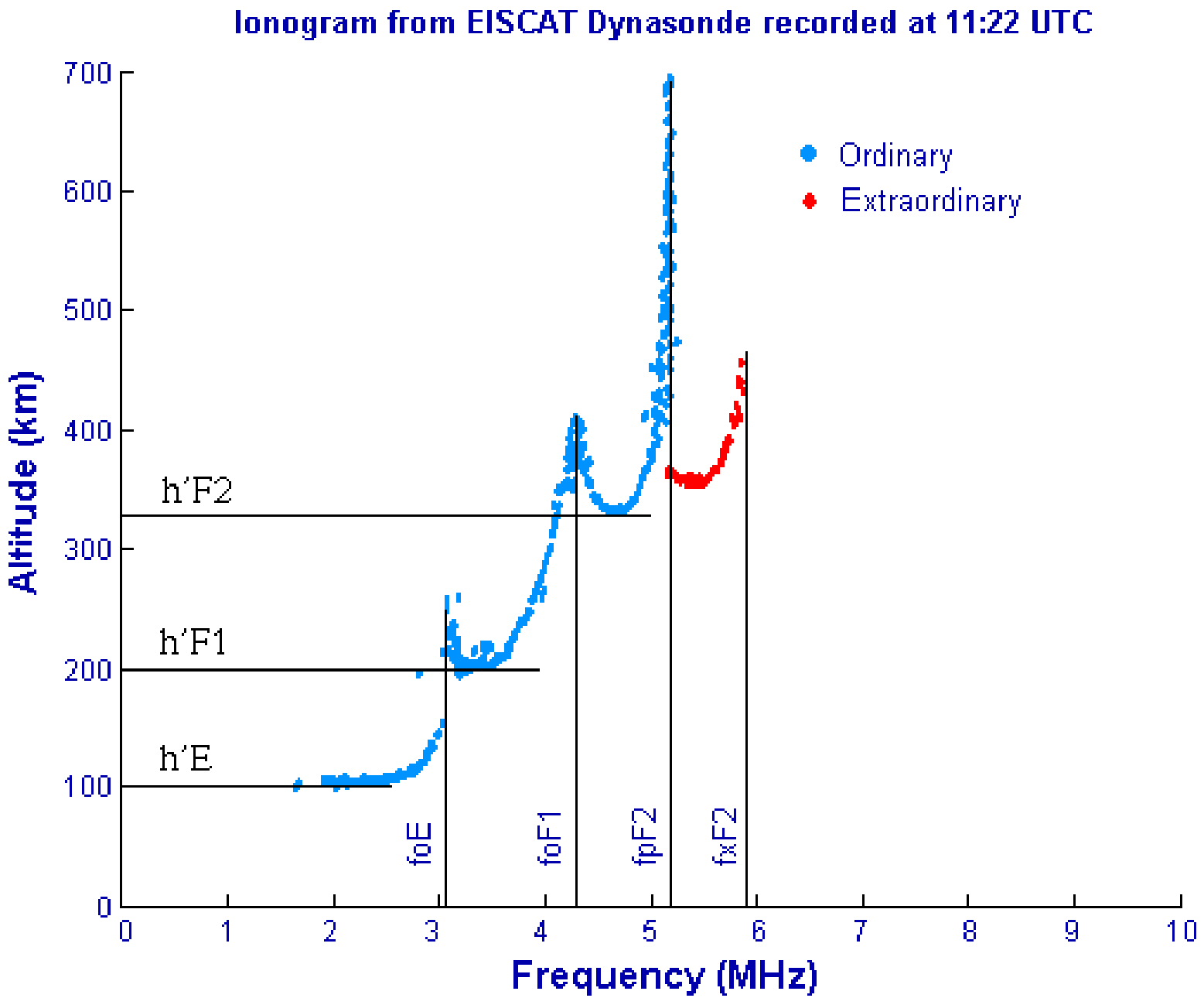
1. The F layers are primarily responsible for long-haul HF communications.

2. Because there is only F layer ionization throughout the hours of darkness, it is carries almost all night-time communications over intercontinental distances.

OBSERVING THE IONOSPHERE

1. Various methods have been used to investigate the ionosphere, and the most widely used instrument for this purpose is the **ionosonde.**
2. I**onosonde** is a high frequency radar which sends very short pulses of radio energy vertically into the ionosphere. If the radio frequency is not too high, the pulses are reflected back towards the ground.
3. **The ionosonde** records the time delay between transmission and reception of the pulses over a range of different frequencies.
4. Echoes appear first from the lower E region and subsequently, with greater time delay, from the F1 and F2 regions.
5. At night echoes are returned only from the F region since the E region is not present.



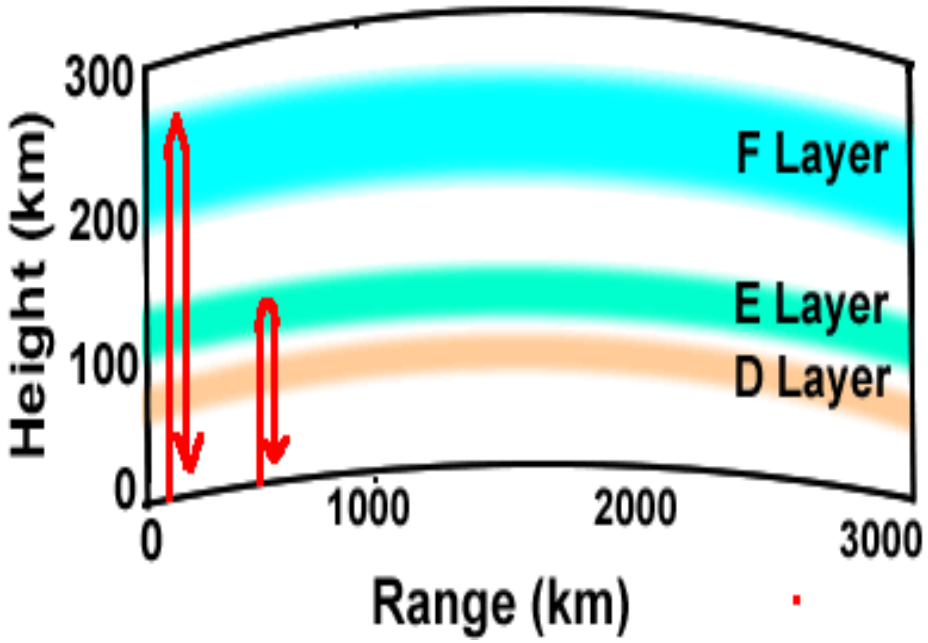

Ionogram from EISCAT Dynasonde recorded at 11:22 UTC
Ordinary
Extraordinary
Altitude (km)
Frequency (MHz)
h'F2
h'F1
h'E
foE
foF1
fpF2
fxF2
0
100
200
300
400
500
600
700
0
1
2
3
4
5
6
7
8
9
10

CRITICAL FREQUENCY (1)

1. When radio waves are transmitted straight up towards the ionosphere (vertical incidence), the radio wave will be returned to earth at all frequencies below the critical frequency, (f_c) .

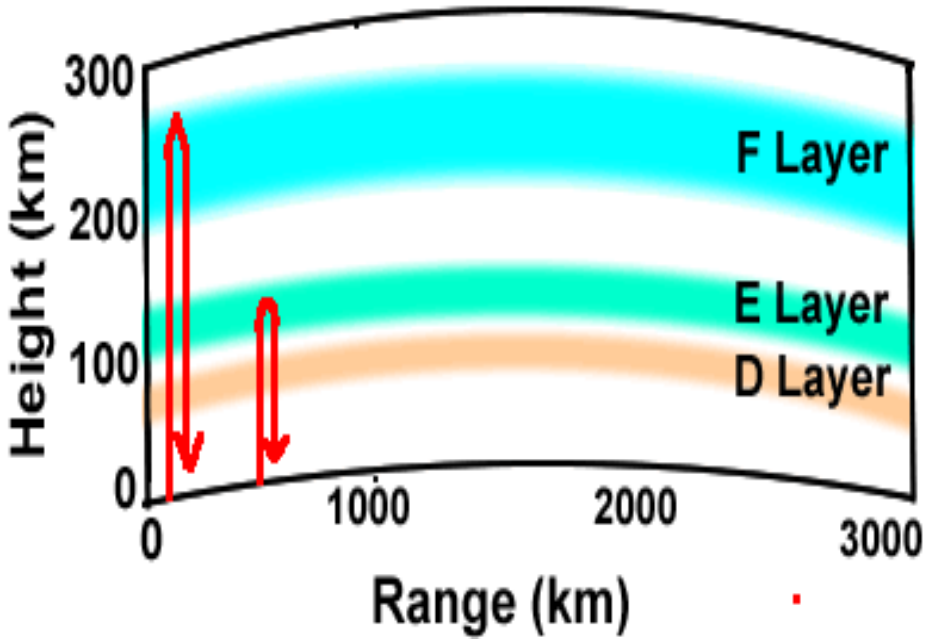
2. The critical frequency depends on the degree of ionization of the ionosphere and is given by the equation:

$$f_{cr} = \sqrt{\frac{N_e}{1.24 * 10^{10}}}$$



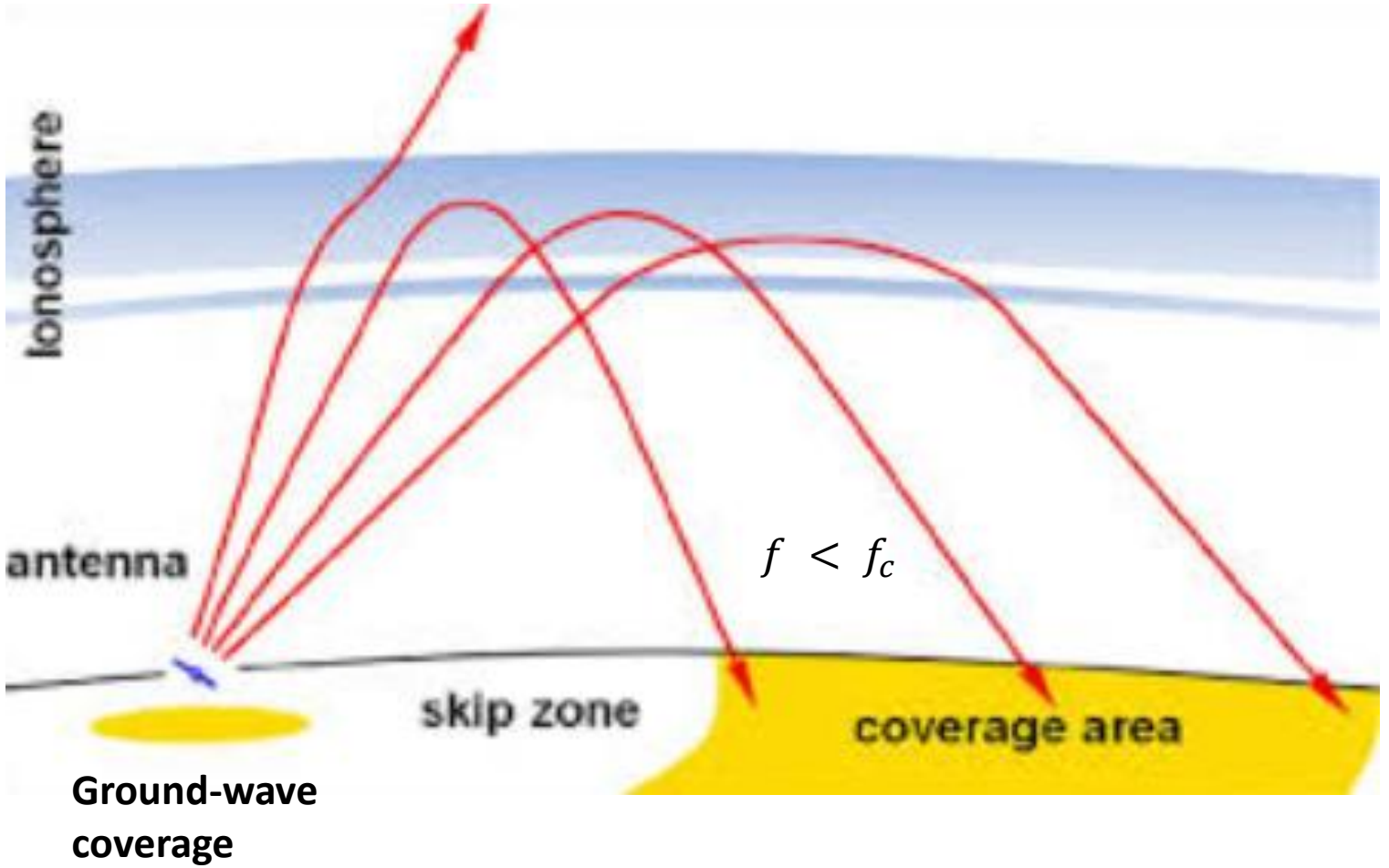
CRITICAL FREQUENCY - DETAILED EXPLANATION

- When waves (i.e. photons) of EM radiation pass through free electrons, the electrons respond by moving.
- The **movements of the electrons, in turn generate their own EM field.**
- If the **transmitted frequency is higher than the plasma frequency,** then the electrons cannot respond fast enough, and they are not able to generate their own EM. The EM waves passes through the electrons unimpeded.
- If the original transmitted EM radiation is at a lower frequency than the plasma frequency, then the energy from the transmitted EM radiation is absorbed by the electrons, causing them to vibrate at that frequency. New EM waves are generated in the opposite (vertical) direction of the original transmission. The EM transmission is reflected back to the surface.
- Therefore, an important parameter is the maximum plasma frequency which determines which vertical transmissions will pass through and which will be reflected back.
- The **maximum plasma frequency is called the critical frequency.** It varies for a given time and location



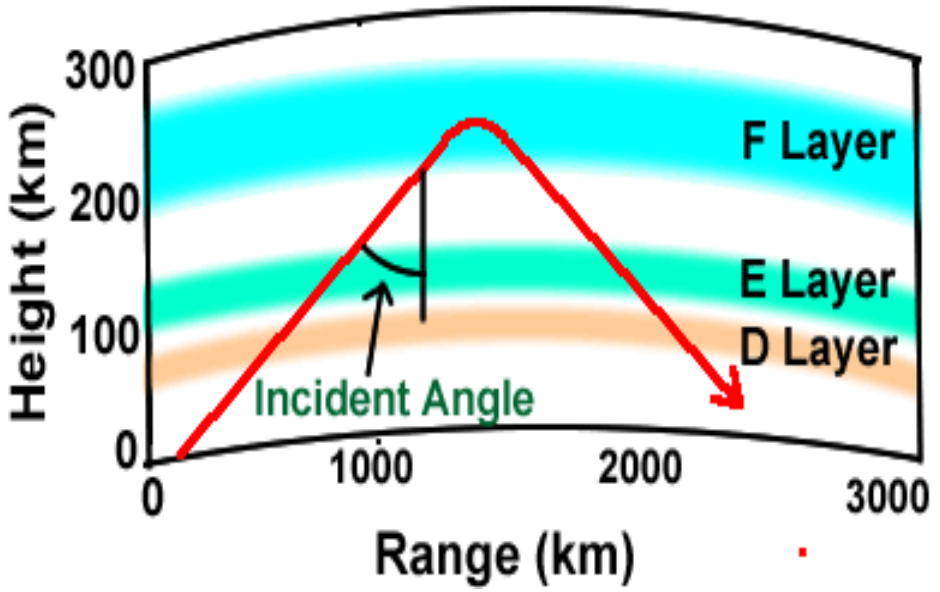
SKIP ZONE & COVERAGE AREA

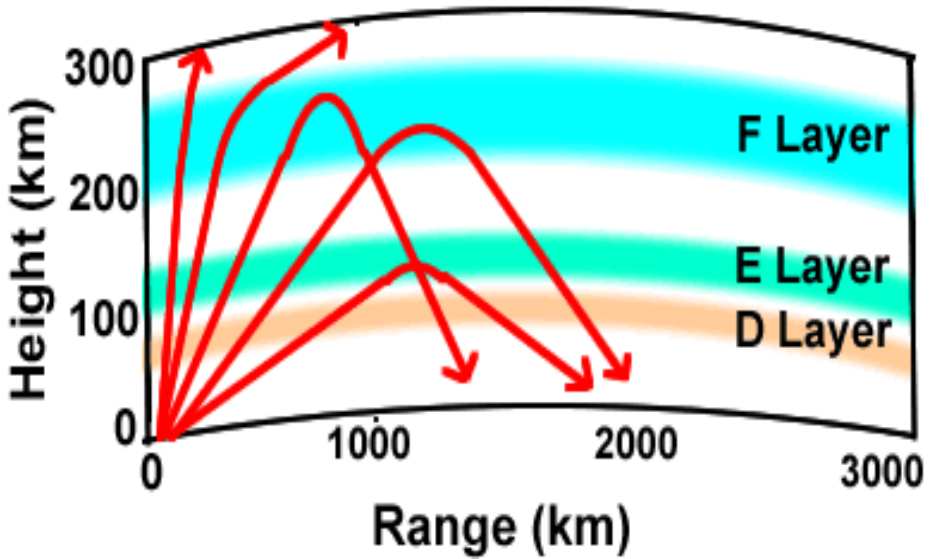
Skip zone is an annular region between the farthest points at which the ground wave can be received and the nearest point at which the refracted sky waves can be received



MAXIMUM USABLE FREQUENCY (MUF)

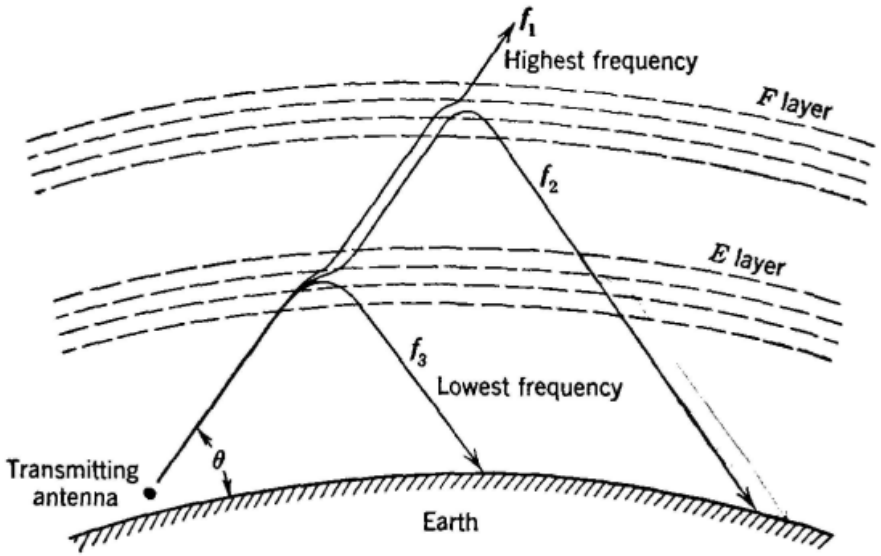
1. HF transmissions take place between two locations on the earth as shown.
2. The EM wave enters the ionosphere at an angle that we call the "incident angle", defined as the angle between the ray direction and vertical.
3. If the incident angle is greater than zero, the maximum frequency that causes a transmission to bend back toward the earth is higher than the critical frequency.
4. **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.



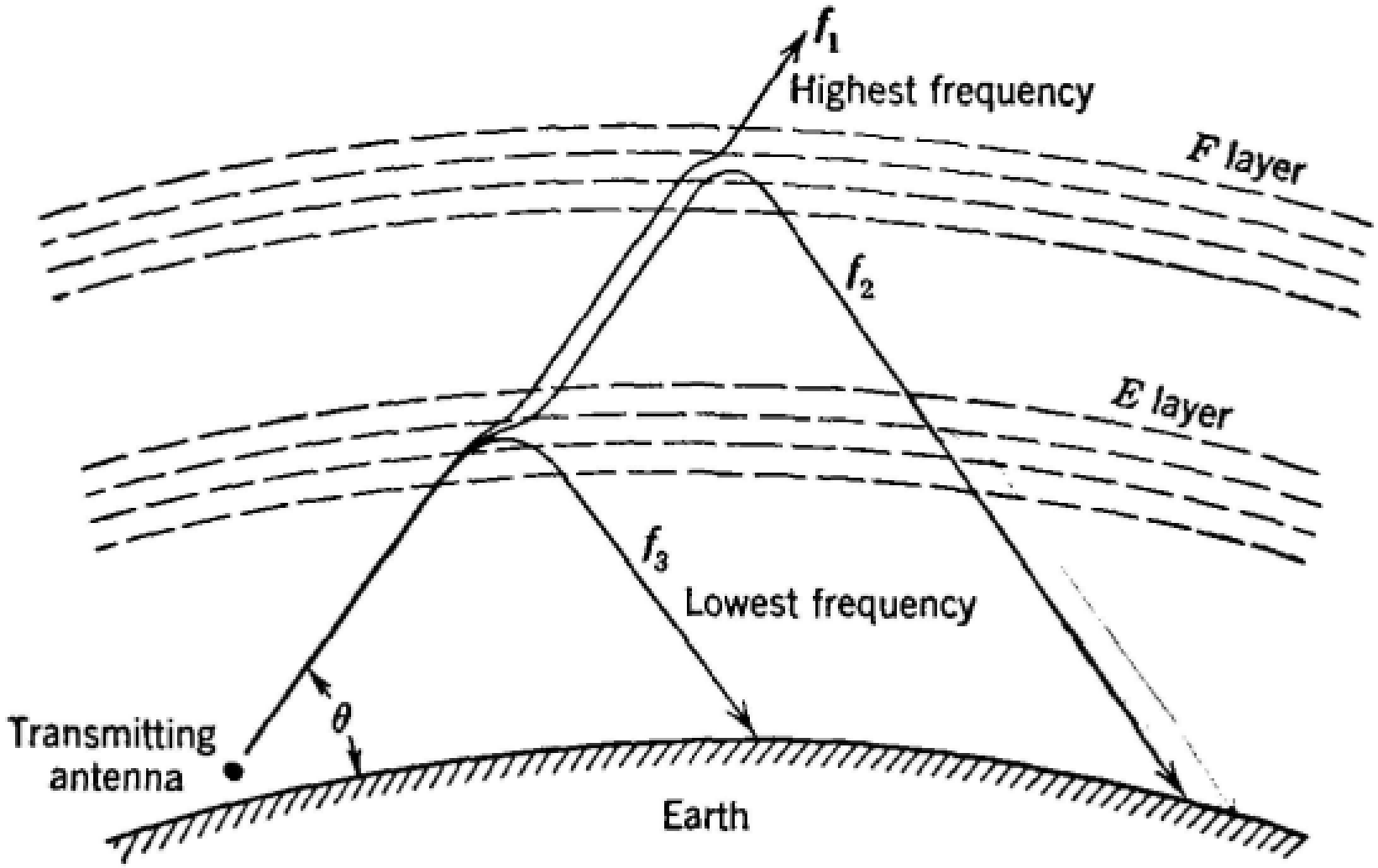


LOWEST USABLE FREQUENCY

- **The lowest usable frequency (LUF) is the lower limit to the frequency that can be used for sky wave propagation during daylight hours.**
- The limit is due to absorption in the D layer which contains a many more neutral atoms and molecules than higher levels.
- **Explanation:** EM radiation causes free electrons to move. Sometimes the free electrons will collide with the neutral atoms resulting in EM energy loss.
- **Lower frequencies have longer wavelengths, which makes the electrons move a greater distance compared with higher frequencies, making then more likely to collide with the neutral atoms.**
- At frequencies below the LUF the transmissions suffer total absorption.



LOWEST USABLE FREQUENCY

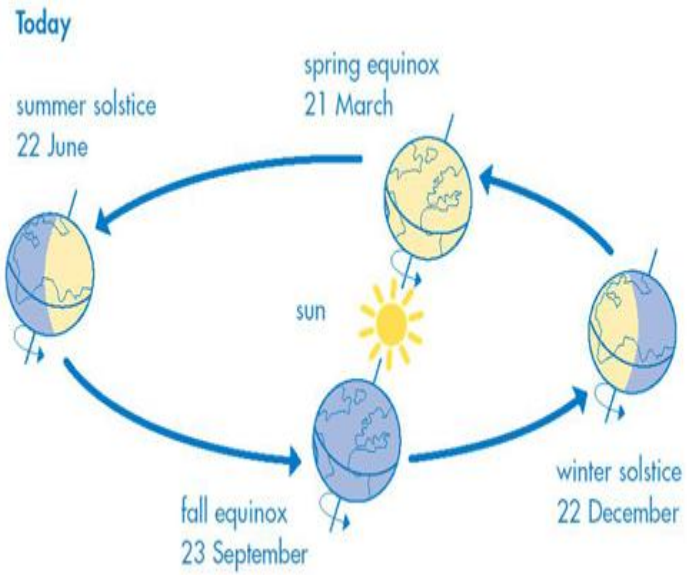


DAILY PROPAGATION EFFECTS

1. Shortly after sunrise, the D and E layers are formed and the F layer splits into two parts.
   - The D layer acts as a selective absorber, attenuating low frequency signals, making frequencies below 5 or 6 MHz useless during the day for transmission.
2. The E and F1 layers increase steadily in intensity from sunrise to noon and then decreases thereafter.
   - Short skip propagation via the E or F1 layers when the local time at the ionospheric refraction point is approximately noon.
   - The MUF's through E and F1 layers are about 5 and 10 MHz respectively.
3. The F2 layer is sufficiently ionized to HF radio waves and return them to earth.
   - Above 5 MHz, long distance communications are possible.
   - Below 5 MHz, the signals returned by the F layer are highly attenuated by the D layer.

SEASONAL PROPAGATION EFFECTS

1. **During the Northern Hemisphere** winter months, the atmosphere is colder and denser.
2. The ionosphere moves closer to the earth increasing the electron density.
3. Electron density can rises to 5 times greater than summer's.
4. Therefore winter MUF's are approximately double summer's.

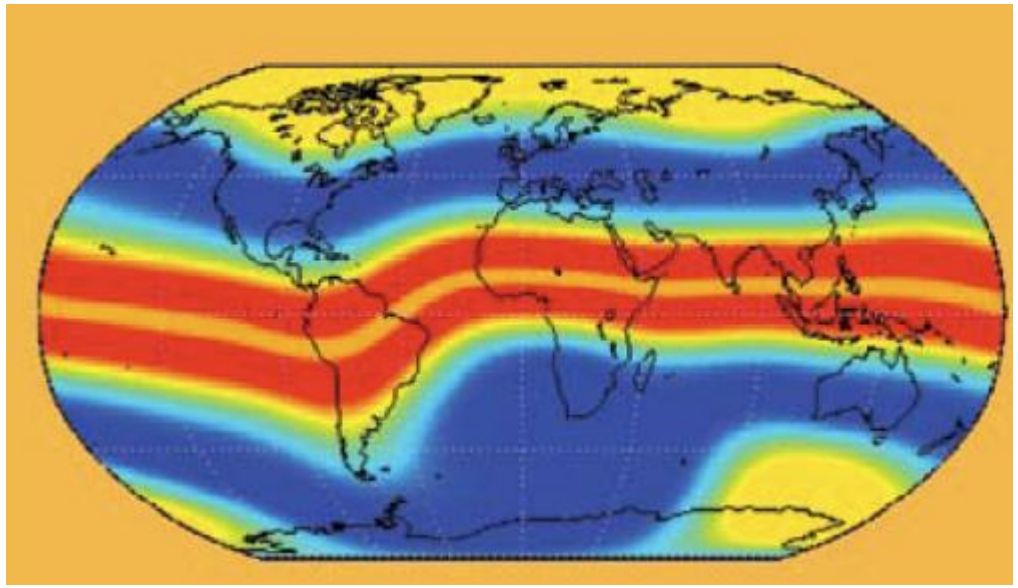


GEOGRAPHICAL VARIATION OF MUFs

1. The sun's ionizing radiation is most intense in the equatorial regions and least intense in the polar regions.

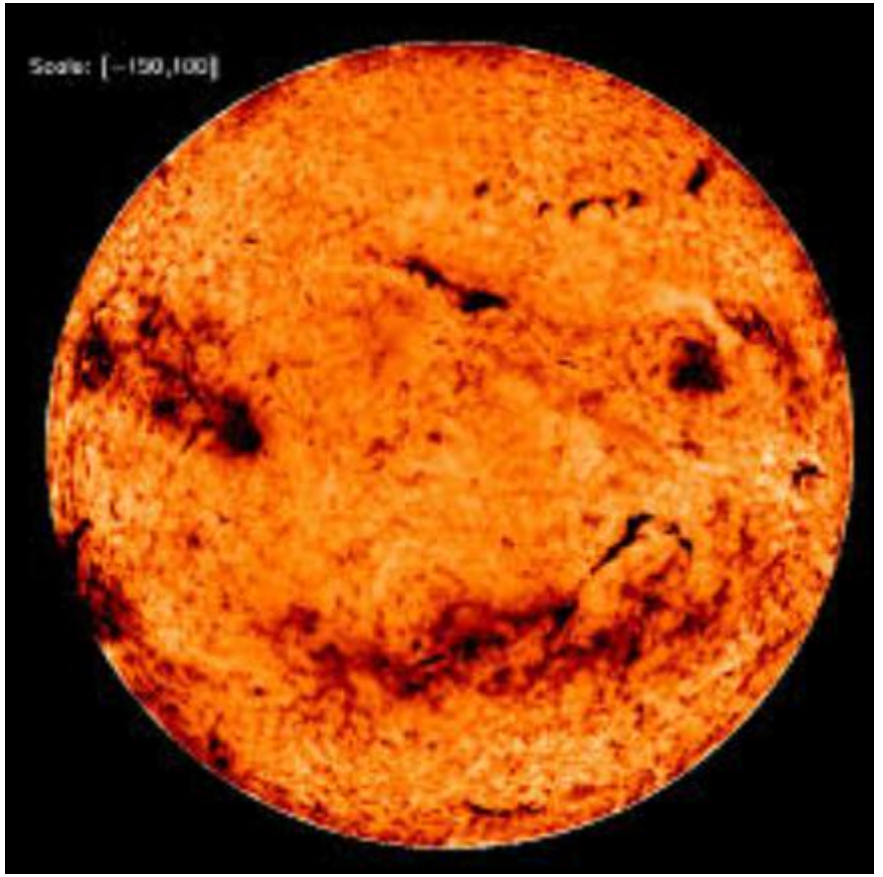
2. Daytime MUF of the E and F1 layers are therefore highest in the tropics.

3. Polar region MUF's for these layers can be three times lower.



EFFECTS OF SUNSPORTS

1. **A SUNSPOT** is an area of intense magnetic activity on the surface of the sun which is cooler than the rest of the sun's surface. Because it is cooler, a sunspot is darker and therefore visible against the hotter, brighter background.
2. **The number of sunspots observed on the sun's surface follows an 11 year cycle.**
3. Sunspots have intense magnetic fields. These fields energize a region of the sun known as the chromosphere, which lies just above the sun's surface. More ultraviolet radiation is emitted, which increases the electron density in the earth's atmosphere.
4. The additional radiation affects primarily the F2 layer.
5. During sunspot maxima, the highly ionized F2 layer acts like a mirror, refracting the higher HF frequencies with almost no loss. MUF can rise to more than 50 MHz.



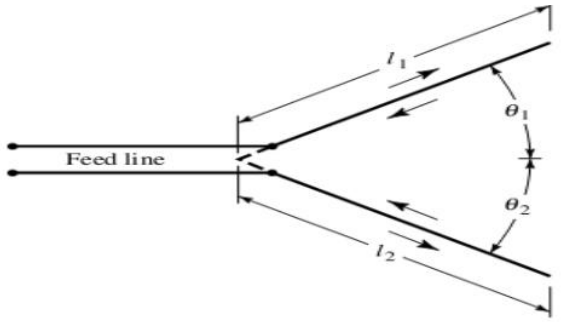
SOLAR FLARE

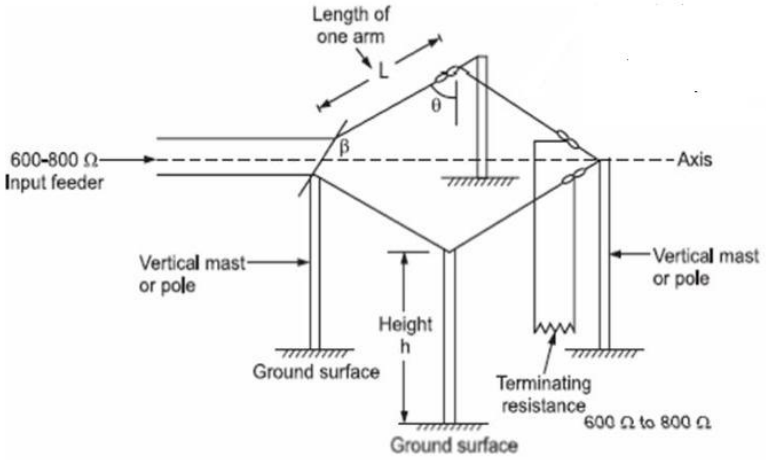
1. A solar flare is a plume of very hot gas ejected from the sun's surface.
2. It rises through the chromosphere into the corona.
3. X-ray emission from the corona increase and reach the earth in less than 9 minutes.
4. If X-rays are intense enough, the ionosphere will become so dense that all HF signals are degraded or even completely absorbed by it and worldwide HF communications are degraded for minutes .



HF BAND ANTENNAS

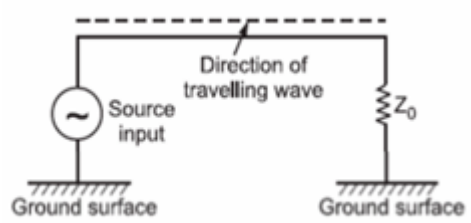
1. V-Antenna;



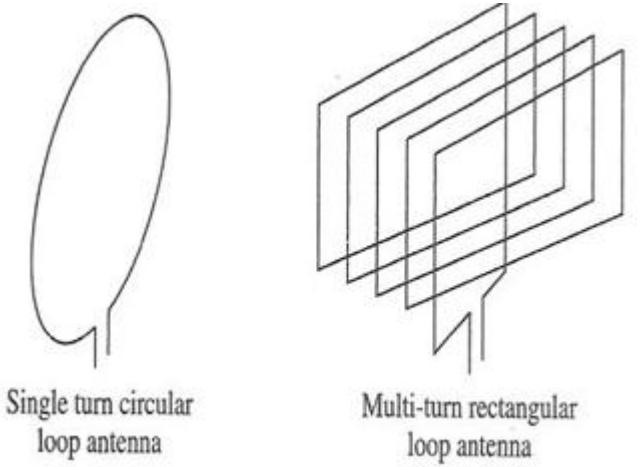


2. Rhombic Antenna

3. Traveling Wave (TW) Antenna



4. Loop Antenna



5. Whip Antenna

