1 The Sun's Solar Cycle

Early on it was known that radio signal strength and quality varied throughout the day and seasonally. By 1910 commercial and government radio operators knew that radio signals traveled further at night and were less noisy in the winter.

It was widely believed at the time that the quality and distance of radio transmissions was directly proportional to wavelength. Radio transmissions covered longer distances and were more reliable using long wavelengths instead of short ones. For this reason government and commercial radio stations operated on 50 to 1000 KHz (wavelengths of 6,000 down to 300 meters). Primarily from antenna considerations, the marine distress frequency was established at 500 KHz. A lower frequency would have been better, but lower frequencies meant longer antennas, recalling that wavelength

$$\lambda = \frac{c}{f}$$

where

c = speed of light
f = frequency

Even at 500 KHz it was difficult to get an antenna to fit aboard ship, as clearly indicated in Figure 1.

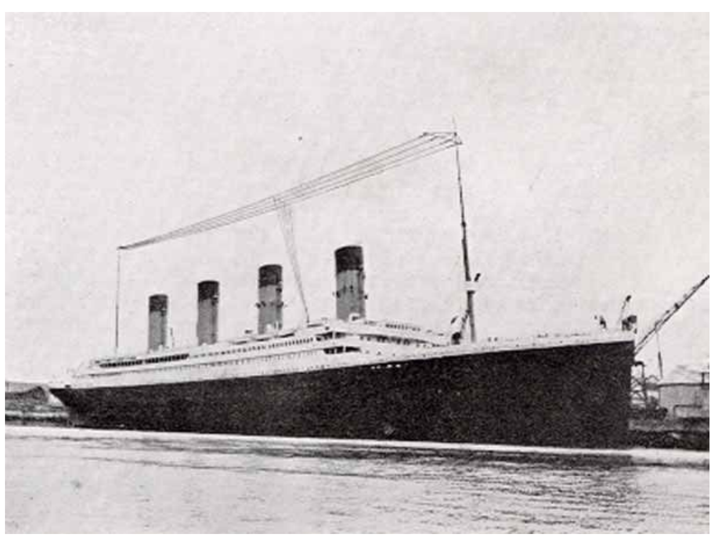
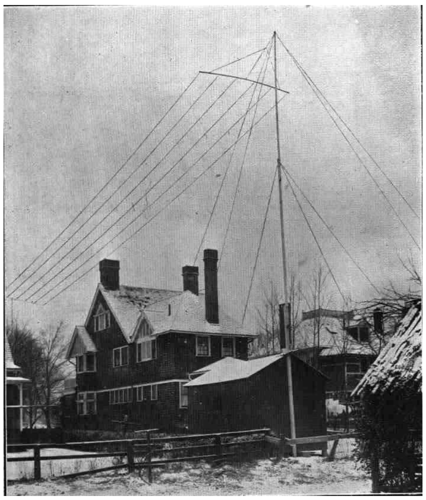
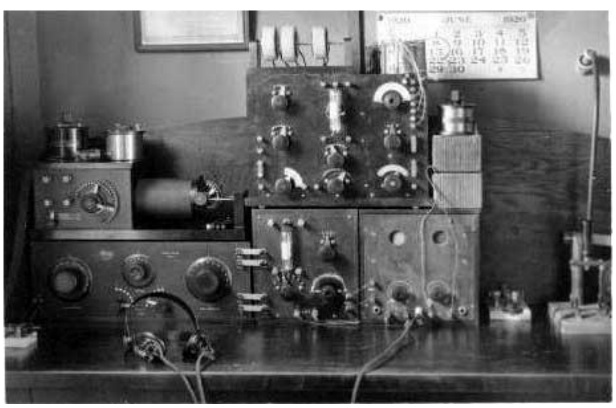


Figure 1 Shipboard antenna (credit: astrosurf.com)

Amateur radio operators were exiled to frequencies in the 200 meter band (approximately 1.5 MHz) so as not to interfere with commercial and government operations. Frequencies at and above 1.5 MHz were considered worthless from a commercial perspective. However, amateur radio operators became very successful operating at these frequencies relaying messages in short hops across country as well as communicating point to point over moderate distances.



(credit: www.arrl.org)



(credit: oldpassions.com)

Figure 2 Early amateur radio stations

In October 1924 amateurs were given the short wave frequency bands of 80 meters (3.5 – 4.0 MHz), 40 meters (7.0 – 8.0 MHz) and 20 meters (14.0 16.0 MHz). Since radio performance was believed to be better on longer wavelengths, these short wave frequency bands were thought to be even more worthless than 200 meters. Some amateurs reluctantly moved to these new frequencies to avoid crowding on 200 meters. The movement became a stampede when it was discovered that Europe, South America, New Zealand, Japan, and other distant places could be reliably worked on 40 and 20 meters. But the good times came to an end. By 1933 the 20 meter band was completely dead. No one knew why, it just died. Around 1935 the short wave bands came roaring back to life. It gradually became apparent that performance on the short wave bands was tracking the solar cycle.

So, what is the solar cycle? The solar cycle refers to the appearance and disappearance of sunspots over roughly a 11 year period. A cycle is arbitrarily defined to begin at sunspot minimum when few if any sunspots are visible. Figure 3 shows the Sun at solar minimum (picture on the left) and solar maximum on the right.

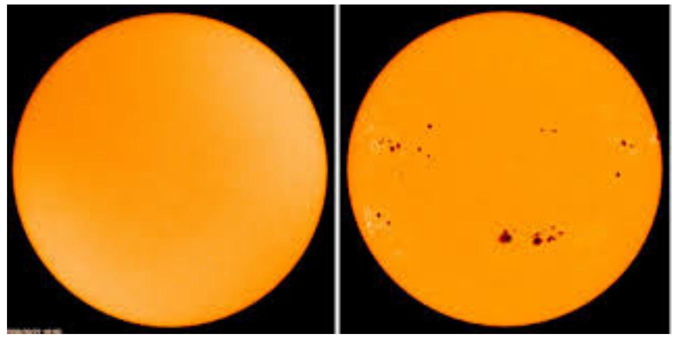
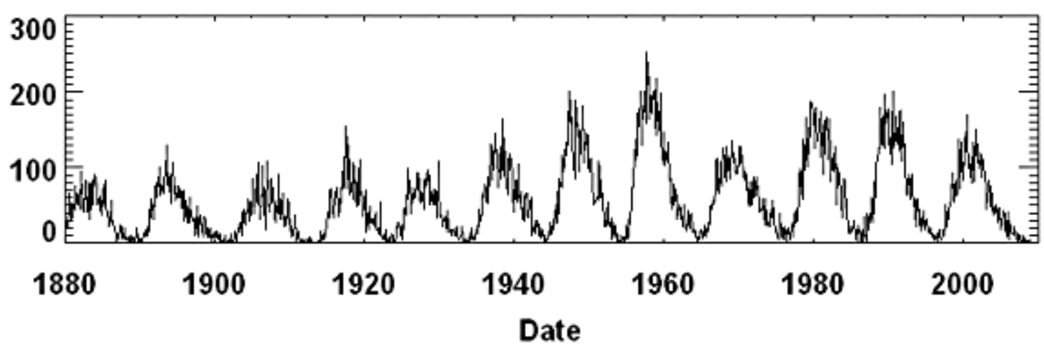


Figure 3 Sun at Solar minimum and maximum (credit: springer.com)

The solar cycles from 1880 to 2010 are shown in Figure 4. The vertical scale on the left side of the graph is the number of sunspots observed each day. Note that the

- Amplitude (the maximum number of visible sunspots),
- Shape, and
- Duration

vary considerably from one cycle to the next.



Solar cycle number 16 peaked in 1928 with excellent long distance communications on 40 and 20 meters. But 20 meters was dead by 1933. In 1935 short wave communications on 20 meters came back, suggesting that short wave radio performance was tied to the solar cycle.

Figure 4 Solar cycles from 1880 to 2010 (credit: SpaceWeather.com)

2 HF Skywave Propagation

In 1925 Edward Appleton proved that HF communications occurred by skywave propagation through Earth's upper atmosphere as illustrated in Figure 5

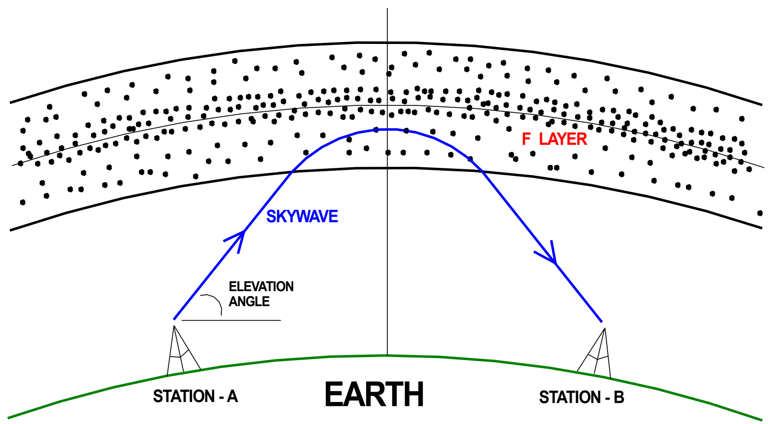


Figure 5 Skywave propagation (credit: author)

Prior to Appleton's experiments in southern England, no one really knew how radio communications occurred. It just did. There were many theories proposed by renowned scientists and prestigious universities, but none of the theories actually matched what was happening. For some time there had been suggestions that an electrified layer existed in Earth's upper atmosphere which radio waves reflected off of. But there was no experimental evidence that such a layer actually existed. Appleton demonstrated that an electrified layer did exist at an altitude of around 90 to 120 km.

After the 40 and 20 meter rollercoaster experience from 1924 – 1935, the question became: how does skywave propagation work and how is it affect by the solar cycle? To answer these questions we first need to know two things:

1. How the ionosphere forms in the Earth's upper atmosphere

2. Why the ionosphere causes radio signals to bend back to Earth.

3 Formation of the Ionosphere

Extreme Ultra Violet (EUV) and X-ray radiation from the Sun ionizes atoms in the upper atmosphere. How does that occur? Solar radiation is absorbed by a neutral atom transferring energy to its electrons. Occasionally, an electron is sufficiently energized that it breaks away from its parent atom forming a free electron and a positive ion (an atom that has lost one of its electrons) as illustrated in Figure 6.

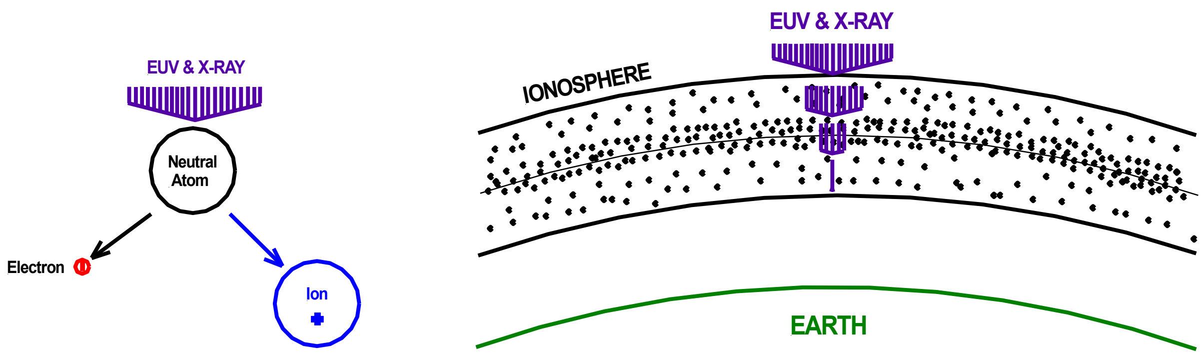


Figure 6 Ionization of atoms in Earth's upper atmosphere (credit: author)

Occasionally is the operative word. There are 1,000 times more neutral atoms in the upper atmosphere than ions. Consequently, the ionosphere is very thin, wispy, and easily blown around.

Solar radiation is intense at the top of the atmosphere, as shown in Figure 8, but there are few atoms available to ionize. As the radiation penetrates deeper into the atmosphere, it encounters more and more atoms (mostly nitrogen and oxygen) resulting in higher levels of ionization. However, the ionization process absorbs energy from the EUV and X-ray radiation. The number of atoms keeps increasing as the radiation penetrates further into the atmosphere, but ionization levels decrease due to weakening radiation. Ionization continues to drop as the radiation weakens further and finally disappears forming the bottom of the ionosphere.

There are two additional things to note in Figure 6. Ions are way too massive to be affected by our puny radio waves. But tiny electrons interact readily with our radio waves. Thus it is electron densities that are so important to us.

4 How Skywave Propagation Works

The highest levels of ion and electron densities occur roughly in the middle of the ionosphere as shown in Figure 7.

A radio wave travels in a straight line from the transmitting antenna to the ionosphere. However, it begins immediately bending as it enters the ionosphere. The direction that it bends in is important.

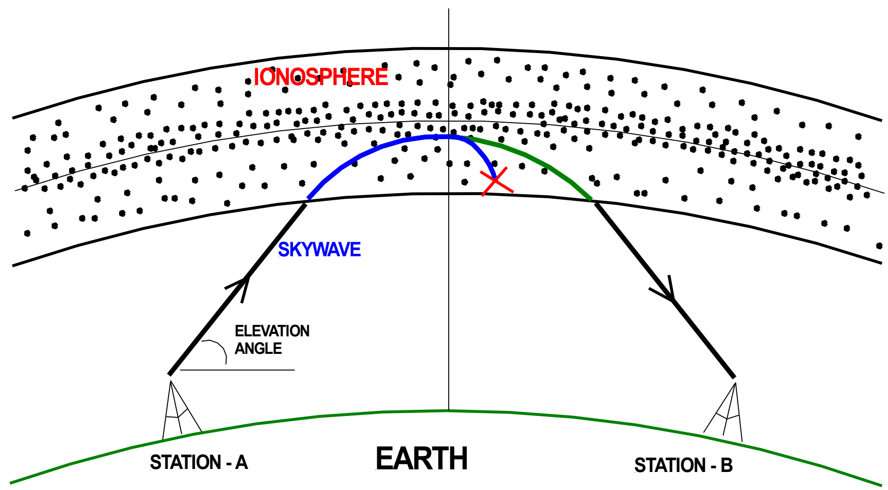


Figure 7 How skywave propagation works (credit: author)

- Radio waves bend toward the Earth as electron densities INCREASE.
- Radio waves bend away from the Earth when electron densities DECREASE.

Electron densities increase from the point of entry into the ionosphere, reaching a maximum near the middle of the ionosphere. Consequently a radio wave begins bending back toward Earth as soon as it enters the ionosphere. Bending eventually reach the point where the radio wave is traveling parallel to the Earth. If it continued to bend in the same direction it would exit the ionosphere near the red X in Figure 7. But that is not what happens. Electron densities decrease as the radio wave travels back toward Earth. As electron densities decrease, the radio wave bends away from the Earth causing it to straighten out and exit the ionosphere at the point shown. It then travels in a straight line from the bottom of the ionosphere to the receiving antenna.

5 Trends in HF Communications During Solar Maximum

Radiation from the Sun is intense during solar maximum when large numbers of sunspots are visible on the Sun. The ionosphere becomes heavily ionized during the day, including a heavily ionized D - Layer. 80 meter signals are quickly absorbed in the D – Layer following sunrise and remain absorbed all day long until just after sunset, as illustrated in Figure 10. 40 meter signals are also absorbed in the D – Layer during mid day. But communications on 40 meters is often possible for an hour or so after sunrise and in the late afternoon. 20, 15, and 10 meter signals are all bent back to Earth with little absorption providing excellent long distance DX contacts all day.

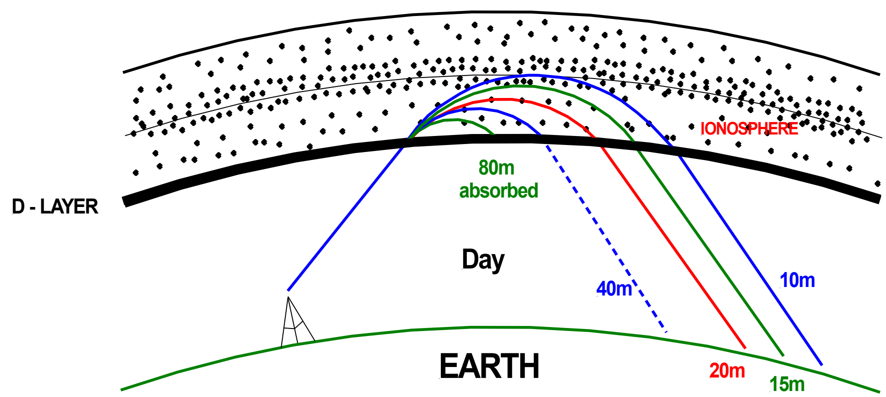


Figure 8 Daytime radio wave propagation solar maximum (credit: author)

At night levels of ionization drop, due to lack of sunlight, as electrons and ions recombine into neutral atoms. The D – Layer disappears an hour or so after sunset providing excellent night time communications on 80 and 40 meters. 80 meter communication typically lasts all night, disappearing just as the Sun rises. 40 meter communications usually dies out in the early morning hours when ionization is at its lowest level. Notice 20 meters in Figure 9. In this figure a 20 meter signal is right in the densest part of the ionosphere. In the early evening, communications on 20 meters is still possible. But as the evening wears on, ionization levels continue to drop resulting in the 20 meter signal passing through the most dense part of the ionosphere without being bent back to Earth. Once that happens the 20 meter signal enters a region of decreasing electron density meaning that the signal bends away from Earth and is lost to outer space. The same thing happens to 10 and 15 meter signals, but much faster. They are lost to outer space shortly after sunset.

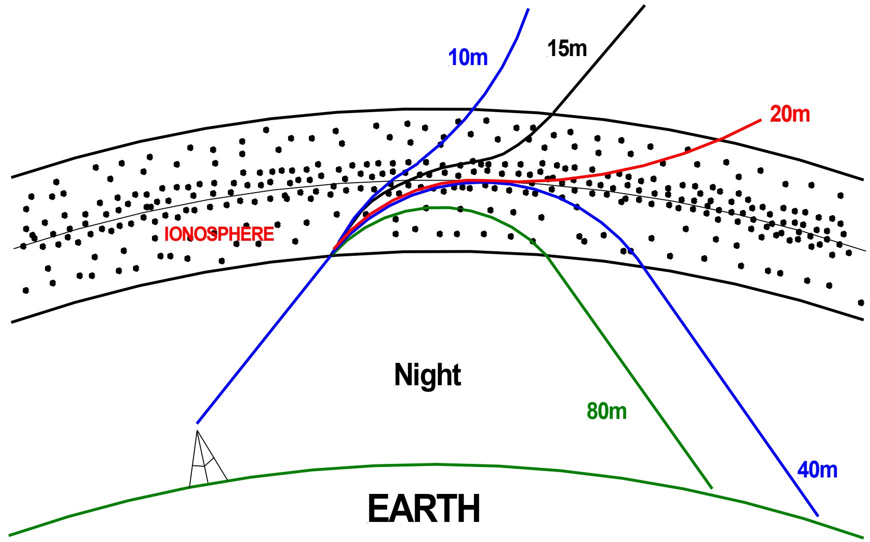


Figure 9 Night time radio wave propagation solar maximum (credit: author)

5.1 Trends in HF Communications During Solar Minimum

The Sun's radiation is weak during solar minimum when few if any sunspots are visible. The Earth's ionosphere is in turn weakly ionized. However, there is still a D – Layer which absorbs 80 meter signals during the day. While present, the D – Layer is weaker during solar minimum permitting regular communications on 40 meters during the day. 20 meter communications is erratic during solar minimum. On some days it is good, but on other days the band is dead. 10 and 15 meter signals are usually lost to outer space most of the time during solar minimum resulting in poor long distance DX.

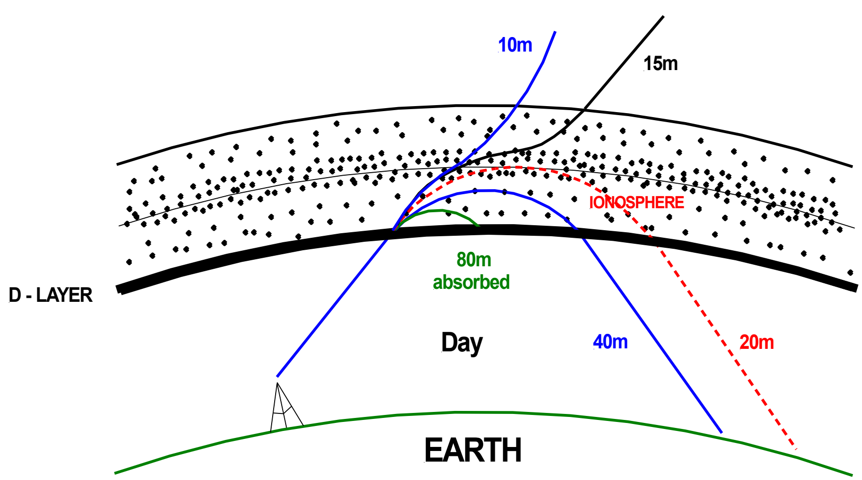


Figure 10 Daytime radio wave propagation solar minimum (credit: author)

At night levels of ionization drop even further, due to lack of sunlight, as electrons and ions recombine. The D – Layer disappears around sunset providing excellent night time communications on 80 meters. Communications on 40 meters lasts into the early evening but then dies out. There is no communications on 20 through 10 meters. These signals are lost to outer space.

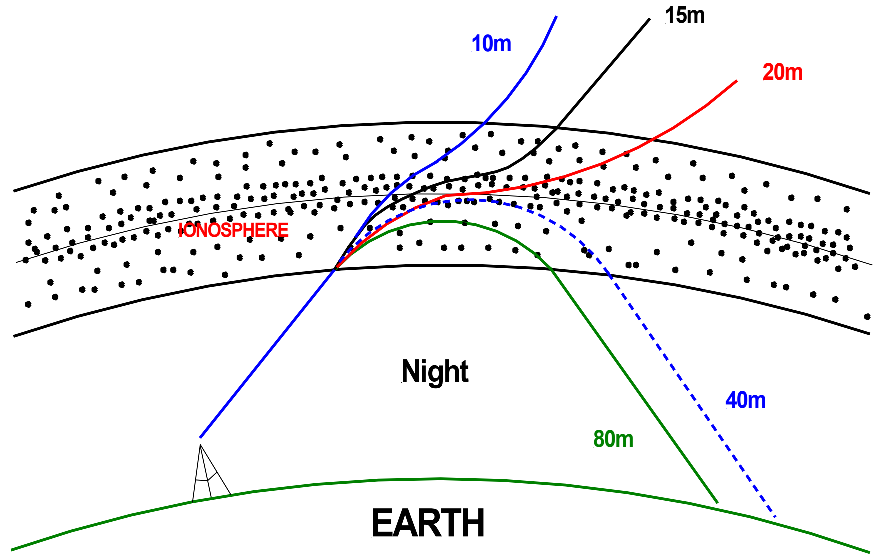


Figure 11 Night time radio wave propagation solar minimum (credit: author)