PROPAGATION

A LITTLE GUIDE

COMMENT

I looked at many sites to try to understand what is going on in the ionosphere. The process in almost all cases was not clear to the layman. So here is what I garnered from many sources distilled down to sort of understandable English about the propagation that affects your QSOs, of course greatly simplified.

Bear in mind that SFI, your antenna system, your location will all influence the following discussion.

OUTLINE

- A LITTLE HISTORY
- IONOSPHERE BASICS
- DIURNAL/SEASONAL VARIATIONS: 10,20,40
- CYCLE 25
- 4 TYPES OF PROPAGATION
    - SPORADIC E
    - LONG PATH/CHORDAL HOP
    - GREY LINE/TERMINATOR
    - SKEWED PATH
- PROPAGATION YOU REMEMBER
- APPENDIX: WITH MORE INFO

A LITTLE HISTORY

1902: **Oliver Heaviside advanced the idea that the Earth's uppermost atmosphere contained an ionized layer now known as the ionosphere. He predicted the existence of what later was dubbed the Kennelly-Heaviside layer.**

A layer of ionized gas occurring roughly between 90km and 150 km above the ground.

They theorized the layer to explain how **Guglielmo Marconi's** 1901 radio signals traveled across the Atlantic **despite the Earth's curvature.**

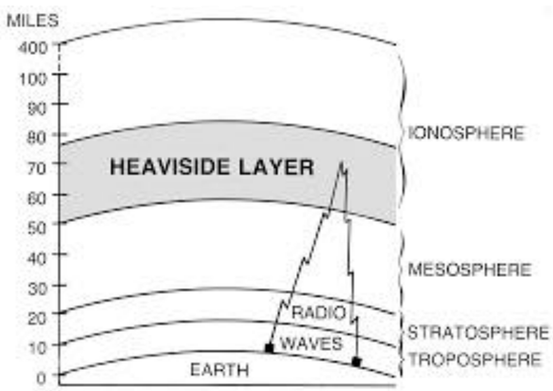
It became known as the E region

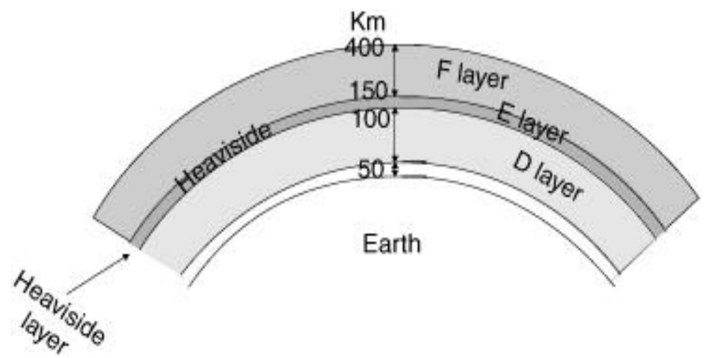
HISTORY

- **1924:** The existence of the **ionosphere** was conclusively confirmed by British physicist **Sir Edward Appleton and Miles Barnett**.
- **1925:** American scientists **Gregory Breit and Merle Tuve** independently confirmed the height of these layers using pulsed radio signals.
- **1927: Appleton** performed further experiments that established the higher "F layer".
- **Earlier hypothesis:** While proven in 1924, the concept of a conducting layer was proposed by **Arthur Kennelly and Oliver Heaviside in 1902.**

HISTORY

Heaviside's proposal included the means by which radio signals are transmitted around the Earth's curvature.

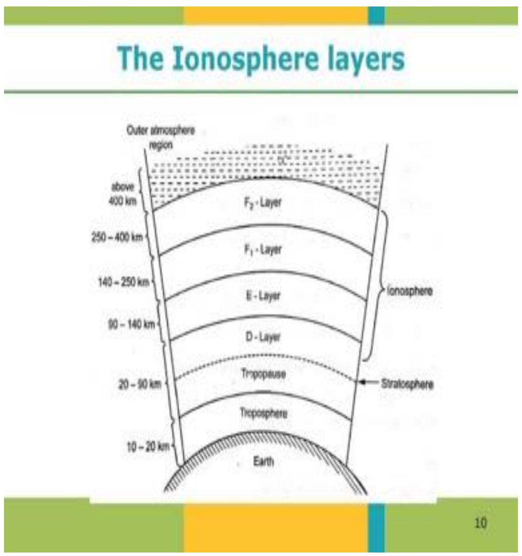




HISTORY

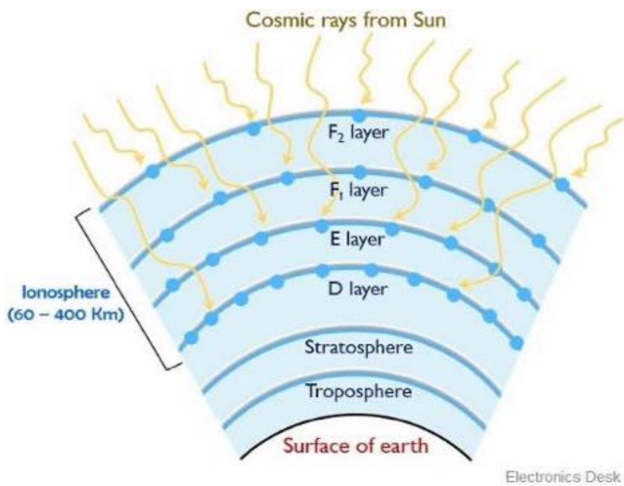
The Heaviside Layer is referenced in the musical Cats. This is where Grizabella ends up being sent. Andrew Lloyd Weber took the idea from an idea by T.S. Eliot where he wrote "Up, up, up to the Heaviside Layer." This layer was well known to Eliot. At that time, it explained the first transcontinental radio reception by Marconi.

IONOSPHERE BASICS



- THERE ARE SEVERAL LAYERS OF THE IONOSPHERE RELEVANT TO MAKING A CONTACT: D, E, F1 AND F2 SEEN ON THE IMAGE.
- EACH LAYER HAS IONIZABLE GAS.
- THE SUN, AS YOU KNOW, IS THE CONTROLLING MECHANISM TO ACTIVATION OF THE IONOSPHERE.

HOW DOES THE SUN AFFECT PROPAGATION?



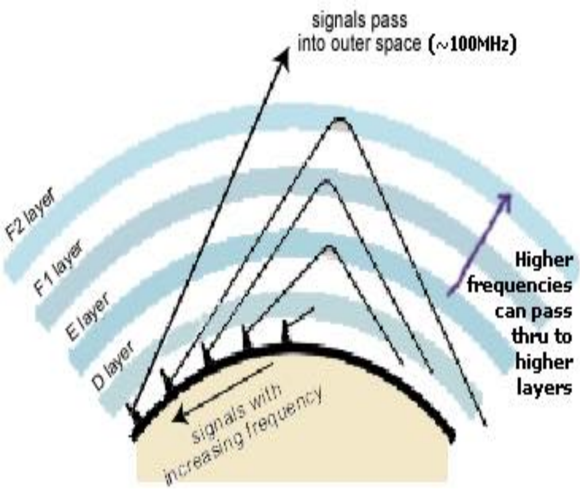
Radio waves (photons) pass through earth's magnetic fields with no interaction at all.

What affects radio propagation is the density of free electrons in layers of the ionosphere.

Depending on the free electron density and the radio frequency, the waves are "bent" back to earth or pass thru the ionosphere.

HERE IS DIAGRAM OF SOLAR RADIATION HITTING THE IONOSPHERE-BLUE DOTS = GAS

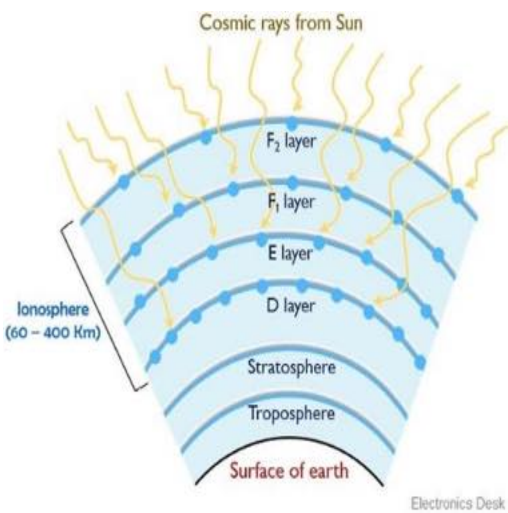
WHAT HAPPENS AS A RADIO WAVE PASSES THRU THE IONOSPHERE?



RADIO WAVES HITTING THE FREE ELECTRONS IN THE IONOSPHERE CAUSE THEM TO VIBRATE AND RE-RADIATE PHOTONS BACK DOWN AT THE SAME FREQUENCY, REFRACTING THE RADIO WAVE BACK TOWARDS THE EARTH.

THE LIFETIME OF FREE ELECTRONS IS GREATEST IN THE F2 REGION. TYPICAL LIFETIMES OF FREE ELECTRONS IN VARIOUS LAYERS: D, E, F1 AND F2: ONLY A SMALL FRACTION OF A SECOND, 20 SECONDS, 1 MINUTE AND 20 MINUTES, RESPECTIVELY.

DAYLIGHT FREE ELECTRONS

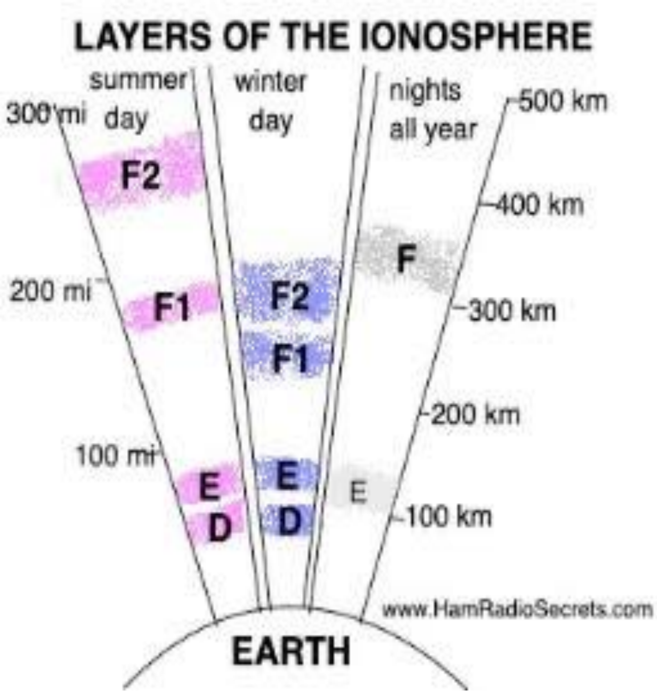


- **THE SUNS RADIATION IONIZES THE HIGHER LAYERS (F1 AND F2) MORE THAN THE D AND E LAYERS.**
- **GASES (Blue dots) IN THE D-LAYER ARE ABUNDANT BUT NORMALLY LEAST IONIZED BY THE SUN; GASES ARE MUCH LESS ABUNDANT IN THE F2-LAYER AND IONIZED MORE.**
- **THIS IS IMPORTANT.**
- **WHEN RADIATION FROM THE SUN HITS THE IONOSPHERE, THE MOLECULES IN EACH LAYER IONIZE INTO FREE ELECTRONS AND POSITIVE CHARGES. THIS HAPPENS DURING DAYLIGHT HOURS. (SEE APPENDIX)**

NIGHT FREE ELECTRONS

- **Without solar radiation, free electrons recombine with their host molecules. Recombination, causes the free electron density to go down, forcing the MUF to go down, which is why by total darkness, 10m (and a bit later 15m) can be "dead".**
- **Free electron density goes down rapidly in the D-layer because there are many more parent molecules to recombine with….not so with the F2-layer. because there are fewer parent molecules hence, recombination in the F2-layer takes much longer and never is complete.**
- **At night the D-layer is no longer ionized and disappears.**

DIURNAL/SEASONAL CHANGES



DIURNAL CHANGES

D-layer: Present all day and disappears at night all year because of the rapid recombination in the lower, thicker atmosphere. At night Low frequency signals now can be reflected by the higher E or F layers

F-layer: There are two layers all day (F1-F2); at night combine into 1 F layer.

(see appendix for a fuller explanation)

SEASONAL CHANGES

WINTER

Temperatures will be lower the winter months → denser gas layers at lower heights which means a smaller one-hop distance.

SUMMER

Longer daytime hours in the summer cause the F2 layer to increase in height due to heating (molecules are now farther apart). The F2 layer persists during summer nights because of reduced electron (recombination) rates, thus maintaining electron density long after the sun has set

Ok what does this mean for making QSO's during the summer? Bear in mind that SFI etc. affect what will occur on a daily basis. See appendix fore more detail.

ANGLE ON INCIDENCE

- With a lower angle, the EMR enters the ionosphere obliquely.
- Lower angles allow the radio wave to travel obliquely for a longer distance through the ionized layers of the ionosphere. The wave passes through a much larger total volume of free electrons.
- While the total number of electrons integrated over your entire low-angle path may be higher, the decreased F2-layer density (summer) can sometimes reduce the Maximum Usable Frequency (MUF).
- Also, bear in mind each hop during the day makes the wave pass through the absorptive D-layer twice! Up and down

REFRACTION OF YOUR SIGNAL

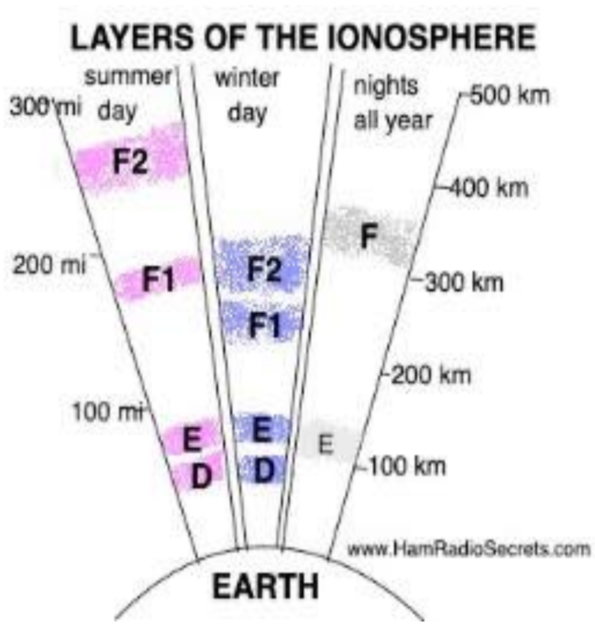
- **HOW YOUR EMR REFRACTS**
- The passing radio wave's electromagnetic field forces free electrons in the ionosphere to vibrate at the same frequency as the wave.
- **Because the wave enters at an angle, the free electrons it encounters push the wave progressively sideways and downward.**
- **Thinking about water and light will help visualize radio refraction**
- A photon appears refracted in water because it interacts with the water's electrons, causing the light wave to effectively slow down. When hitting the water's surface at an angle, this change in speed causes the path of the photons to be refracted, shifting the perceived position of underwater objects.

WHY IS 28 MHz POOR IN THE SUMMER?

28 MHz

- **Intense D-Layer Absorption:** The long day summer sun makes the D-layer extremely ionized acting to absorb 28 MHz signals. However, if the wave makes it thru the D-layer....
- **F2-Layer Changes:** In the summer, extreme solar heating causes the F2- layer to expand and decrease in free electron density. The free electrons are farther apart **making it less efficient at refracting high-frequency signals like 28 MHz (smaller wavelength)** leading to the **summertime propagation doldrums.**
- **As a result, 28 MHz signals usually fail to refract back to Earth, often passing straight through to space.**

F-layer AND 14 MHz IN THE SUMMER



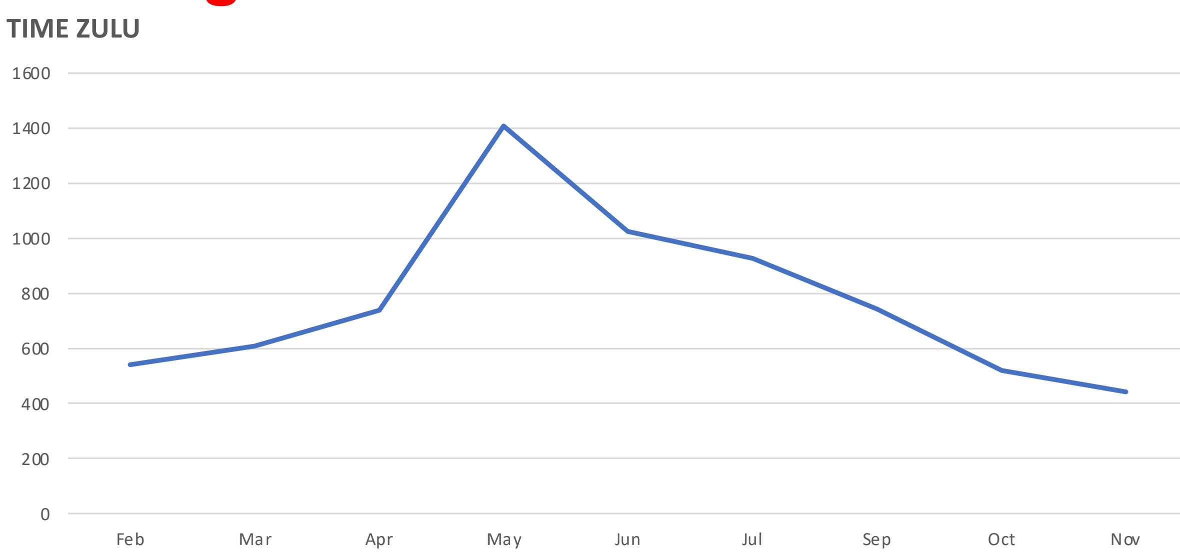
THE OPENINGS TO THE FAR EAST (JA) ON 14 MHz SHIFT DURING THE YEAR. GRAPH ON THE NEXT SLIDE.

THIS IS DUE TO THE LINGERING OF THE F2 LAYER AFTER SUNSET IN THE SUMMER. THE F2 LAYER IS IONIZED THE MOST AND NEVER DISAPPEARS.

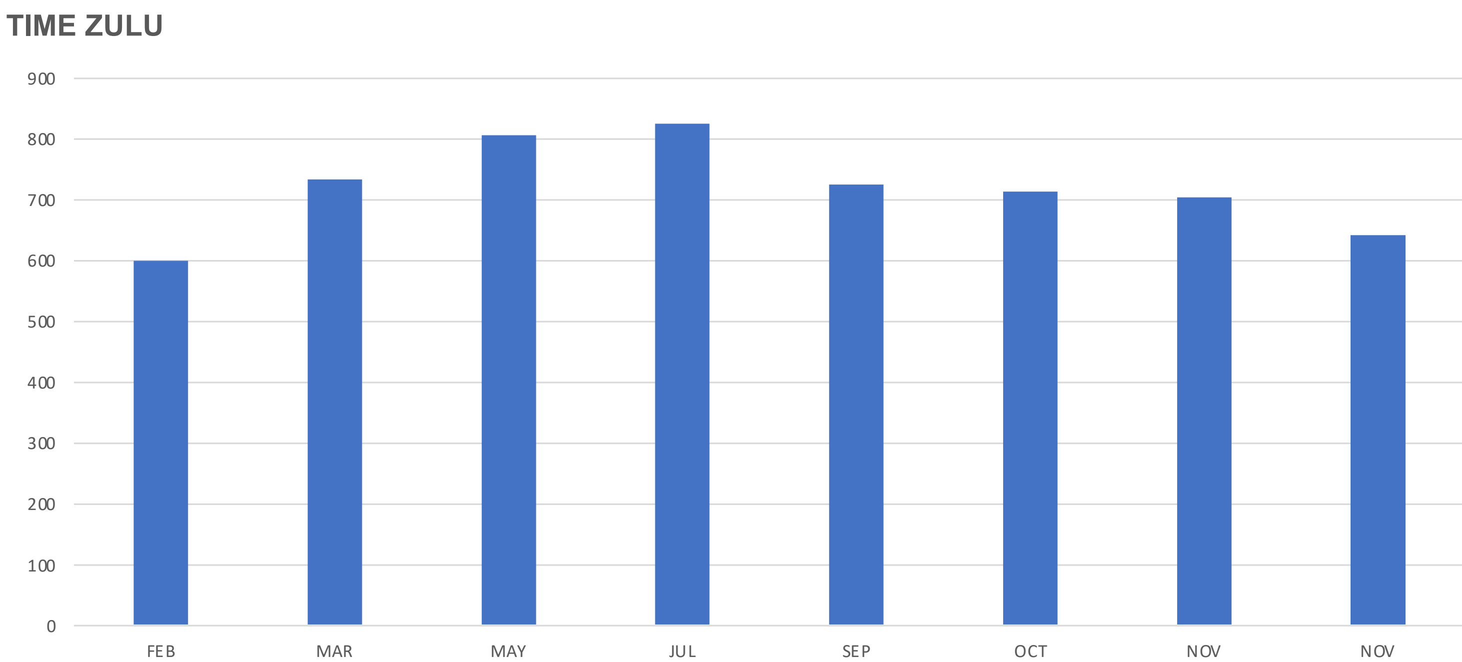
ON THE NEXT SLIDE, YOU CAN SEE THE SHIFT BETWEEN FEB TO APRIL AND JUNE TO NOVEMBER.

LAST JA WORKED ON 14 MHz N6RO

14 MHz is exceptional during the summer because intense, long-duration sunlight creates high-density F2-layer ionization, allowing the band to remain open for long-distance communication through late-night or even all night.

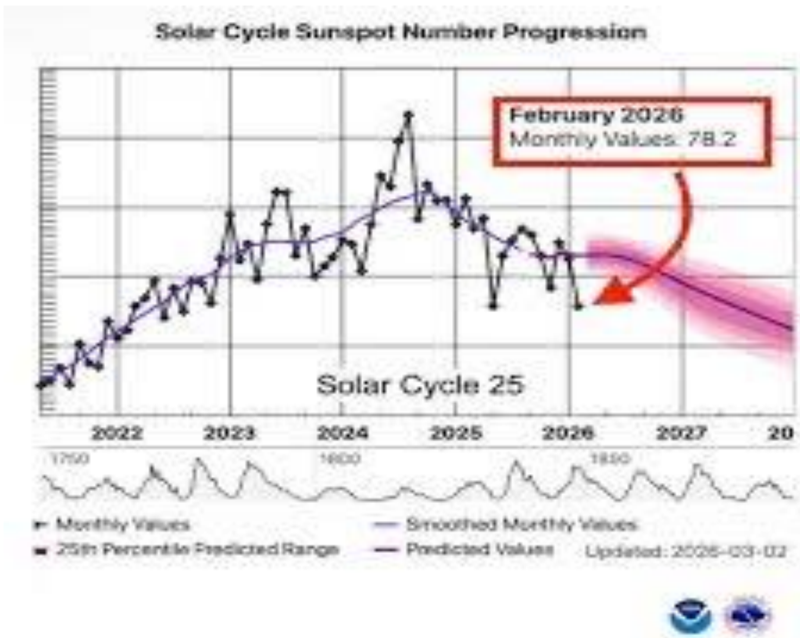


FIRST JA WORKED ON 7 MHz AT N6RO. DUSK IN JAPAN IS THE CONTROLLING FACTOR (see appendix for more 160-40-meter information)

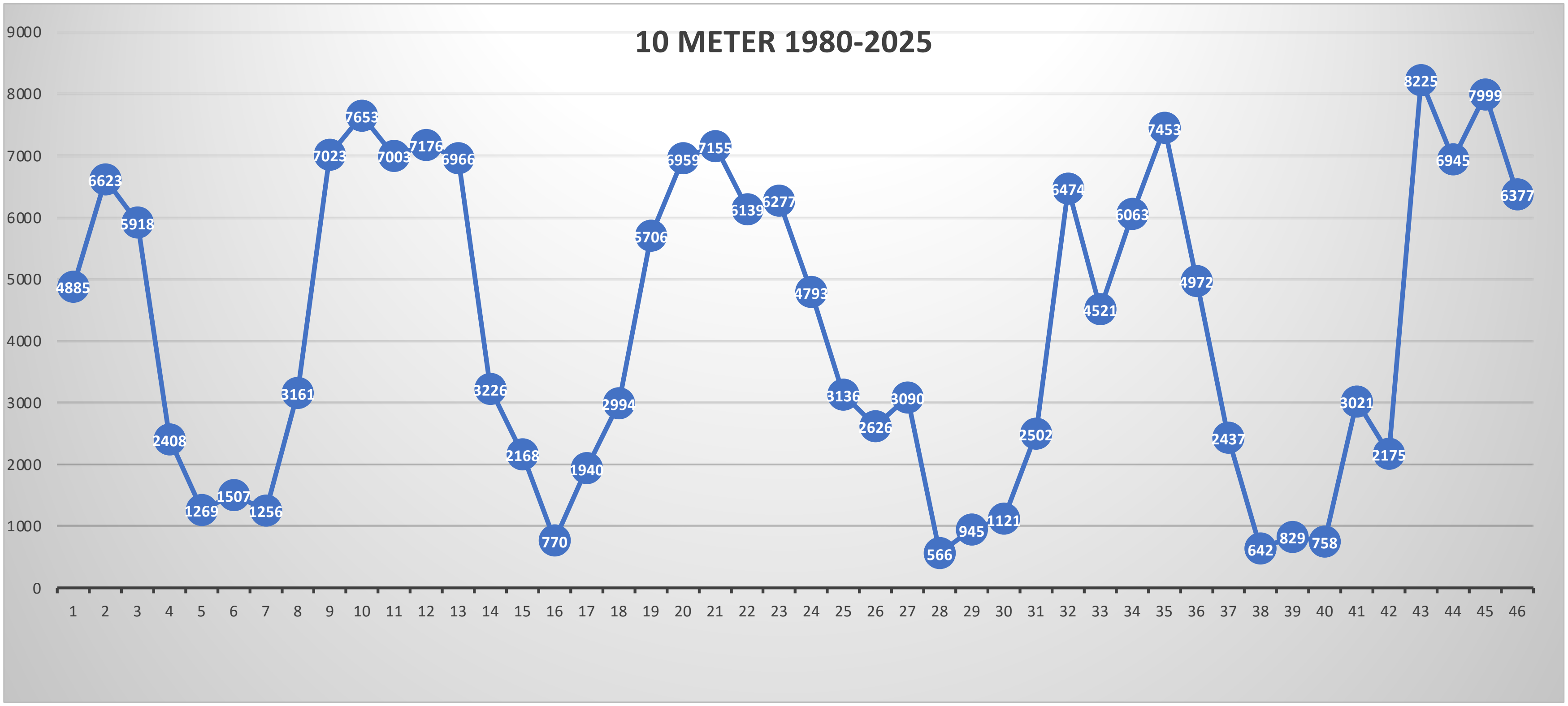


CYCLE 25

YOU CAN SEE THAT THE CYCLE IS DECLINING. MORE EVIDENCE IS SEEN IN THE NEXT SLIDE DATA FROM THE 10 METER CONTEST



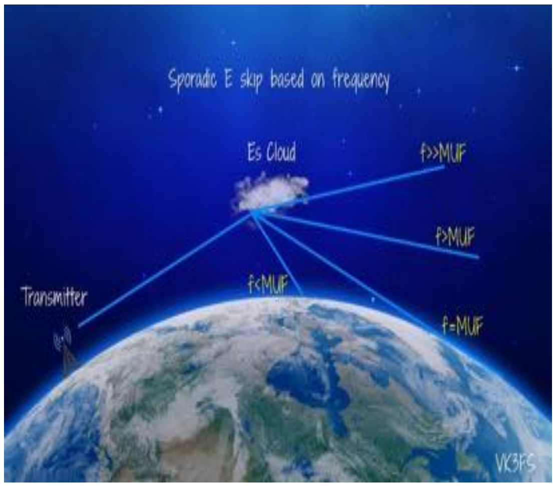
5 SOLAR CYCLES: LARGEST # TOTAL QSOs FOR EACH 10 METER CATEGORY ADDED TOGETHER



FOUR TYPES OF PROPAGATION

- FOUR TYPES OF PROPAGATION YOU HAVE PROBABLY ENCOUNTERED:
- SPORADIC E: Es
- LONG PATH/CHORDAL HOP
- GREY LINE/TERMINATOR
- SKEWED PATH

SPORADIC E PROPAGATION (Es)



- **Sporadic E (Es) propagation** is probably the most interesting form of signal enhancement for anyone interested in the **28Mhz or higher.**
- **As its name suggests**, **Es is an unpredictable event. Es activity peaks near the summer solstice. A smaller peak occurs around the winter solstice.**

There seems to be no correlation between the formation of sporadic E clouds and the eleven-year sunspot cycle.

SPORADIC E PROPAGATION (Es) 28 MHz

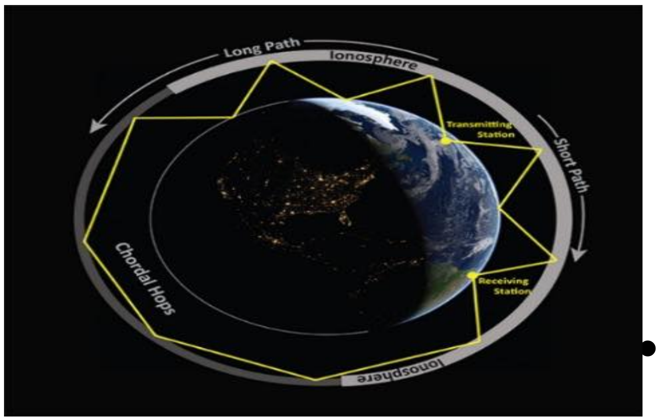
The next slide shows 14 years of 10-meter contest evening QSO history.
Although the next slide contains a lot of data (you can look at it later), here is a summary.

Es is not predictable. Two or more Es events can occur in an evening. Two evenings with a good Es opening is a rare event. You need to be alert!

14 YEARS OF 10 METER CONTEST EVENING OPENINGS: SUNSET ABOUT 443PM EACH YEAR; CONTEST STARTS AT 4PM (# of Qs in opening). SFI FOR EACH YEAR ON LAST LINE.

- **2011 : FIRST NIGHT: 0016 ID, WA, BC, NV (6) END 0256; 0430 CO, TX, SD (6) END 0506; SECOND NIGHT: 0008 IN, IL, UT, WA, OR, MN, CO, AB. IA (14) END 0123**
- **2012 :FIRST NIGHT: NO QSOs OUTSIDE CA; SECOND NIGHT: 0041 KS, TX, NM (7) END 0138;**
- **2013: FIRST NIGHT: 0012 ID, WA OR, AZ NV (16) END 0209; SUDDENLY 0224 CO, NE, MS, NM, OK, TX, WY (65) END 0402; SECOND NIGHT: 0000 FL, GA, MI, IL, NY, IN, TN, KS, AL, MS, OH, WI, PA, NC, ON, CT, VT, SC, KY (54) 0052; 0103 WA, OR (4) END 0117**
- **2015: FIRST NIGHT: 0019 NV, CO (3) END 0113; SECOND NIGHT: NO USA QSOS OUTSIDE CA**
- **2016: FIRST NIGHT: 0044 NV (2) END 0149; 0249 TX, AZ END 0311 (2); 0449 WA, ID, NM, AZ (9) END 0558; SECOND NIGHT: 0006 WA, BC, OR (42) END 0138; 0212 NM, TX, AZ (6) END 0242**
- **2017 : FIRST NIGHT: 0053 SK, MB, MT, ID, AB, CO, UT, (13) END 0229; 0232 FL, LA, TX, KS, AR, ND, MN, WI, IN, MO. MS, NE, IL (23) END 0340; 0342 ID, UT, SD, AZ, MN, KS, OR, BC, CO, ID, TX, NM (38) END 0602; SECOND NIGHT: 0026 NV, AZ (4) END 0102**
- **2018: FIRST NIGHT: 0019 WA, CO, NM, AZ (6) END 0717; SECOND NIGHT: NO QSOs OUTSIDE CA**
- **2019: FIRST NIGHT: 0000 NV, CO, AZ, TX, NM, WA, SD (31) …SUDDENLY 0044 IN, PA, OH, MT, AB, IL, WA, WY, TX, CO, ID, VA, BC, MO, AR, LA, UT, OK, KY, VA, TN, MN, NC, WI, KS, GA, IA, SK, FL, AL, OR, AB, NE (211) END 0530: SECOND NIGHT: 0103 CO (1) END 0103**
- **2020: FIRST NIGHT: 0000 AZ, NV, WA, CO (34) SUDDENLY 0120 OK, TX, AZ, AR, MS, LA, CO, PA, GA, NM, FL, MD, KY, VA, OH, NC, AL, SC, AL, IL, NJ, MO, TN, CT, UT, ID, MA (126) END 0421; 0421 CO, AZ, WA, BC, MT, NM, TX (31) END 0650; SECOND NIGHT: 0343 AZ, OR, WA (13) END 0525**
- **2021: FIRST NIGHT: 0001-0026 AZ, NV, CO (5) END 0026; 0134 NV, CO (2) END 0157; 0408 BC, WA (3) END 0443; SECOND NIGHT: 0040: NM, AZ, LA, NC, TN, AL, KY, OH, NE, KS, IN, SD, CO, OK, PA, WV, GA, MO, SC, VA, FL, AR, TX, SC, UT, MD, MS (139) END 0532; 0547 NM, AZ, UT, MT, ID (17) END 0653**
- **2022: FIRST NIGHT: 0118 CO, NV (3) 0145; SUDDENLY 0200 VA, OH, NE, TN, TX, MD, CO, IN, KY, IA, DC, KS, MO, NM, SD UT, WI, ON, AL, MN, MI, AZ, IL, AR, NJ, GA, LA, NV, MS (182) END 0535; SECOND NIGHT: NO USA Qs OUTSIDE CA**
- **2023 : FIRST NIGHT: 0000 FL, NC, SC, GA, TN (14) END 0009; 0047 AZ, NV, WA, OR (7) END 0135; SECOND NIGHT: 0056 UT, TX, OR (3) END 0107**
- **2024: FIRST NIGHT: 0005 FL (4) END 0013; SECOND NIGHT: NO QSOs OUTSIDE CA**
- **2025: FIRST NIGHT: 0000 LA, OK MO, PA, TX, AR, GA, ME, TN, KS, SC, AL, NH, IL, OH, ON, MD, MA, NY, WV, VA, MS, NJ, NC, FL (79) END 0035; SECOND NIGHT: NO QSOs OUTSIDE CA**
- **SFI: 2011 140; 2012 104; 2013 176; 2015 108; 2016 73; 2017 72; 2018 71; 2019 71; 2020 82; 2021 77; 2022 142; 2023 127; 2024 172; 2025 168**

CHORDAL HOP PROPAGATION



- **IONOSPHERIC PROPAGATION CAN OCCUR WITHOUT SURFACE REFLECTIONS. SIGNALS TRAVEL IN MULTIPLE REFRACTIONS WITHIN THE IONOSPHERE BEFORE RETURNING TO EARTH.**
- **THIS PROPAGATION MODE IS CALLED *CHORDAL HOP PROPAGATION*.**
- **CHORDAL HOP PROPAGATION IS A PROPAGATION MODE INVOLVING THE DAYLIGHT F2 LAYER AND NIGHT-TIME F LAYER.**

HOW DOES CHORDAL HOP PROPAGATION OCCUR?

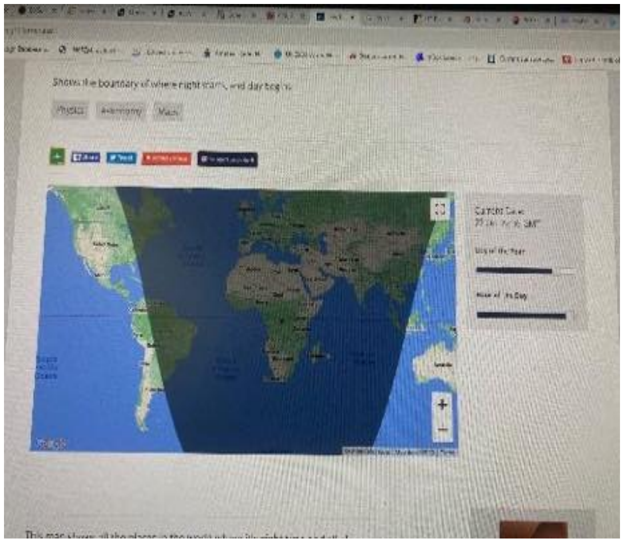
DAY: The daylight-side ionosphere maintains a stronger refractive effect with its dense population of ions. The radio wave refractive angle is steeper sending the signal to the earth.

NIGHT: The refracting strength of the ionosphere on the night side of earth bends signals at a shallow angle that can allows multiple skips without returning to earth.

The daylight ionosphere bends the signals more steeply, returning them to the surface.

The next slide illustrates this idea

CHORDAL HOP PROPAGATION AKA LONG PATH

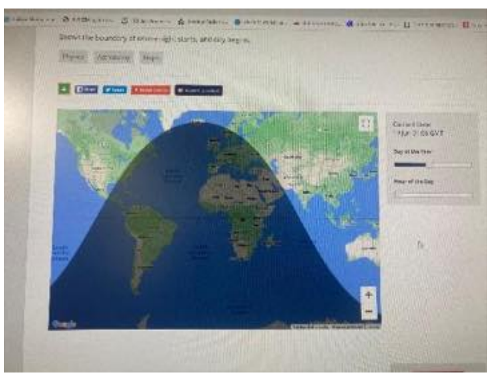


AN EXAMPLE OF LONG PATH/CHORDAL PROPAGATION DURING THE CQ WW SSB CONTEST:

ABOUT 2230z: BEAMING AT ABOUT 90 DEGREES OVER AFRICA ON 20 METERS.

IN THE IMAGE TO THE LEFT, THE SIGNAL TRAVELS IN DAYLIGHT VIA EARTH HOPS THEN TO THE NIGHT TIME IONOSPHERE WHERE IT TAKES CHORDAL HOPS TO THE DAY LIGHT OVER VK6 DROPPING TO THE GROUND FOR A ZONE 29 QSO. IF YOU BEAM ALONG THE TERMINATOR THE SIGNAL GOES AWAY

GREY LINE PROPAGATION

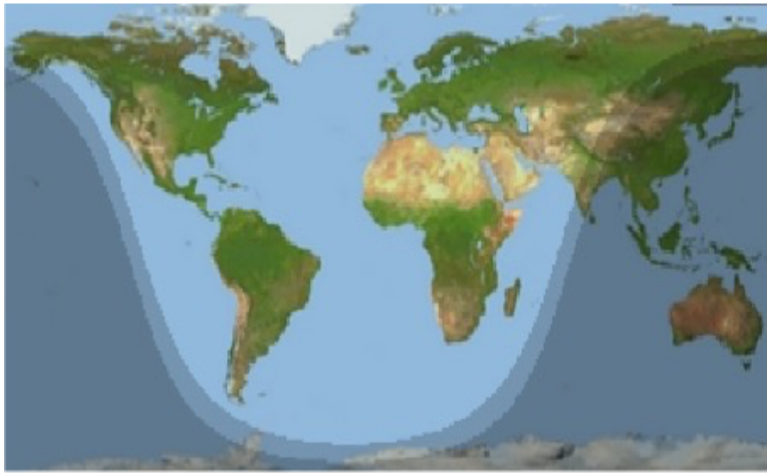


Grey line propagation (the term was coined in 1975) – propagation that occurs along a line separating night from day called the terminator.

The shape of the terminator curve changes with the seasons.

Equinox (TOP IMAGE) compared to the terminator curve from a solstice (BOTTOM IMAGE JUNE).

GREY LINE PROPAGATION



In radio terms, the radio terminator is not the same as the visual one.

It is no good looking for grey line DX exactly at your visual sunrise/sunset.

Radio sunrise/sunset refers to the way the sun illuminates the ionospheric D, E and F layers.

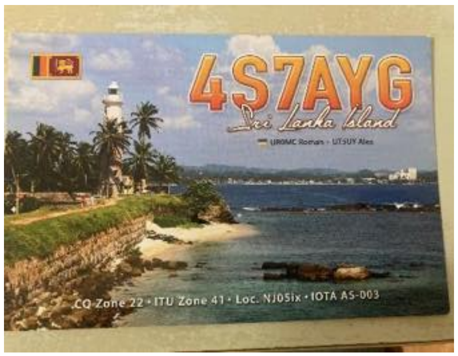
GREY LINE PROPAGATION

- **HOW IT WORKS**
- **The day end of the path has been illuminated all day.**
- **The night end of the path has been in darkness all night.**
- **As the terminator approaches the night end of the path, the F region on the sunrise end starts getting illuminated and thus the MUF starts building. MUF is still high on the sunset side of the earth.**

HOW IT WORKS CONTINUED

- **The D region has not yet formed on the sunrise side, and is rapidly dissipating on the sunset side. This results in low absorption along the terminator.**
- **The net result is for a period stations can communicate along the grey line zone.**
- **40-meters is the premier low-frequency band**, with **grey line openings** to the middle east, Europe and central Asia from **October through March**. 40-meter propagation **does not peak** to the west before sunrise but **about 30 minutes after sunrise.**

EXAMPLE OF GREY LINE PROPAGATION

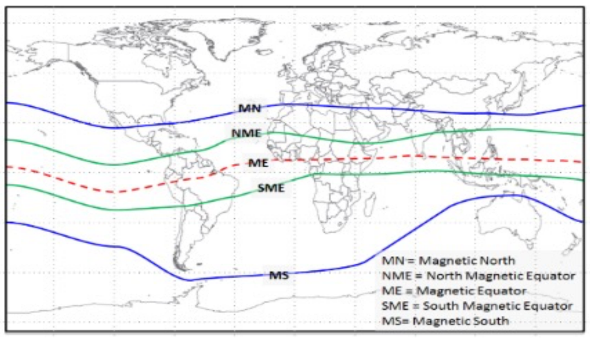


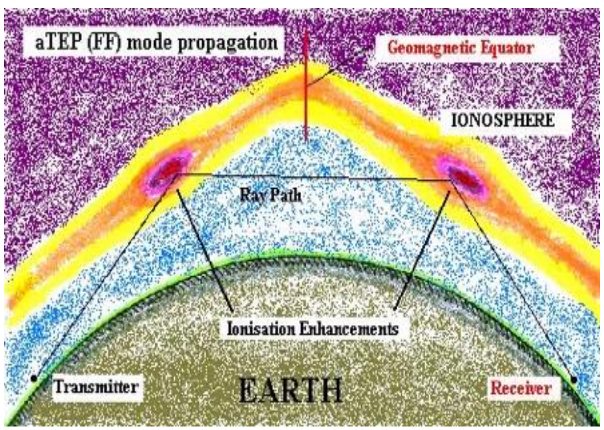
A GREY LINE QSO: A SKED WAS MADE WITH 4S7AYG BEFORE THE CQ WW SSB CONTEST FOR 40m....BEAMING AT 150 DEGREES ALONG THE TERMINTOR. Sunset was 0110z; QSO was at 0051z The window lasted <30 mins, the 4S7 signal was a real 58 and went to inaudible in a short time.

SKEWED PATH (EQUATORIAL ENHANCEMENT)

- During a **solar event**, you may find your beam was pointed in an unexpected direction. **Not via the true great circle path, but rather along a skewed path on headings between 60 and 80 (Europe) or 240 (JA).**
- It is possible to work Europe or Japan via a skewed path. **When you beam direct path to Europe the band noise disappears, almost silent.**
- **On each side of the magnetic equator are enhanced nodes of ionization.**

EQUATORIAL ENHANCEMENT





Highly ionized patches appear daily about 15-20 degrees either side of the magnetic equator.

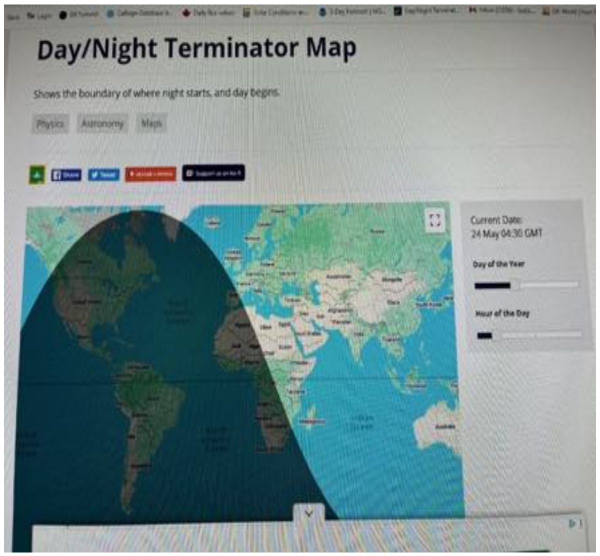
This can significantly skew a signal off one great circle path and onto another great circle path.

By beaming at about 60-70 degrees (Europe), and 260 to Japan your signal can bounce off the enhanced equatorial ionization and **reflect via F2 propagation to Europe or Japan.**

Finally, What makes radio propagation so interesting is the unexpected. I am sure you have your own examples. Here are two recent examples I remember.

- **It's the unexpected that you remember.**

What makes radio propagation so interesting is the unexpected.



During the 2025 CW WPX, ten meters died about 8 pm except to Oceania. At 0430z beaming 220 degrees, suddenly, QSO: 28026 CW 2025-05-24 0427 NR6O 599 0157 4Z5ML 599 0045; QSO: 28011 CW 2025-05-25 0433 NR6O 599 0397 9A1A 599 0386; QSO: 28003 CW 2025-05-25 0435 NR6O 599 0398 LZ4TX 599 0384; QSO:28030 CW 2025-05-25 0439 NR6O 599 0399 YT1X 599 0500. It was over: 0427-0440! Local sunset 7:54 PM (11 Euros worked in whole contest)

Here is the terminator at that time (to the left)

ANOTHER PROPAGATION ANECDOTE: ONE WAY SKIP

- To make a QSO, the ionosphere has to support every hop in both directions at the frequency you are using. Here is a real example of one-way skip. An experience on 10 proves it can happen. **Having trouble working any JA**, **I beamed both 305 and 240 at the same time hoping for an answer**. Finally, a VK called me saying I had a huge pileup of JAs calling me. I heard not a peep. The VK said JA6GCE was calling with big antennas…. Nothing. My signal was making it but their signals somehow were not. Each hop has to support 28 MHz From the JA side a hop didn't make it to me.
  These are the things you remember.

USEFUL PROPAGATION TOOLS

USEFUL REAL TIME PROPAGATION TOOLS

- **REMOTE BEACON NETWORK (RBN)**
- **An explanation of how it works**
- **https://www.reversebeacon.net/pages/How+to+get+spotted+by+the+RBN+44**
- **THE TERMINATOR https://academo.org/demos/day-night-terminator/**
- **REAL TIME MUF DATA https://prop.kc2g.com/**
- **PSK REPORTER https://pskreporter.info/pskmap.html**

USEFUL INFORMATION

- **SOLAR CONDITIONS & HAM RADIO PROPAGATION https://solar.w5mmw.net/**
- **DAILY SFI VALUES OVER THE YEARS**
- **https://spaceweather.gc.ca/forecast-prevision/solar-solaire/solarflux/sx-5-flux-en.php?year=2026**
- **DX SUMMIT VOCAP PREDICTONS**
- **DXHEAT.COM**

Acknowledgments

- Australian Space Weather https://www.sws.bom.gov.au/Category/Educational/Other%20Topics/Radio%20Communication/Intro%20to%20HF%20Radio.pdf
- Stu Turner, WØSTU : https://www.hamradioschool.com/articles/d-layer-absorption.html
- The New Shortwave Propagation Handbook: W3ASK, N4XX and K6GKU
- https://www.qsl.net/4x4xm/HF-Propagation.htm#Seasonal
- Various public internet sources

THANK YOU!

YOU CAN REFER TO THE APPENDIX FOR A LITTLE MORE INFORMATION

APPENDIX: A LITTLE MORE INFORMATION

MORE INFORMATION ABOUT THE D-LAYER AND F-LAYER

- THE TWO LAYERS MOST IMPORTANT FOR COMMUNICATION ON A DAILY BASIS ARE THE D AND F-LAYERS.
- FIRST A LITTLE MORE HISTORY ABOUT HOW THE EMR WE USE EVERYDAY CAME ABOUT

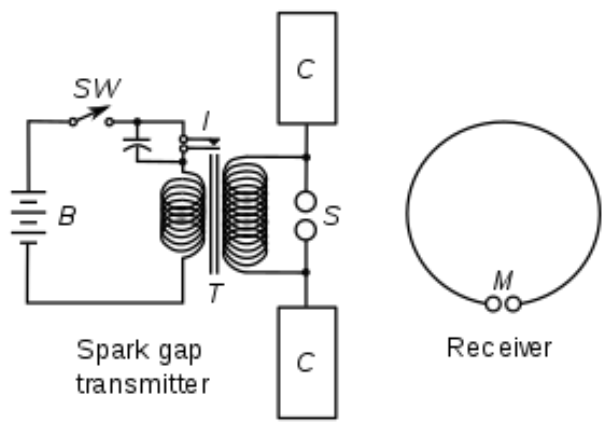
THE ORSTED-FARADAY-MAXWELL-HERTZ-TESLA-HEAVISIDE CONNECTION THEN THINGS REALLY TOOK OFF

- **The men who discovered the properties of EMR were true experimenters. Almost none thought about the commercial application of EMR. It was Marconi's clever skill to take the ideas of others and make commercial use of EMR**
- **The Invention of Radio as we know it.** Like most significant inventions, radio had not just one "father," but many. British mathematician **James Clerk Maxwell** first proved the existence of radio waves mathematically in **1864**. The German physicist **Hertz** set out to prove Maxwell's equations and did so in **1885**. After that, lots of others jumped into the fray.

THE ORSTED-FARADAY-MAXWELL-HERTZ-TESLA + HEAVISIDE CONNECTION then things really took off

- **1819: HANS CHRISTIAN ORSTED**
- Discovered that **electric currents create magnetic fields**, which was the first connection found between electricity and magnetism. .
- **1831: MICHAEL FARADAY**
- His demonstrations established that a **changing magnetic field produces an electric field.**
- **1861: JAMES CLERK MAXWELL**
- Took Faraday's findings and **showed equations predicting the existence of waves of oscillating electric and magnetic fields that travel through empty space at a speed equal to light**.

THE ORSTED-FARADAY-MAXWELL-HERTZ-TESLA + HEAVISIDE CONNECTION then things really took off



1887: HERTZ PROVED MAXWELL'S THEORY.

AFTER ALL THE THEORY, A TX AND RX WERE INVOLVED FOR THE FIRST TRANSMISSION OF "HERTZIAN WAVES" = RADIO WAVES.

THE ORSTED-FARADAY-MAXWELL-HERTZ-TESLA + HEAVISIDE CONNECTION then things really took off

- **1895: NIKOLA TESLA:** It was **Tesla who created the first actual radio design.**
- **1902: Oliver Heaviside advanced the idea that the Earth's uppermost atmosphere contained an ionized layer now known as the ionosphere**.
- **He patented, in England, the coaxial cable**.

TWO LAYERS ARE MOST IMPORTANT TO CONTESTING

- THE D-LAYER
- THE F-LAYERS

- FIRST THE D-LAYER

THE D-LAYER: DAYLIGHT

- Because of its relatively low altitude, **the density of atmospheric gases in the D-layer is much greater** than gas density in the higher E and F layers. This fact increases the probability in the D-layer of an accelerated free electron encountering other particles in collision or recombination than in the higher altitude ionospheric layers.

- D layer RF energy absorption increases as frequency is lowered. While the 20-meter band and higher frequencies are not significantly attenuated by D layer energy absorption due to their smaller wavelengths, absorption at lower frequencies is usually too severe for long distance contacts during the daylight presence of the D layer.

THE D-LAYER

- The D-layer only affects EMR during daylight hours.
- The D-layer **does not reflect HF radio waves**. It has three general effects:
- It attenuates EMR (some heat)
- It absorbs EMR (heat)
- It disappears at night
- The D-layer is the lowest and densest layer of the ionosphere, but it has a relatively low concentration of free electrons. To reflect a radio wave back to Earth, a layer requires a specific electron density. The higher the frequency of the radio wave, the more-free electrons are required to bend it.
- How does the D-layer effect propagation on 160-40 meters?

Next slide

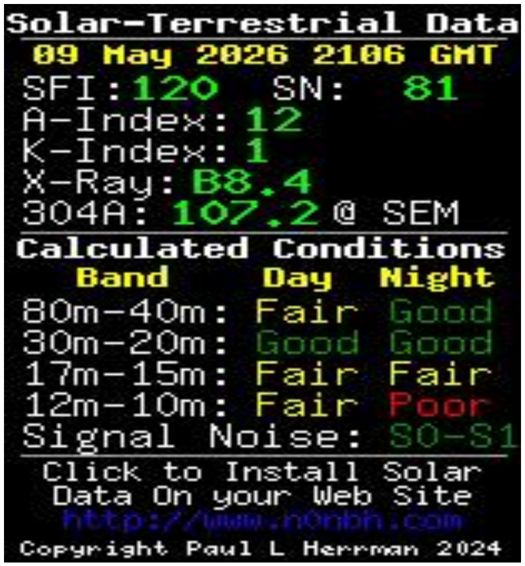
LOWER FREQUENCIES ARE ABSORBED MORE READILY BY THE D-LAYER

- The **greater the density and life of free electrons**, the higher the frequencies that can be reflected.
- As a radio wave travels through the ionosphere it causes the free electrons in the layer to be moved a distance that is commensurate with the **size of the wavelength.** A **lower frequency (160-30 meters)** has a **longer wavelength** and will displace an electron a greater distance during waveform travel than will a higher frequency signal. This means the electric field of a longer wave has a longer **period** of time to act upon the electron and accelerate it as the wave passes by at the constant speed of light..
- **These longer travel distances increases the probability that another particle will be encountered as the electron accelerates**. Thus, **low frequency signals** lose much energy to colliding electrons and recombining atoms because the electrons must travel a great distance through a **high-density population of D layer particles**, and **the probability of surviving as a free electron is very low.** Free electrons in the **D layer** of the ionosphere have a very short lifetime, lasting only a **small fraction of a second**.
- The D layer *does* absorb higher frequency signals somewhat, but not nearly as much as it absorbs the lower frequencies. **The amount of the absorption is a function of wavelength and time of year. Winter means a colder, lower and denser ionosphere; summer means a hotter, higher and with sparser free electrons.**
-

WHAT DOES THE D-LAYER REFLECT?

- For EMR with very long wavelengths (like **Extremely Low Frequency and Very Low Frequency waves**), the D-layer acts like a shiny metallic mirror. These waves are efficiently reflected, allowing them to bounce between the D-layer and the Earth's surface to travel quite a distance.
- **ELF and VLF Waves**: Extremely Low Frequency (**ELF, 3–300 Hz**) and Very Low Frequency (VLF, **3–30 kHz**) signals are reliably reflected by the D-layer during the day. The space between the Earth's surface and the D-layer forms a natural "waveguide" that bounces these waves around the globe.
- **MF (Medium Frequency)**: Standard AM radio waves (**around 530–1700 kHz**) experience slight reflection at steep angles, but daytime propagation is highly limited

YOU KNOW WHAT SFI, K AND A MEAN. WHAT ABOUT X-RAY EFFECT ON THE D-LAYER?



X-Ray: This is the number of X-Rays penetrating the lower atmosphere and **how much it is affecting the D layer absorption.** Lower letters and numbers are better. The letter A means minimal effects on the D layer. The letter B slightly more, Letter C about average. **Letters M & X mean lots of Absorption so DX conditions are not optimal no matter what the SFI says**. Signals cannot pass through the D-layer of the atmosphere and therefore cannot bounce off the upper layers. **That means no dx on any band**.

CRITICAL FREQUENCY (CF), MUF AND OPTIMUM WORKING FREQUECY (OWF)

- Each ionospheric layer has a maximum frequency, known as the "critical frequency. The **Critical Frequency** or CF is the highest frequency below which a radio wave is refracted by the F2, F1 and E-layers back to earth at **vertical incidence**, independent of transmitting power. **Each layer has its own CF.**
- **Maximum Usable Frequency (MUF):** The highest frequency at which 50% of communications are successful. **The MUF is about 3-4 times the CF.**
- Increased solar activity raises the MUF, peaking at noon and in summer.
- The degree of bending (refraction) decreases as frequency increases. High-frequency waves must travel higher, to the F2-region, to find sufficient electron density at that frequency to be refracted back to Earth.
- The Optimum Working Frequency or OWF is the **most reliable operating frequency for ionospheric radio communication between two points, typically chosen to be roughly 85% (or 80-90%) of the Maximum Usable Frequency (MUF).** It ensures the highest probability of success, typically working 90% of the days in a month by avoiding, ionospheric absorption, and high MUF variability. It is the most effective frequency for a given path and time.

F-LAYERS

- THE F2 LAYER IS THE MAIN LAYER RESPONSIBLE FOR LONG DISTANCE COMMUNICATION.
- During the day there are two upper layers in the ionosphere, the F1-layer and the F2-layer. **Shortly after sunset these two layers merge into the F layer and split up again into F1 and F2 layer at sunrise. The F1 layer is greatly reduced after sunset due to rapid recombination rate. Free electron life in the F1-layer ~ 1 minute.**

F-LAYER

- **The Atmospheric Composition Change**
- F2 layer actually exhibits **lower free electron densities in the summer than in the winter**, a phenomenon known as the **Seasonal Anomaly**.
- **During the summer s**trong solar heating alters the chemical mix of the thermosphere**, increasing the ratio of molecular gases (like N2 and O2 relative to atomic oxygen O**
- Because free electrons recombine with molecular ions thousands of times faster than they do with atomic ions, the heightened presence of molecular gases in summer accelerates free electron loss. **This lowers the overall peak free electron density during summer days.**

Why the F Layer Splits during the day

The daytime split of the F layer into the F1 and F2 layers is caused by the differing rates of electron production and recombination at various altitudes, combined with thermal expansion.

The F region is primarily ionized by solar Extreme Ultraviolet (EUV) radiation. During the day, intense solar heating expands the upper atmosphere.

This creates two distinct zones governed by different chemical and physical behaviors:

- **F1 Layer (Lower Region, ~150–220 km): In this region, atmospheric density is relatively high. When solar EUV radiation hits gases, it produces free electrons rapidly, but they quickly recombine with parent molecules ~ LIFE TIME 1 MINUTE.**

THE DAY AND NIGHT F LAYER

- **F2 Layer (Upper Region, ~220–800 km): Here, the atmosphere is incredibly thin. While the actual production rate of free electrons drops due to a lack of neutral atoms, the loss rate of free electrons drops drastically: ~ LIFE TIME 20 MINUTES.**
- **Because the air is too sparse for quick recombination, free electrons accumulate and linger in the F2 layer, creating the highest overall peak of electron density in the entire ionosphere.**
- **At night, without the sun's driving radiation, the temporary F1 layer vanishes as its free electrons quickly recombine. The F2 layer survives through the night because its sparse environment prevents rapid recombination, causing the two zones to merge into a single F layer**

SEASONAL ANOMALY

- While summer daytime ionospheres are highly ionized by intense, direct sunlight, this actually causes a phenomenon called the "Seasonal Anomaly".
- The F2-layer expands to a higher altitude, which causes a decrease in peak free electron density despite the increased solar radiation. While the total number of electrons integrated over your entire low-angle path may be higher, the decreased density can sometimes reduce the Maximum Usable Frequency (MUF) compared to winter.

F-LAYER

- The summer F-layer **reduces long-distance daytime HF propagation** while significantly **extending late-night DX opportunities**.
- **The Daytime "Summer Slump“ Lower MUFs:** The Maximum Usable Frequency (MUF) drops significantly during summer days **due to the Seasonal Anomaly**.
- **Midnight DX Slow Recombination:** The thermosphere remains warm at night during summer, causing the F-layer to lose its ionization very slowly.
- **Nighttime Openings: Bands like 20 meters often stay open long past midnight, or even a full 24 hours, allowing for excellent late-night DX.**

28 MHZ DURING THE SUMMER

- **The D and F-Layers Affects 28 MHz More in Summer**
- While absorption hits lower frequencies hardest, 28 MHz is still low enough to experience significant signal loss (attenuation) **if the D-layer is highly charged**.
- Ultimately, 28 MHz gets squeezed in the summer: the F2 layer is too weak to reflect it, and the hyper-ionized D-layer absorbs more of the signal energy.
- 10 is very poor during the summer

21 MHZ DURING THE SUMMER

- In the summer, the **D-layer of the ionosphere affects the 21 MHz by causing increased signal absorption and lifting the Lowest Usable Frequency (LUF)**.
- While the 21 MHz band is traditionally a daytime band that relies on a strongly ionized F-layer to bounce long-distance signals, the unique atmospheric conditions of summer dramatically alter how the D-layer interacts with a 21 MHz radio wave.
- Free electron collisions convert some of the radio wave's RF energy into **heat**, **absorbing some of the signal** rather than letting it pass through cleanly to the higher F-layer for reflection

21 MHZ DURING THE SUMMER

- Radio propagation is bounded by a window between the Maximum Usable Frequency (MUF) and the Lowest Usable Frequency (LUF).
- In the winter, 21 MHz is safely above the LUF and passes through the thin winter D-layer with ease.
- In the summer, the D-layer becomes so hyper-ionized that the LUF rises significantly. It creeps up close to or even above 21 MHz, severely attenuating signals on the 15-meter band and causing what hams often call the **"summer doldrums."**

14 MHZ SUMMER DAY

- In the summer, the sun is higher in the sky and daylight hours are longer, causing the Earth's D-layer to absorb more solar radiation. This increased ionization severely attenuates lower frequencies; while 14 MHz generally punches through, **it still experiences noticeable daytime signal loss (absorption) and a shortened maximum usable distance.**
- The 14 MHz band is high enough to typically survive complete absorption, but it does suffer from weakened signal strengths and "high noise" during daylight.
- Simultaneously, solar heating causes the upper F2-layer to expand and thin out. **This lowers the Maximum Usable Frequency (MUF). With the MUF dropping from above and the LUF rising from below due to the D-layer, the usable radio window for 14 MHz is compressed from both sides**

A CLARIFICATION

Long-path propagation is not the same as **Terminator propagation** (often called **Gray-line propagation**) although they can overlap and share similarities.

- They are entirely different concepts in radio propagation, though they often work together to produce strong long-distance signals.
- **Long Path:** Refers to a directional heading. It is the route around the globe that is the opposite of the direct, "short path" (i.e., pointing your antenna 180 degrees away from the shortest great-circle distance).
- **Chordal Hop:** Refers to a physical propagation mechanism. It happens when a radio wave bounces between layers in the ionosphere without ever touching the Earth's surface in between.
- **Long-distance "long path" communications frequently rely on "chordal hop" propagation** because Earth surface bounces are highly absorptive and cause significant signal loss. By skipping from the ionosphere to the ionosphere (a "chord"), the signal preserves its strength over thousands of kilometers.