Outline

How the sun affects the ionosphere
   Structure of the ionosphere
   The solar spectrum

Solar cycle progress
   Signs of life of the next solar cycle

Radio wave generation and skywave HF propagation

Anatomy of a space weather event and its effects on propagation

Not talking about VHF/UHF, aurora scatter, meteor scatter, sporadic E, or tropospheric propagation
The ionosphere consists of layers which change from day to night.
Electromagnetic Spectrum

X-rays
Bad

EUV
Good

F_{10.7}
Proxy for EUV

Zoom in for next slide

UV and X-rays are stronger during solar maximum.
Where are we in the solar cycle?
The sun is the driver of ionospheric density. It follows an 11 year cycle, on average.
Comparison of sunspot number and solar radio flux

https://www.nasa.gov/msfcsolar
Dominion Radio Astrophysical Observatory
Penticton B.C. Solar Flux Monitoring

$F_{10.7}$
Solar Flux Index (SFI)
Solar Flux Units (SFU)

10.7 cm wavelength
2800 MHz
https://www.nasa.gov/msfc/solar
Solar Cycle 25 Preliminary Forecast

Sunspots are a result of solar magnetic fields
Zeeman Splitting

Transitions

No Magnetic Field

Magnetic Field

http://www.pas.rochester.edu/~bla ckman/ast104/zeeman-split.html


No magnetic field

Longitudinal magnetic field

Transverse mag. field

Mercury spectral lines
Good news for Cycle 25

So far in 2020 a dozen sunspots have been observed

• 75% have the right magnetic polarity to be from Cycle 25
• Only 17% of sunspots in 2019 had this polarity
• In 2018 0% were from Cycle 25

Source [https://spaceweather.com/](https://spaceweather.com/) 15 July 2020

An M1-class solar flare on May 29, 2020—the strongest flare in three years. Credit: NASA/SDO
Solar cycle 25 is showing signs of life

We don’t know exactly when or how strong the next cycle will be but the peak should be between 2023 and 2027 and may be about the same strength as cycle 24

A few spots from the new cycle have been seen
Radio wave generation and ionospheric propagation – a simple mental model

Shake an electron and you get electromagnetic waves

Expose an electron to electromagnetic waves and it shakes, making more waves
    Called a Hertzian dipole

Solar UV and X-rays knock electrons off the neutral atoms and molecules

Free electrons in the ionosphere get shaken by your RF and emit some more RF

The density of the electrons, the density of neutrals around them, and the magnetic field all affect the way they move and emit RF
A game of Xs and Os

• But the ionosphere is in the Earth’s magnetic field and electron motion is affected by magnetic fields
• This is called birefringence and causes waves of different polarization to propagate differently
• The most important effect is that your linearly polarized signal becomes split into right and left hand circularly polarized waves which propagate differently
  • Ordinary wave is stronger and refracts lower - O
  • Extraordinary wave is weaker and travels higher and farther - X
• What arrives at the other end is elliptically polarized - a combination of the two
• This is NOT Faraday rotation (which results in linearly polarized signal)
• This is all described nicely in Eric Nichols’ KL7AJ QST article in Dec. 2010 and his book Radio Science and Propagation
HF skywave propagation is by refraction not reflection – but it can be approximated by reflection from a virtual height.
Why are some parts of the ionosphere helpful and others are not?

F-layer
- long-range skip
- higher with fewer neutral atoms for the free electrons to interact with
- created by UV from the sun

D-layer
- absorbs lower frequencies
- deeper in the atmosphere where there are more neutral atoms to collide with
- created by X-rays from the sun
Multiple hops give longer DX paths

Figure 19.17 — Multihop paths can take many different configurations, including a mixture of E and F layer hops. (A) Two F layer hops. Five or more consecutive F layer hops are possible. (B) An E layer hook up to the F layer. (C) A top-side E layer reflection can shorten the distance of two F layer hops. (D) Refraction in the E layer above the MUF is insufficient to return the signal to Earth, but it can go on to be refracted in the F layer. (E) The Pedersen Ray, which originates from a signal launched at a relatively high angle above the horizon into the E or F region, may result in a single-hop path, 5000 km (3100 miles) or more. This is considerably further than the normal 4000 km (2500 mile) maximum F-region single-hop distance, where the signal is launched at a very low takeoff angle. The Pedersen Ray can easily be disrupted by any sort of ionospheric gradient or irregularity. Not shown in this figure is a chordal hop — since chordal hops are most prevalent in the equatorial ionosphere, refer to Figure 19.21 and Figure 19.22.
So how come I can work Brazil on 10m at solar minimum? Transequatorial propagation and the Appleton Anomaly

- The equatorial fountain effect enhances F layer density on either side of the equator
- It peaks between 5 and 10 pm
- Less likely in summer
The magnetic equator doesn’t follow the geographic equator
Not your grandpa’s gray line propagation

- We were taught that gray line propagation occurs along the terminator (the line of twilight) due to reduced D and E layer absorption with higher F layer density.
- However, the real story is more complicated than that involving magnetic field effects which skew RF away from day side into the night side.
- See Bruce AC4G’s presentation to NADXC for a thorough explanation with examples.

ARRL Handbook 2018
Backscatter allows you work somebody too close for normal F layer communications

- An example is working Atlanta on 20m
- You both have to have a path to some scatter point
Space weather forecasts and propagation predictions and nowcasts are available

Space weather information
  • NOAA site
    https://www.swpc.noaa.gov/

VOACAP (based on IONCAP)
  • Included with RMSEExpress
  • On-line version voacap.com
  • Example on next slide

ASAPS – Advanced Stand-Alone Prediction System (from VK land)

W6ELProp

Who is hearing whom?
  • DXSummit.fi
    • Click on a call and select VOACAP predictions
  • PSKReporter
  • WSPRNet
Propagation Summary

HF radiation is refracted by the ionosphere to support over-the-horizon communications

Solar ultraviolet radiation forms the F layer which supports long-distance communications
  20m and the higher “daylight” bands provide long distance communications during solar maximum

Solar X-ray radiation forms the D layer which absorbs 80m and below during the day
  X-ray flares can enhance the D layer so much that even the higher “daylight” bands can be shut down
Approximate propagation – day vs night for 3 primary bands

- Good all night at solar max
- Closes early at solar min
- Higher bands are better at solar max

- X-rays
- EUV
Other bad things from the Sun

Highly energetic charged particles
- Protons from solar particle events
- Cause polar cap absorption (PCA) – bad for high-latitude HF propagation

Less energetic charged particles
- Solar wind – carries magnetic field and can disturb Earth’s magnetic field
- Causes geomagnetic storms
  - Makes aurora – sometimes good for VHF
  - Disturbs high-latitude HF propagation
  - Geomagnetic indices are Ap and Kp – high is bad for HF
GOES-15 Summary: 2017-09-01

- X-rays 1-min: XL(0.1-0.8 nm), XS(0.05-0.4 nm)
- EPEAD Protons 5-min: pB(>1 MeV)c, pB(>5 MeV)c, pB(>10 MeV)c, pB(>30 MeV)c, pB(>100 MeV)c

Key dates and times:
- 9/4 0 UT
- 9/6 7 UT
- 9/6 12 UT
D-region absorption model

https://www.swpc.noaa.gov/
GOES-15 Summary : 2017-09-01

X-rays 1-min: XL(0.1-0.8 nm), XS(0.05-0.4 nm)

EPEAD Protons 5-min: pB(>1 MeV)c, pB(>5 MeV)c, pB(>10 MeV)c, pB(>30 MeV)c, pB

9/6 7 UT
Polar Cap Absorption caused by energetic protons
D-region absorption caused by X-ray ionization
Space Weather Summary

• Near solar minimum the extreme ultraviolet emissions are lower so the ionosphere is less dense
  • The F-layer doesn’t support higher frequency propagation as well

• Fewer X-rays mean less D-layer absorption
  • Even at solar minimum there can be X-ray flares which ionize the D-layer causing absorption of HF especially at lower frequencies

• There can also be solar proton events which cause degradation of polar paths

• At solar maximum higher band HF propagation is generally much better but the risk of X-ray flares, which cause D-layer absorption, is greater
Backup
Another way to look at frequency-dependence of the paths

**Critical frequency**
Frequency at which a vertical signal is returned

**MUF** – maximum usable frequency
Higher for higher F layer density

**LUF** – lowest usable frequency
Driven by D-layer absorption

Figure 19.8 — The relationships between critical frequency, maximum usable frequency (MUF) and skip zone can be visualized in this simplified, hypothetical case. The critical frequency is 7 MHz, allowing frequencies below this to be used for short-distance ionospheric communication by stations in the vicinity of point M. These stations cannot communicate by the Ionosphere at 14 MHz. Stations at points B and E (and beyond) can communicate because signals at this frequency are refracted back to Earth because they encounter the Ionosphere at an oblique angle of incidence. At greater distances, higher frequencies can be used because the MUF is higher at the larger angles of incidence (low launch angles). In this figure, the MUF for the path between points A and F, with a small launch angle, is shown to be 28 MHz. Each pair of stations can communicate at frequencies at or below the MUF of the path between them, but not below the LUF — see text.
Ionosphere and HF propagation

D layer is region of absorption of lower bands

F layer is region of long-range skip

7/22/2020

Rob Suggs KB5EZ  NASA MSFC Amateur Radio Club
Include audio of digisonde....

One of 4 magnetic crossed dipoles

http://www.digisonde.com/instrument-description.html

300w
DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS

SUNSPOT AREA IN EQUAL AREA LATITUDE STRIPS (% OF STRIP AREA)

AVERAGE DAILY SUNSPOT AREA (% OF VISIBLE HEMISPHERE)

http://solarscience.msfc.nasa.gov/
Solar Dynamics Observer/Helioseismic Magnetic Imager
Figure 19.13 — Typical electron densities for the various ionospheric regions.
The eclipse “turned off the sun” for a time almost 3 years ago
Will show some KB5EZ and NN4SA transmitted data.

K9AN had a very complete received dataset.

W3PM (local) had nice 160 and 630m data.