Introduction to HF Propagation

Part 1

Rick Fletcher, W7YP

FVARC

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Topics

- The HF Bands
- How HF propagation works
- Overview by HF band
- Sources of solar and propagation information
- Effects of solar weather (Part 2)
- Working HF during poor propagation (Part 2)
- Q&A

HF Bands

- 3-30 MHz
  - 160m band (1.80-2.00 MHz) is sometimes included but is actually a MF band
  - 80m - 3.50-4.00 MHz
  - 60m - 5.3305-5.4069 MHz - Five 2.8 kHz USB channels centered on:
    - 5332 kHz, 5348 kHz, 5358.5 kHz, 5373 kHz and 5405 kHz
  - 40m - 7.00-7.30 MHz
  - 30m - 10.100-10.150 MHz (1979 WARC (World Administrative Radio Conference))
  - 20m - 14.000-14.350 MHz
  - 17m - 18.068-18.168 MHz (1979 WARC)
  - 15m - 21.000-21.450 MHz
  - 12m - 24.890-24.990 MHz (1979 WARC)
  - 10m - 28.000-29.700 MHz

160m Band

- Day – Local to a few hundred miles
- Night – Long distances possible
- Often noisy
- Antennas difficult because of size
    - A half-wavelength dipole centered on 1900 kHz would be 233’ long, assuming uninsulated wire with a velocity factor of 0.9

80m Band

- Day – Local to several hundred miles
- Night – World wide possible
- Often noisy
- Popular band for nets
- Antenna difficult in small lot
  - A half-wavelength dipole centered on 3750 kHz would be 118’ long, assuming uninsulated wire with a velocity factor of 0.9

40m Band

- Day – Local to 1000 miles or more
- Night – World wide possible
- Very reliable band – almost always open somewhere
- Antennas are manageable
  - A half-wavelength dipole centered on 7150 kHz would be 62’ long, assuming uninsulated wire with a velocity factor of 0.9
  - Verticals (33’) with good radial system are effective DX antennas
  - Beams require heavy duty rotor

30m Band

- Day – 1000 miles or more
- Night – World wide possible
- Similar to 40m for antenna requirments
- WARC Band
    - CW and data only
    - 250W maximum

20m Band

- Day – 500 miles to world wide
- Night – World wide possible
- Many consider it the best DX band
- Antennas are very manageable
  - A half-wavelength dipole centered on 14175 kHz would be 31.2’ long, assuming uninsulated wire with a velocity factor of 0.9
  - 17’ vertical with good radial system is excellent for 20m DX
  - Beams (yagis) are common

17m Band

- Day – hundreds of miles to world wide
- Night – open world wide with high sunspot levels
- Antennas
  - A half-wavelength dipole centered on 18118 kHz would be 24.5’ long, assuming uninsulated wire with a velocity factor of 0.9
  - Beams and verticals are very manageable
- WARC (World Administrative Radio Conference) Band
  - Three band plans approved around the world
    - 30m
    - 17m
    - 12m
  - Due to their relatively small bandwidth, it is agreed that these bands will not be used for general contesting

15m Band

- Day – hundreds of miles to world wide
- Night – stays open late with high sun spot levels
- Great DX band in moderate to high sunspot years
- Antennas
  - A half-wavelength dipole centered on 21225 kHz would be 20.9’ long, assuming uninsulated wire with a velocity factor of 0.9
  - Beams and verticals very manageable/portable

12m Band

- Day – Hundreds of miles to world wide
- Night – Open only in high sun spot years
  - Great DX band in those years
- Antennas are very manageable
  - A half-wavelength dipole centered on 24940 kHz would be 17.7’ long, assuming uninsulated wire with a velocity factor of 0.9
  - Beams and verticals are very manageable/portable
- WARC Band

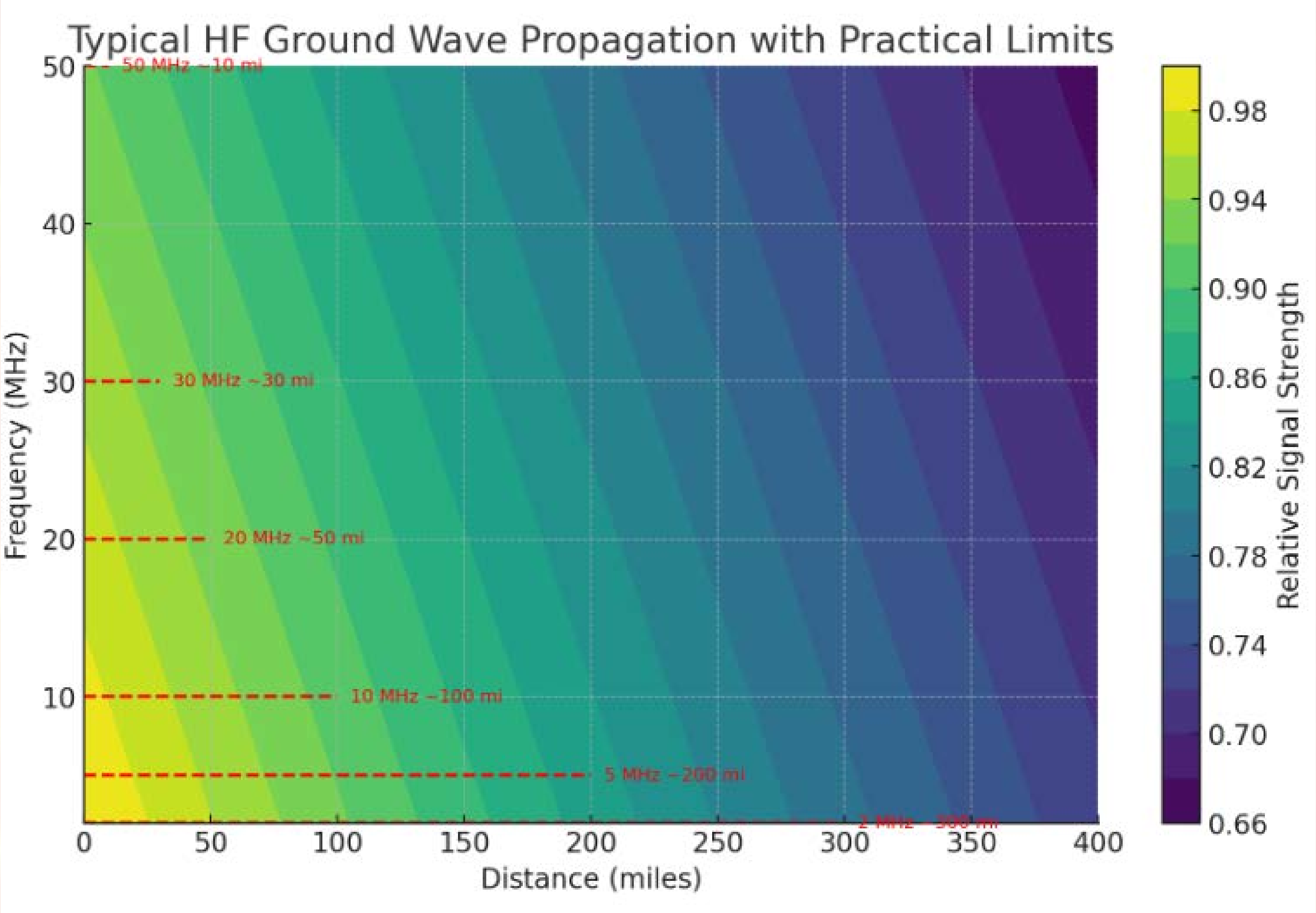
10m Band

- Day – Hundreds of miles to world wide
- Night – open for hours in high sun spot years
- Excellent DX band in high sun spot years
  - Very quiet
  - Modest stations can talk world wide
  - Large bandwidth allocation helps avoid crowding on the band
- Antennas
  - A half-wavelength dipole centered on 28850 kHz would be 15.3’ long, assuming uninsulated wire with a velocity factor of 0.9
  - Beams and verticals are common and very manageable
- Many propagation modes
  - F (with moderate to high sun spot levels)
  - E_s
  - Aurora

How HF Propagation Works – Ground Wave

The portion of the RF Signal which travels close to the ground

- NOT limited by the distance to the horizon
- Frequency dependent:
  - **2 MHz:** up to ~300 mi
  - **5 MHz:** up to ~200 mi
  - **10 MHz:** up to ~100 mi
  - **20 MHz:** up to ~50 mi
  - **30 MHz:** up to ~30 mi
  - **50 MHz:** only ~10 mi



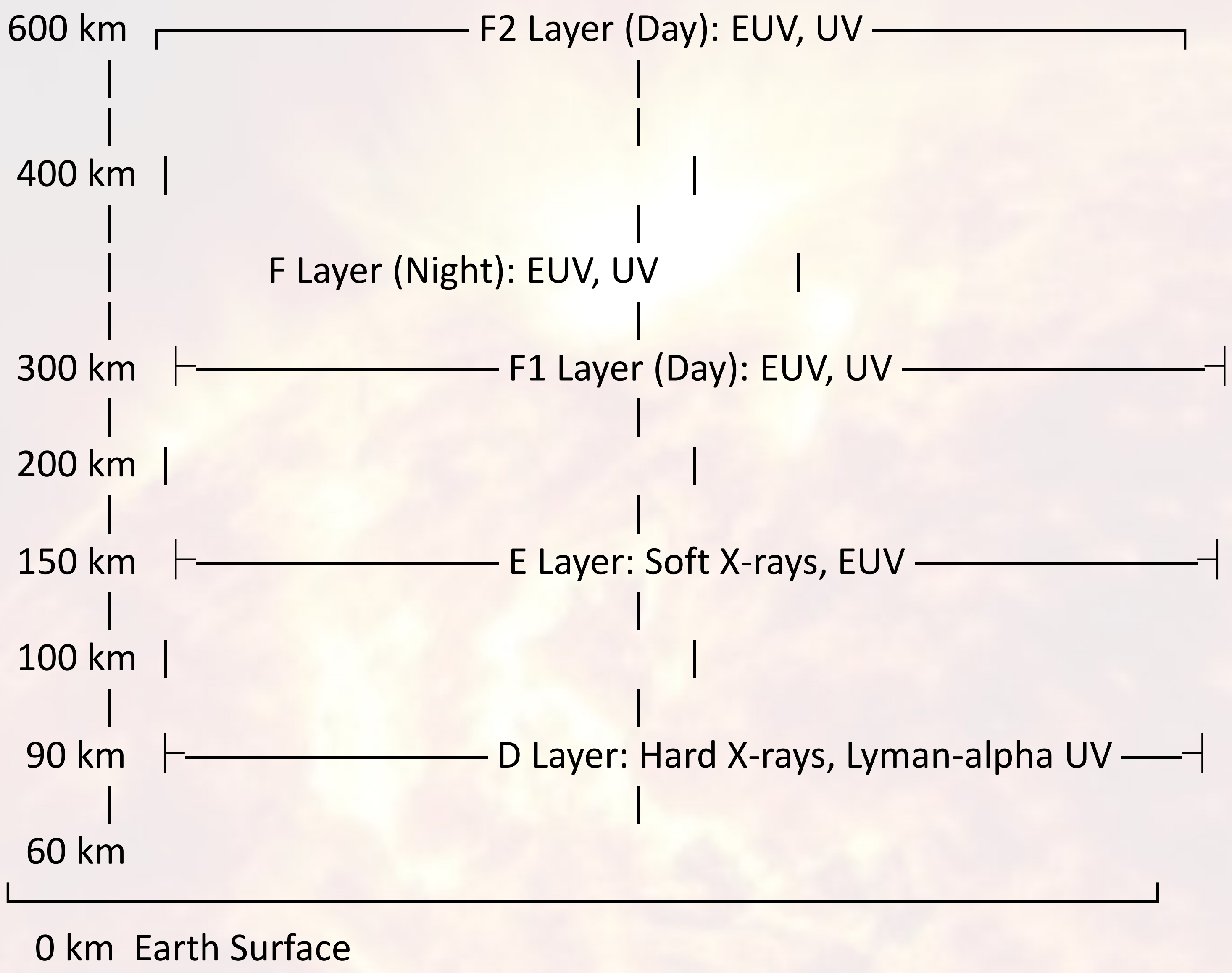
How HF Propagation Works – Ground Wave

- How does the ground wave travel over the horizon?
  - **Diffraction around the Earth's curvature**
    - Radio waves at lower frequencies (especially below ~3–5 MHz) have long wavelengths, which allows them to "bend" or diffract around the surface of the Earth
    - This bending means the wave doesn't stop abruptly at the horizon but instead creeps along the curve of the Earth
  - **Surface (ground) wave conduction**
    - Part of the radio wave couples to the Earth's surface, traveling along it
    - This "creeping" wave loses energy as it interacts with the ground, which is why **soil conductivity and moisture** matter — sea water is excellent, dry rocky terrain is poor
    - That's why maritime HF or MF communications can extend hundreds of miles, while inland ranges are shorter
  - **Attenuation with frequency**
    - Lower frequencies couple to the Earth more effectively and bend better, so they travel farther
    - At higher frequencies (above ~10–15 MHz), the ground absorbs more energy, and the wave doesn't bend as well — so the ground wave fades quickly after the horizon

How HF Propagation Works – Sky Wave

- Signals travel up to the ionosphere, where some of the energy may be reflected back towards the earth
  - Signals reflected back may bounce again back up to the ionosphere
    - This process may repeate itself many times, resulting in the signal's traveling great distances, even completely around the earth ("long path")
- Ionosphere: Region above the upper atmosphere composed of charged particles called "ions"
  - The sun's UV radiation, especially EUV, charges this layer and the level of 'excitement' affects the radio waves and how they travel
  - X-rays from solar flares
  - Solar particles (protons and electrons)
    - Auroral ionization at higher latitudes nearer the poles
  - Cosmic rays modulated by the sun
    - Higher latitudes and altitudes
    - Most obvious during solar minima

The Layers of the Ionosphere:



The D Layer

- Lowest and densest region of the ionosphere
  - Roughly 60-90 km above the earth's surface
  - Forms during the day, peaking at midday
    - "Closes" the low bands via absorption
  - Disappears at night
    - "Opens" the low bands
  - Absorbs lower frequencies
    - The longer the wavelength, the greater the absorption
    - 160m and 80m most affected
    - 40m somewhat affected
    - Absorption is slight or inconsequential on 20m and up

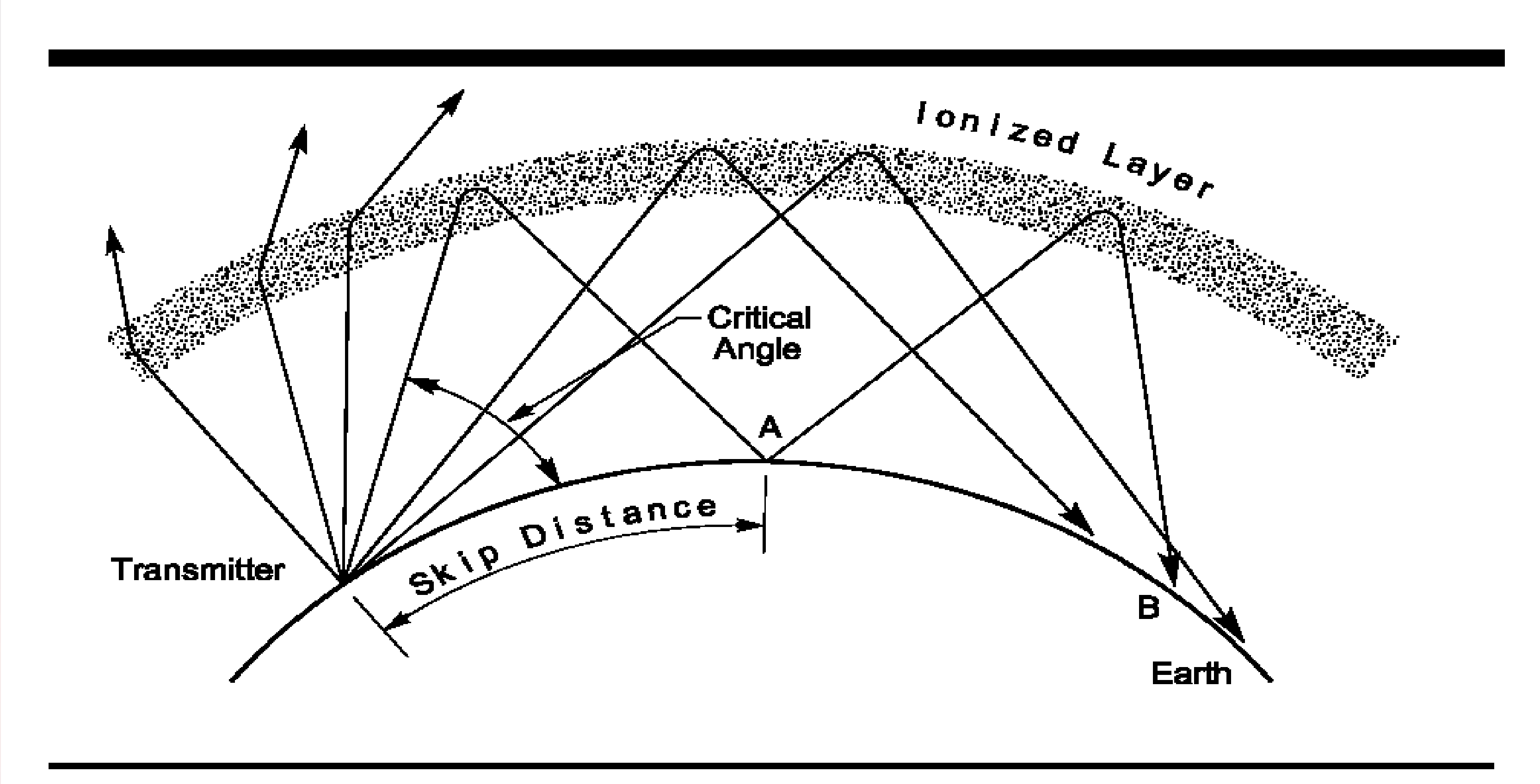
The E Layer

- 90-150 km above the earth
- It is the lowest portion of the ionosphere that is useful for long distance communications
- Ionization occurs rapidly after sunrise
- Ionization diminishes quickly after sunset
  - Normally minimal only a few hours after sunset
- Absorbs long wavelength signals, just like the D layer, during the day
  - Absorption is highest when the sun is at its highest angle (local ‘noon’)
- Also affects bands above 30 MHz

The F Layer

- 150-600 km above the earth
- Responsible for most long-distance HF communication
  - MUF (Maximum Usable Frequency) varies with ionization level
- Much less dense than the lower layers
  - Takes longer to ionize and positively affect radio communication
  - Effects often last longer than in the lower layers
- During higher solar radiation (e.g., summer days), can become two separate layers called F-1 and F-2
  - F1 doesn’t last long after sunset
- Changes with the seasons, as the angle between the sun and the earth changes
  - Bands like 10m and 15m open and stay open longer and 20m may be open all night in the summer, when there’s high solar activity

“Skipping” Signals off the Ionosphere



High Angle Radiation

- NVIS – Near Vertical Incidence Sky-wave
  - Signals that take off at very high angles are reflected straight back to earth
  - Used for close-in communication (e.g., “nets”)
  - Can provide reliable communication with a few hundred mile radius
  - 80m during the day and 40m at night are popular choices
  - Unlike ground wave, NVIS signals are not affected by terrain

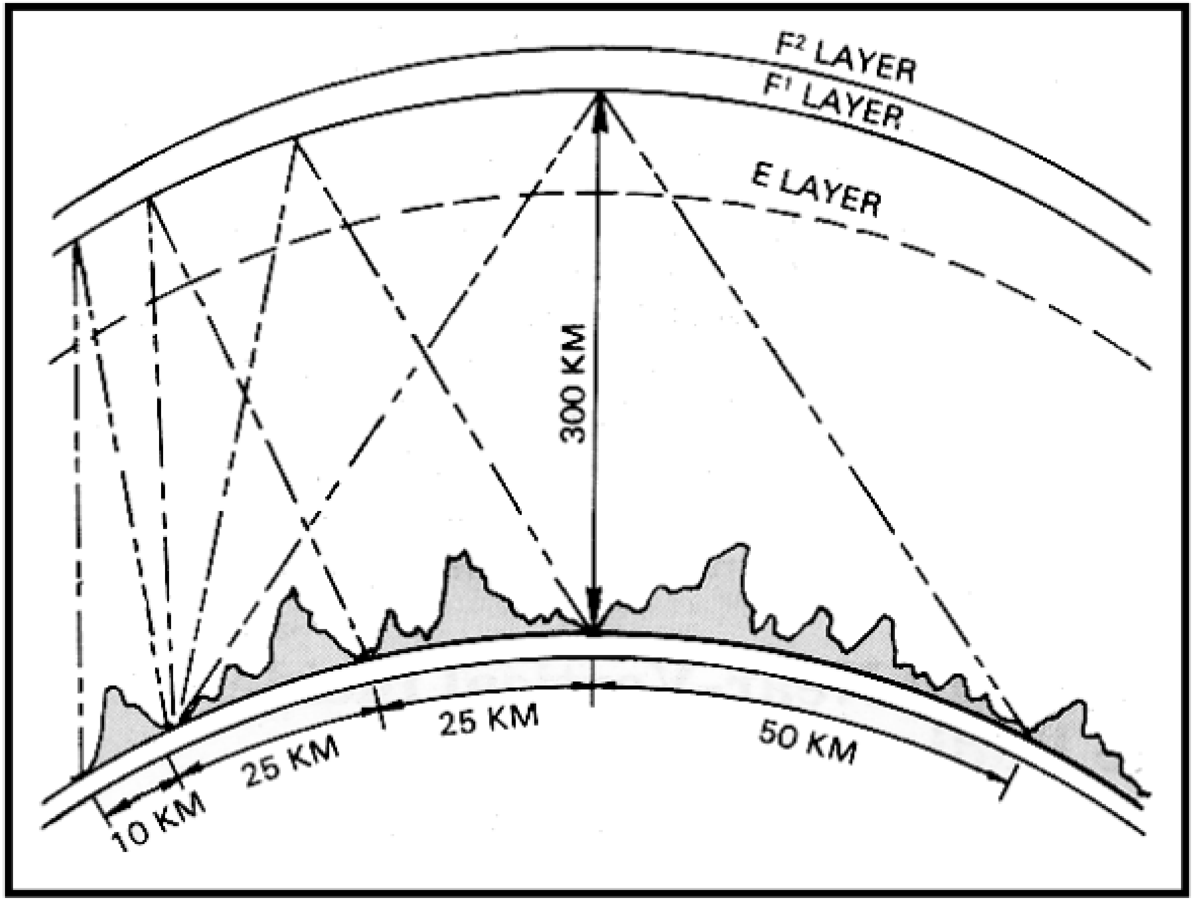
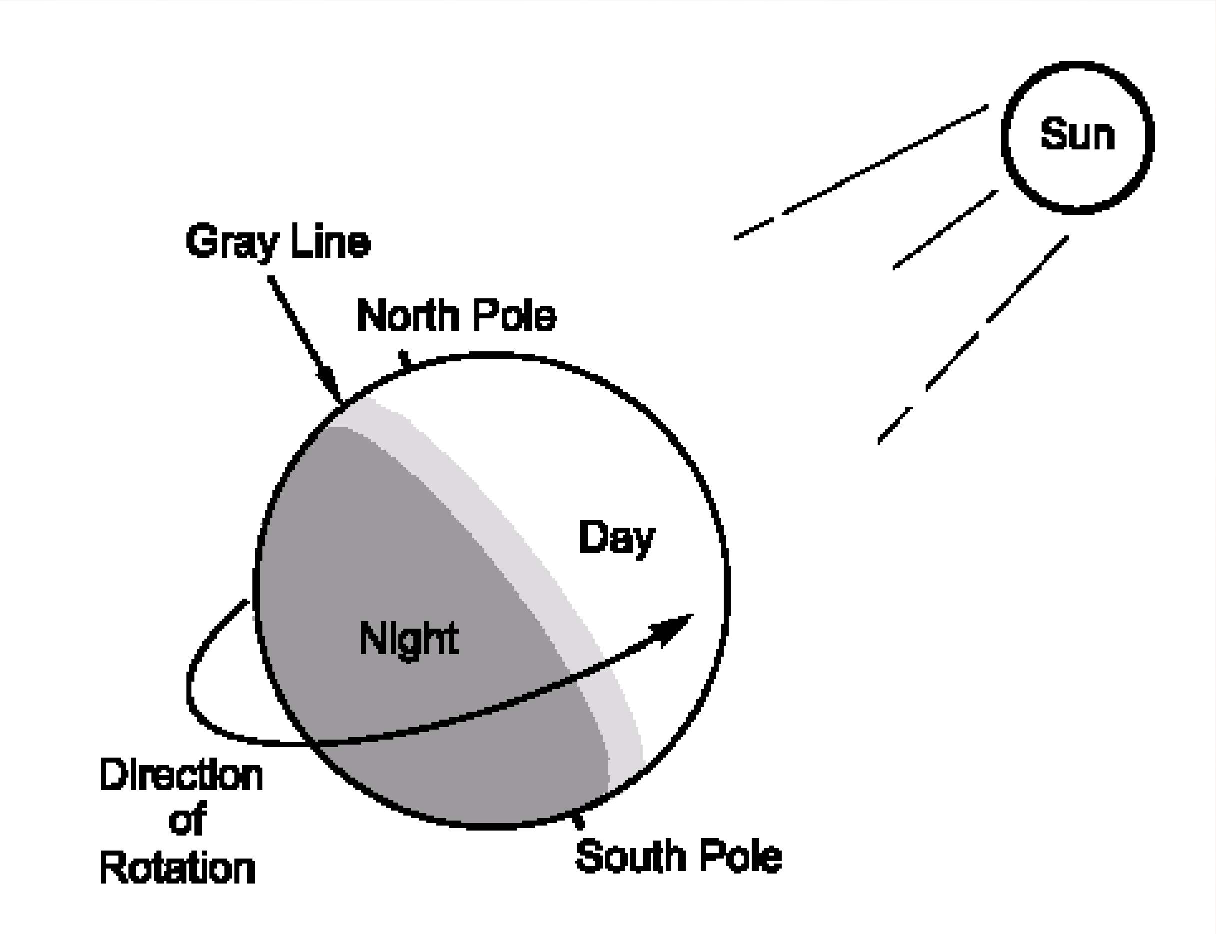


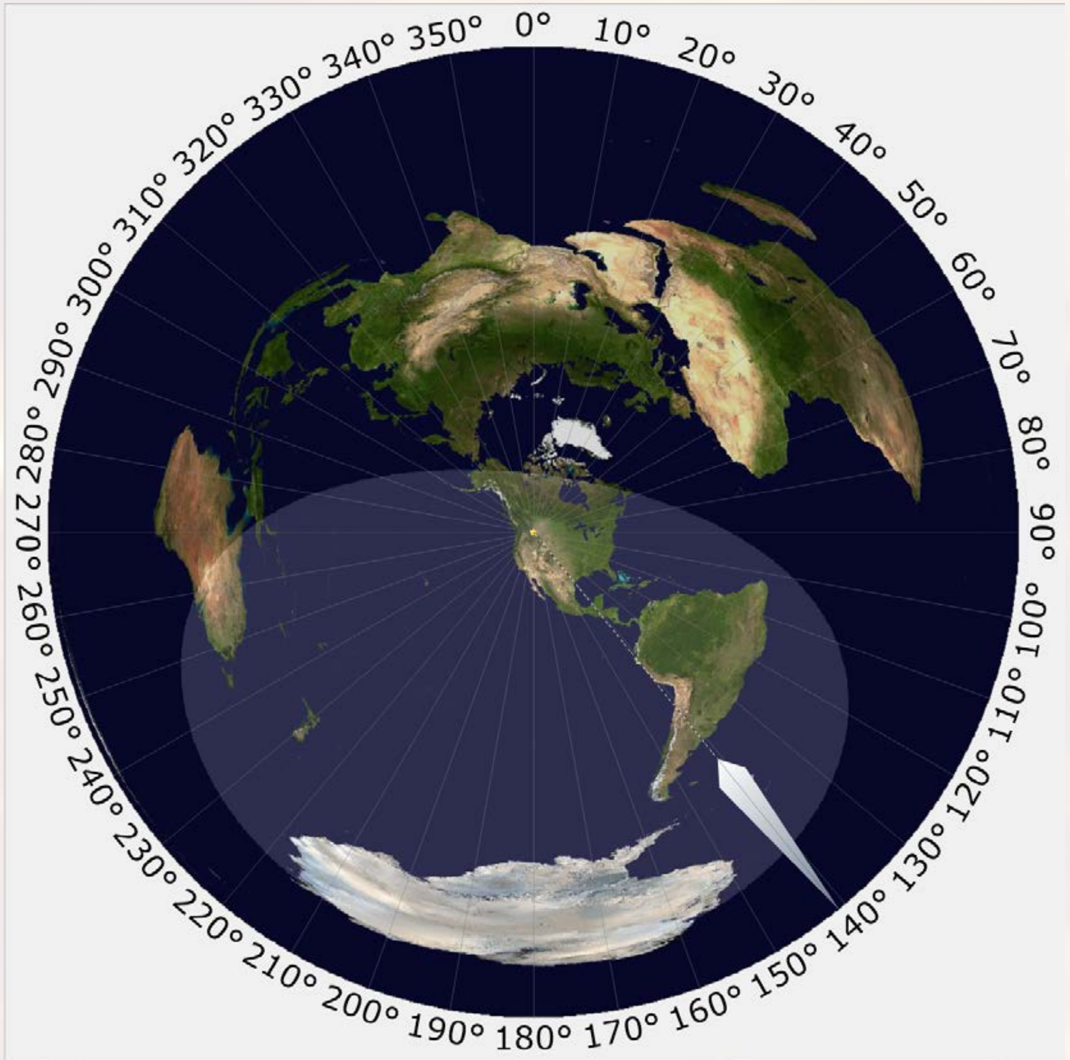
Figure M-1. Near-vertical incidence sky-wave propagation concept.

The Gray Line

- The area of transition between daylight and darkness
  - Offers some unique propagation
    - The D Layer, which absorbs HF signals, hasn't built up yet on the sunny side of the line and disappears quickly on the shady side of the line
  - Very long range communication can be possible between points along the gray line



Azimuthal Map of the Gray Line



Ionization and the Sun

- Ionization level corresponds closely to sun spot activity
- Sun spots follow a roughly 11 year cycle
  - Sun spot numbers range from 0 to approximately 150
  - A ‘smoothed’ number is used (13-month moving average)
- Solar flux Index (10.7 cm, or 2800 MHz) is also a predictor of F-layer ionization
  - Ranges from approximately 60 to approximately 250
  - Is used as a basic indicator of solar activity and of the level of radiation reaching the earth
  - Lower SFI generally means a lower MUF, while higher SFI generally favors HF communication on the higher HF bands (15m, 12m and 10m)
    - Low SFI generally favors 80m and 40m for night-time communication

Geomagnetic Field – The K Index

- Stability of the earth's magnetic field is reported as A & K indices
  - While geomagnetic and ionospheric storms are interrelated, the former is a disturbance of the earth's magnetic field while the latter is a disturbance of the ionosphere
  - Solar flares cause high A and K (with auroras and polar route absorption)
- "K_p" is a planetary average of the quasi-logarithmic K index of the level of magnetic disturbances as seen by the different magnetic observatories around the world
  - Values between 0 and 1 represent quiet geomagnetic conditions (good HF propagation if there's sufficient solar flux)
  - Values between 2 and 4 indicate unsettled or active magnetic conditions
  - A value of 5 represents a minor geomagnetic storm
  - A value of 6 indicates a medium storm
  - 7 through 9 represent major storms that may well result in HF blackouts

Geomagnetic Field – The A Index

- "A_p" is an average for the planet of the A indices as measured at different sites around the planet
    - The "A" metric was developed to provide a longer-term view of the state of the earth's magnetic field than is afforded by the K index
        - At 3 hour intervals, each site's K index is converted to an equivalent A index
        - At the end of each day, an average is taken of the 8 values to produce the sites A-index for that day
            - Varies up to around 100
            - May reach up to 400 during very severe geomagnetic storms
    - A_p is the computed average of the daily A indices as calculated at each site

Relationship between A and K Values

A	*K*	*Comments*
0	0	Quiet
2	1	Quiet
3	1	Quiet
4	1	Quiet to unsettled
7	2	Unsettled
15	3	Active
27	4	Active
48	5	Minor storm
80	6	Major storm
132	7	Severe storm
208	8	Very major storm
400	9	Very major storm

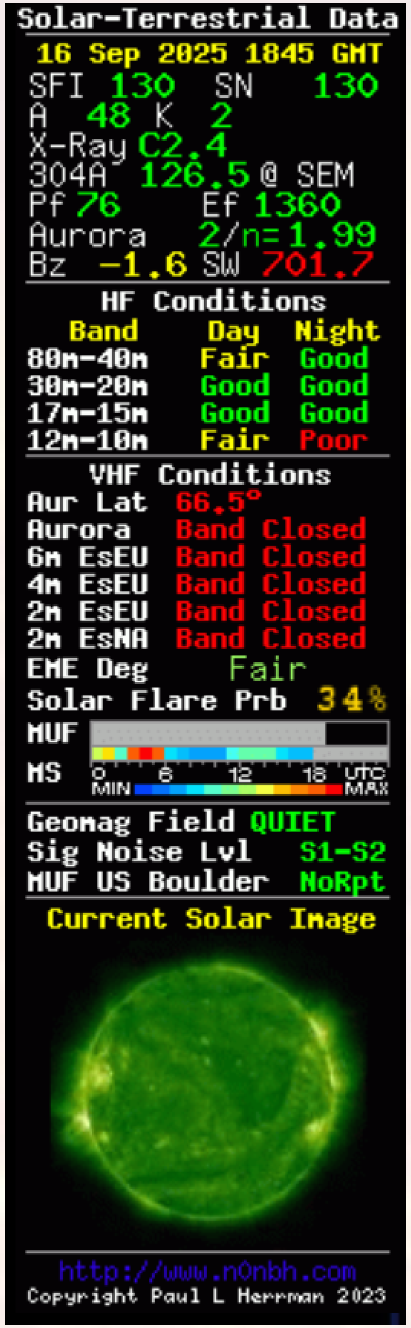
Interpreting the values

- High levels of solar flux is generally good news for HF propagation
  - In general, the higher the flux number, the better conditions will be for the higher HF bands and even 6m
    - These higher levels need to persist for at least a few days to build up a good average ionization in the F-2 layer
      - Values of 150 or more will usually ensure good propagation
        - MUF will rise with this number
- Geomagnetic activity has an adverse effect and decreases MUF
  - Solar flares cause increased ionization in the lower ionosphere
  - The higher the A_p and K_p, the lower the MUF
  - Both the severity of a storm and its duration will determine the overall effect
  - As activity fades, HF openings may occur
- For best conditions, flux should remain above 150 for a few days while K remains below 2

Propagation Software

- The easiest and most accurate way to predict HF propagation
  - https://www.hamqsl.com/solar.html
  - W6ELProp (https://www.qsl.net/w6elprop/)
  - VOACAP (http://www.voacap.com/)
  - HAMCAP (http://www.dxatlas.com/hamcap/)
  - ACEHF (http://hfradio.org/ace-hf/)
  - HFWIN (http://www.greg-hand.com/hfwin32.html)
  - DXToolbox (https://www.blackcatsystems.com/software/ham-shortwave-radio-propagation-software.html)
- More exhaustive list of resources:
  - https://rsgb.org/main/technical/propagation/propagation-prediction-programs-and-forecasts/

HAMQSL.COM



Solar-Terrestrial Data
16 Sep 2025 1845 GMT
SFI 130 SN 130
A 48 K 2
X-Ray C2.4
304A 126.5 @ SEM
Pf 76 Ef 1360
Aurora 2/n=1.99
Bz -1.6 SW 701.7
HF Conditions
Band Day Night
80m-40m Fair Good
30m-20m Good Good
17m-15m Good Good
12m-10m Fair Poor
VHF Conditions
Aur Lat 66.5°
Aurora Band Closed
6m EsEU Band Closed
4m EsEU Band Closed
2m EsEU Band Closed
2m EsNA Band Closed
EME Deg Fair
Solar Flare Prb 34%
MUF
MS
0 6 12 18 UTC
MIN MAX
Geomag Field QUIET
Sig Noise Lvl S1-S2
MUF US Boulder NoRpt
Current Solar Image
http://www.n0nbh.com
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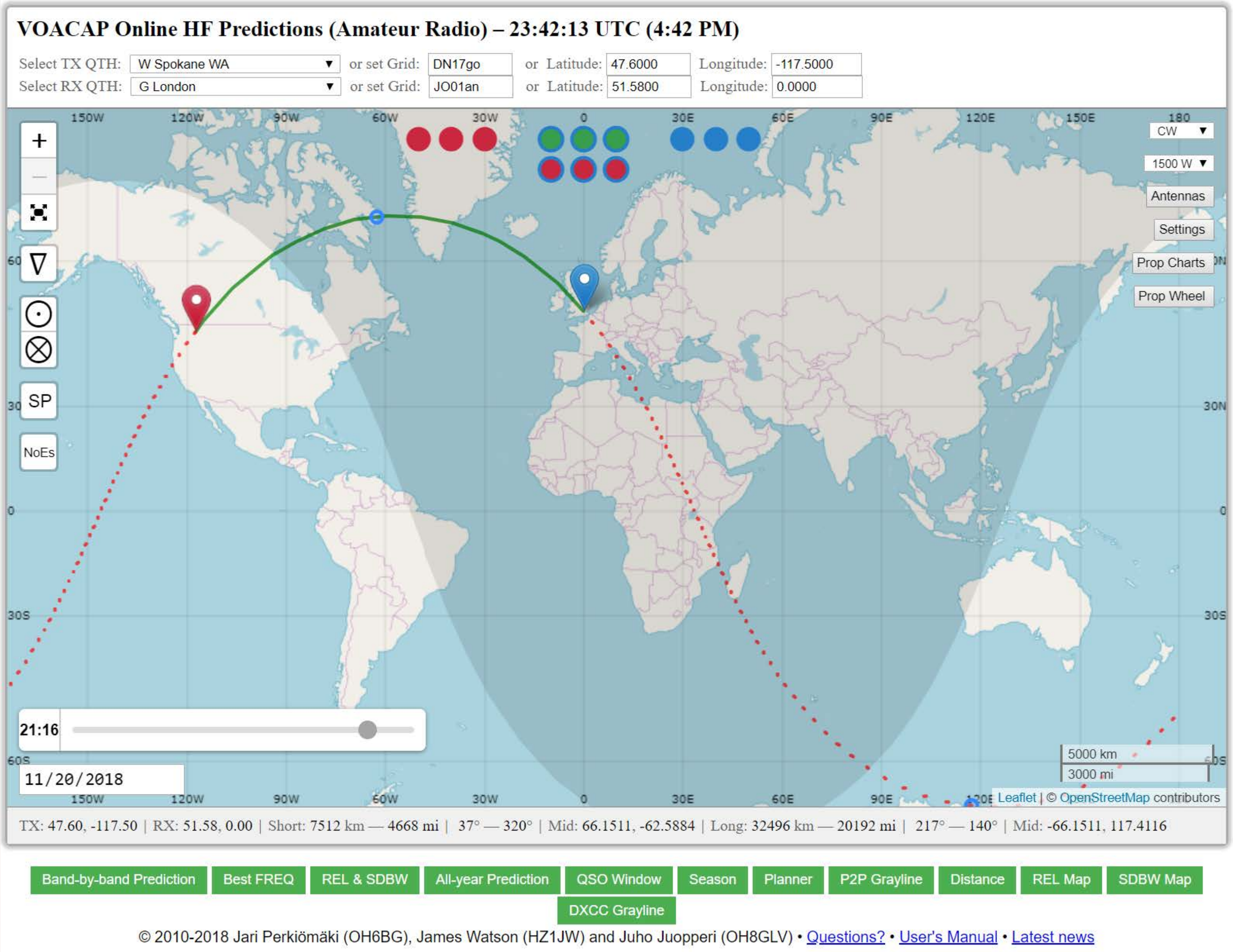
HF Propagation Website Tools

- VOACAP Online (http://www.voacap.com/hf/)
- HAMQSL (http://www.hamqsl.com/solar3.html)
- HAMWAVES (https://hamwaves.com/propagation/en/index.html)

VOACAP Online



HF Beacons

- Use beacons to check for openings:
  - NCDXF (http://ncdxf.org/pages/beacons.html)
  - W6NEK Beacon Tracker (http://www.w6nek.com/)
  - IARU International Beacon Project (http://www.iaru.org/beacon-project.html)


Q&A