Propagation

Ed Callaway, N4II
N4II@arrl.net
South Florida DX Association

W6RGG operating from BS7H (Scarborough Reef, in the South China Sea) in 2007

Propagation, *n.*: How signals get from DX to you (and, hopefully, vice-versa).

See also: "conditions."

NOTICE

- Strictly speaking, everything I will say in this presentation will be a lie.
  - Propagation is a complex phenomenon, so every statement will be a generality, and will have exceptions – which I may, or may not, mention.
- If in the course of this presentation I discover a statement that is not a lie, I'll make note of it.

A Note on Ionospheric Science

- Behavior of the ionosphere has been studied since ~1901
- However, *understanding* how it works required the space program, and space probes only recently launched
- Many fundamental discoveries are now being made that change what we thought we knew about how the ionosphere works
- …but not all textbooks have been re-written!

The Early Years 1

- In the beginning, RF was assumed to go around the Earth via diffraction ("ground wave")
  - Everyone "knew" RF travelled in straight lines…
- However, Marconi spanned the Atlantic in 1901…
- In 1902, Kennelly and Heaviside independently proposed an ionized layer of gas in the upper atmosphere to explain this
- …but nothing further was done.

The Early Years 2

- With ground wave propagation, the lower the frequency, the longer the range
- This led to a “race to the bottom,” with wavelengths measured in miles, gigantic antennas, and megawatt Tx power
- Amateurs given the “useless” short waves, 200m and down (1.5 MHz and up).

Revelation

- With the discovery in 1921-1923 of long-range shortwave propagation, we entered the "modern" radio propagation era
- Appleton experimentally verified the existence of the Kennelly-Heaviside layer in 1924
- Most of the rest of today's talk will be on the behavior of this layer.

What is the Ionosphere?

- The ionosphere is a collection of ionized gas ("plasma") regions in the upper atmosphere
- Chemical structure of the atmosphere changes as one goes up, so the molecules (and atoms) that get ionized change
- Combinations of available gasses and available ionizing radiation produce different regions of ionization as one goes up
  - "layers"
  - Diffuse regions, not mirror-like surfaces

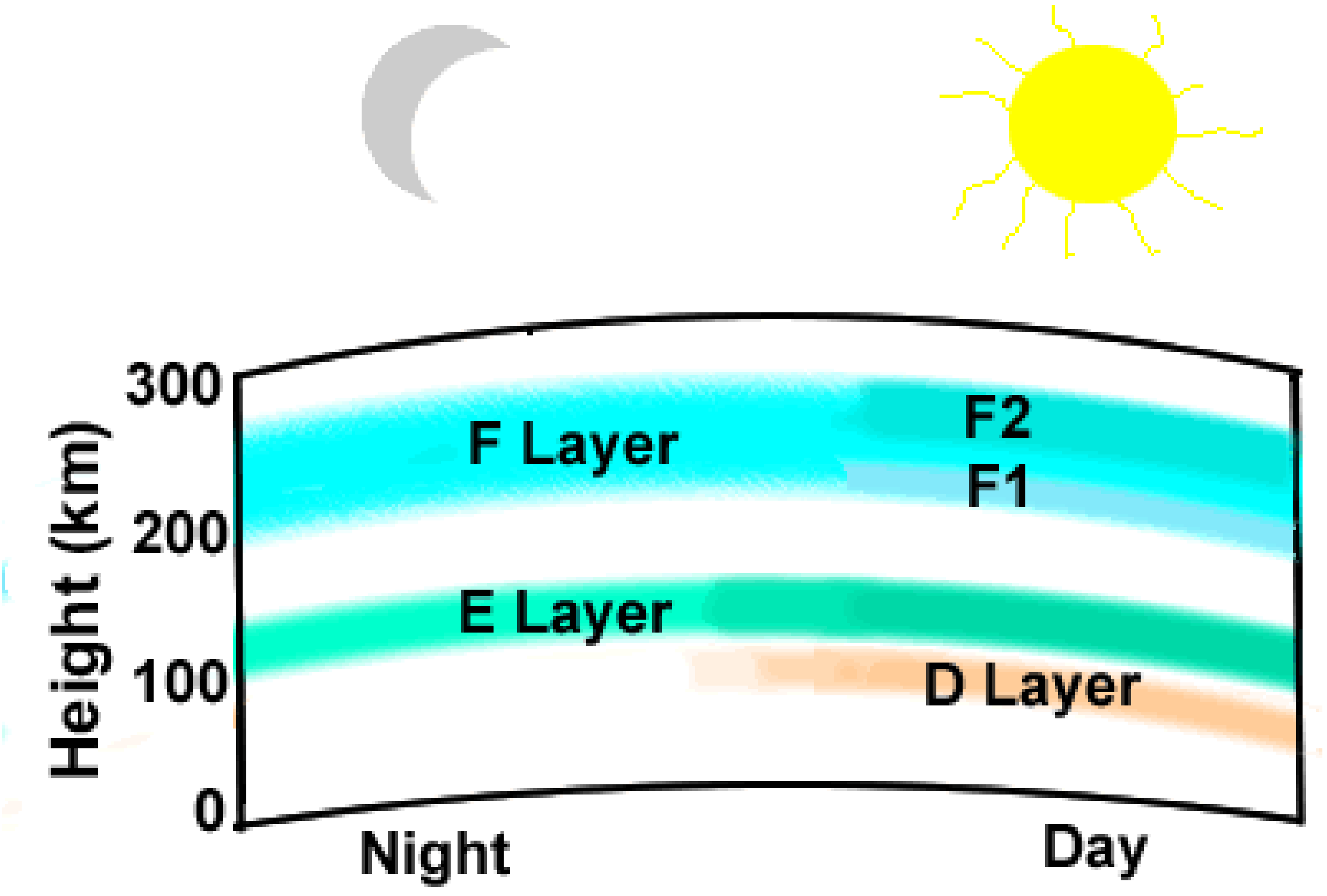
Ionization

- The amount of ionization at any given time is a result of competing processes:
  - Ionization processes
    - Solar radiation
    - Cosmic rays
    - Meteors, natural radioactivity, etc.
  - Deionization processes
    - Recombination

Layers

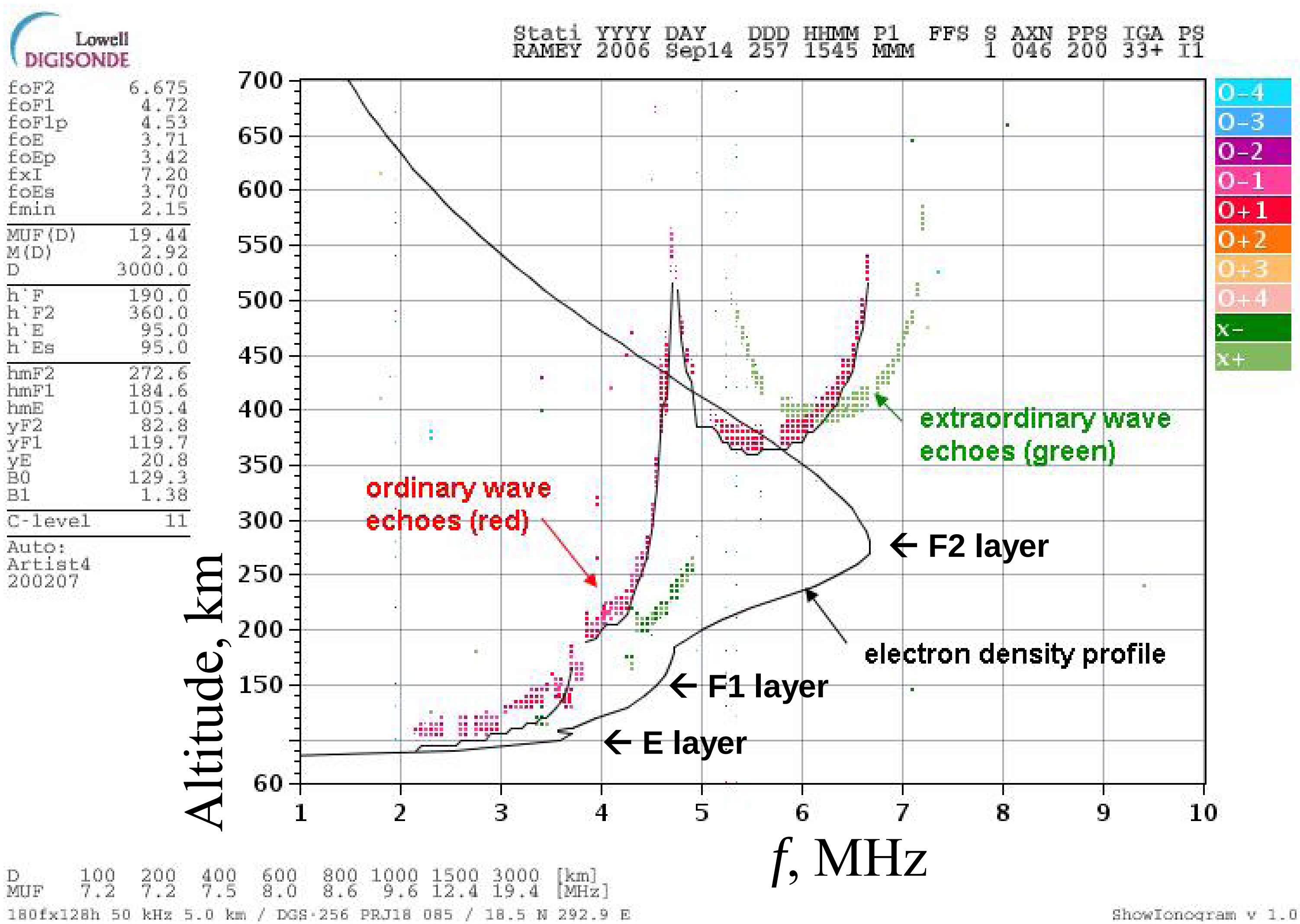
- Three layers the most important for HF propagation
  - D, E, and F layers
  - What happened to the A, B, and C layers?
- D layer: NO + 121.5 nm ultraviolet → e^-
  - 50-80 km up
- E layer: O_2 + 1-10 nm soft X-rays → e^-
  - 90-120 km up
- F layer: O + 10-100 nm ultraviolet → e^-
  - 120-400 km up

Where is the Ionosphere?



http://upload.wikimedia.org/wikipedia/commons/thumb/7/7e/Ionosphere_Layers_en.svg/250px-Ionosphere_Layers_en.svg.png

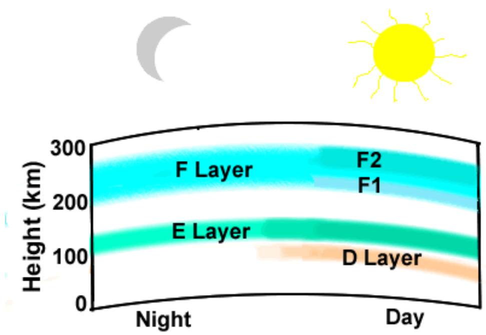
Where is the Ionosphere?



http://mysite.verizon.net/k9la/The_Structure_of_the_Ionosphere.pdf

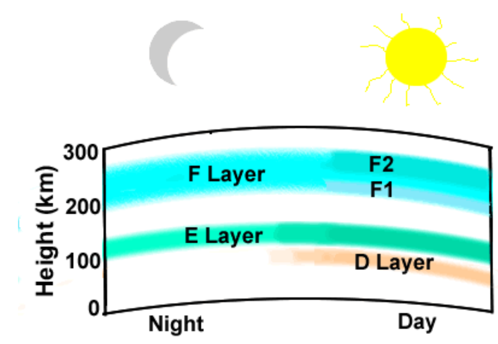
Mythbusting #1

- Ionospheric layers are **not** smooth and uniform
- Rather, the layers have irregular patches of ionization
  - Best analogies: oatmeal (with lumps), cirrus clouds
- Very dynamic: Changes with both time and space (location)



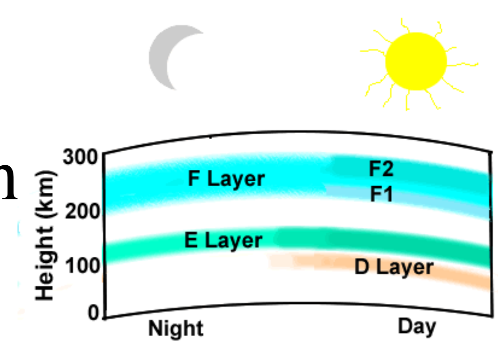
Mythbusting #2

- Ionospheric layers do not **reflect** radio waves!
- Rather, the layers **refract** (bend) radio waves
- Amount of bending an inverse function of frequency
  - The higher the frequency, the less the bending
  - Beyond a critical frequency, there's not enough bending to return to ground
  - At lower frequencies, even vertical signals are returned



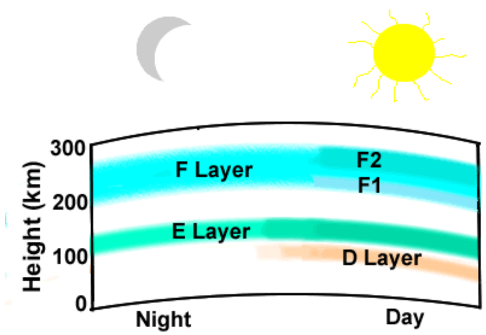
Basic Ionospheric Rule 1

- The higher the frequency, the higher in the ionosphere refraction occurs. . .
  - and the longer the skip. . .
  - until it's too high, and goes out into space
    - This frequency is called the f_oF_2 ("Eff – Oh – Eff – Two")
- This means that, for a given distance, higher frequencies need fewer hops
  - less attenuation
  - as long as the frequency is not *too* high
  - F layer used for most DX

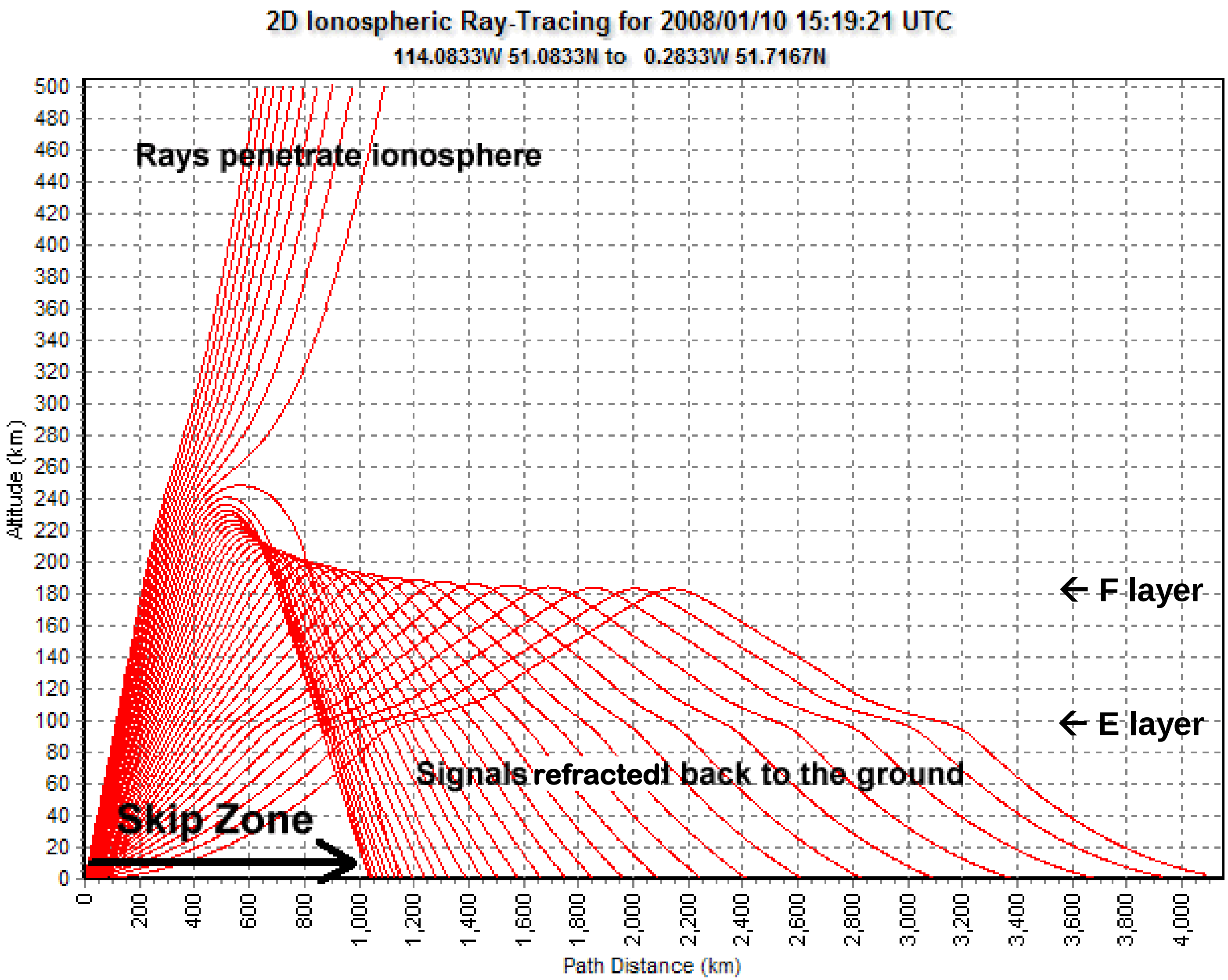


Basic Ionospheric Rule 2

- The lower the elevation angle, the less bending needed to return the signal to Earth, so the higher the frequency that can be used
- Also, due to the geometry, the lower the angle, the longer the hops and the fewer needed to reach a given DX
- If the angle is too high, the signal does not return, and a "skip zone" results
  - No propagation close-in

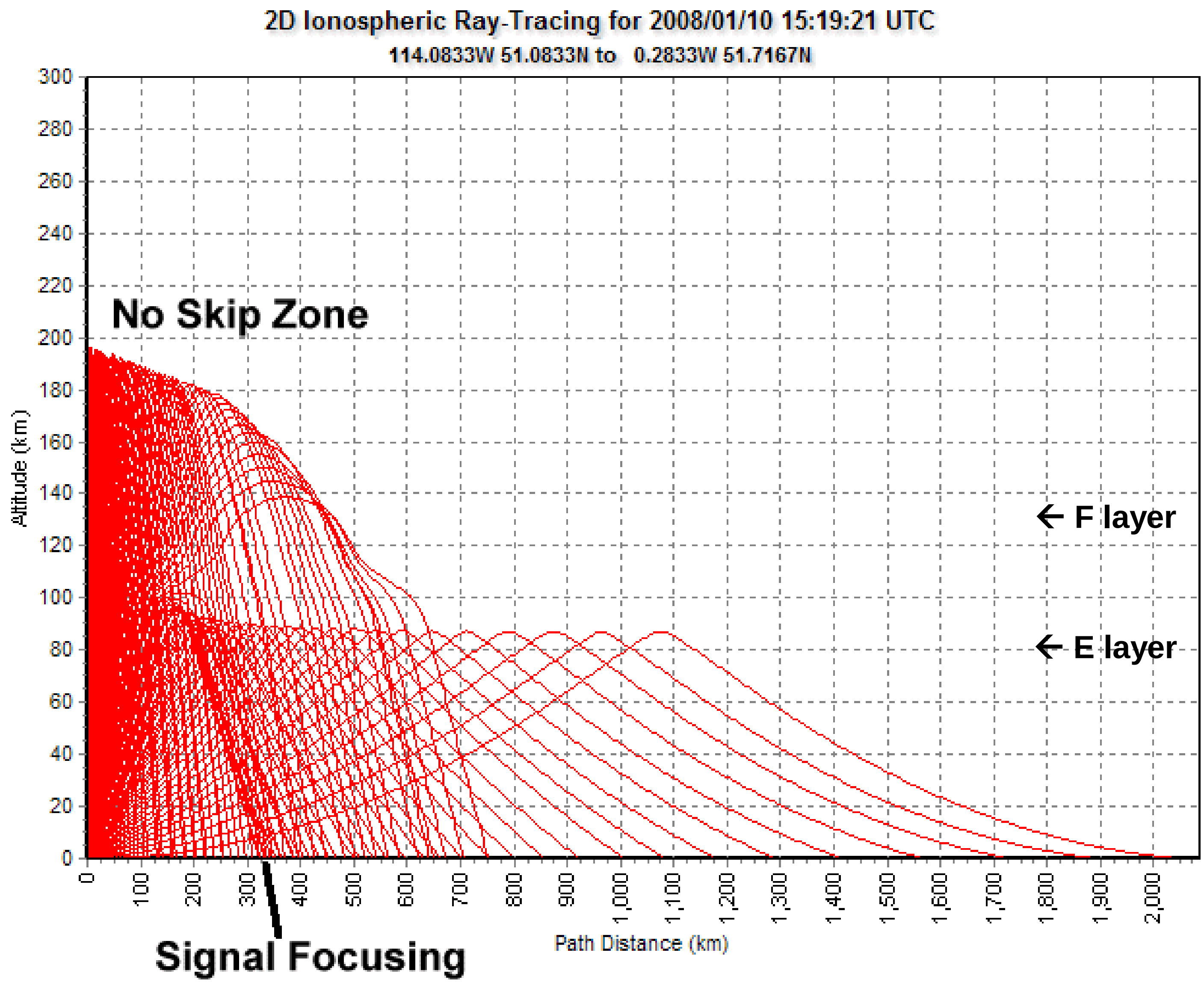


Geometry 1 – Higher Frequency



http://en.wikipedia.org/wiki/File:Skip_Zone_Example.gif

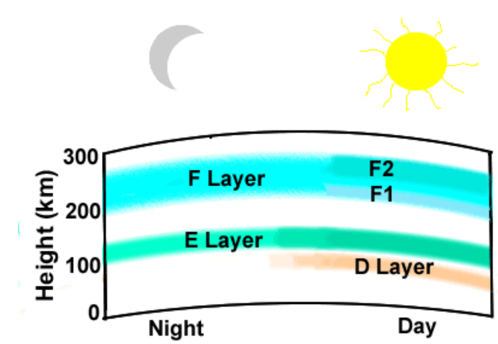
Geometry 2 – Lower Frequency



http://upload.wikimedia.org/wikipedia/en/e/ed/No_Skip_Example.gif

Basic Ionospheric Rule 3

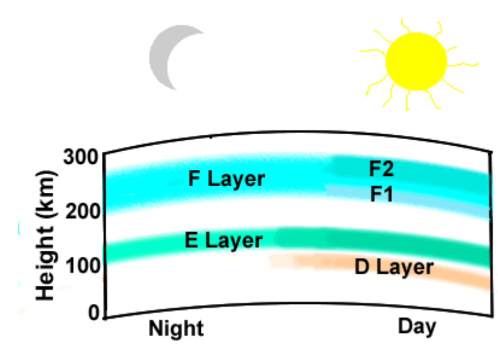
- Signals are attenuated by layers through which they pass (mainly the D layer)
  - Attenuation proportional to $1/f^2$
  - Lower bands affected more severely
  - Lower bands better at night (no D layer)
- Long DX on lower bands therefore suffers a double whammy
  - More attenuation per layer
  - More hops for a given DX
    - More passes through the lossy layer
    - Not to mention ground reflection losses



Ionospheric Variation

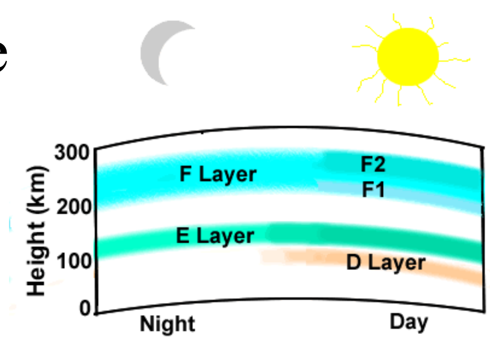
Causes of Ionospheric Variation

- Solar ionizing radiation
  - Sunspot number
  - Solar Flux Index
- Solar wind/geomagnetic activity
  - Charged particles from the sun (protons) hit the Earth's magnetic field and spiral along the magnetic field lines
  - Aurora borealis and aurora australis
  - A and k indices
- Neutral atmosphere (e.g., winds)



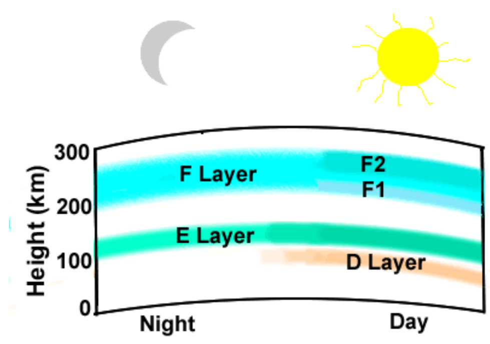
Sunspot Number

- Daily Sunspot Number:
  - 10 × (number of sunspot groups) + (number of sunspots)
  - Minimum > 0 is 11!
- (Monthly) Smoothed Sunspot Number:
  - [(n1/2)+(n2+n3+........n11+n12)+(n13/2)]/12
  - For July 2009, take half of January 2009 plus the sum of Feb-Dec 2009, plus half of January 2010, all divided by 12
  - Future values predicted, of course. . .
  - Used in all propagation prediction software



Solar Flux Index

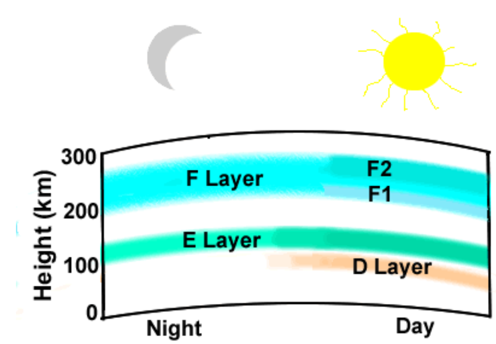
- The amount of radio noise or flux (in 10^{-22} W/m^2/Hz) from the Sun at a frequency of 2800 MHz (10.7 cm)
  - Measured at local noon
  - Minimum around 67-68; max = ?
- Used as a *<u>surrogate</u>* for the amount of solar ionizing radiation
  - 10.7 cm wavelength reaches the ground; uv and X-rays do not
  - All there was, before spacecraft
  - Well-correlated to monthly SSN



k Index

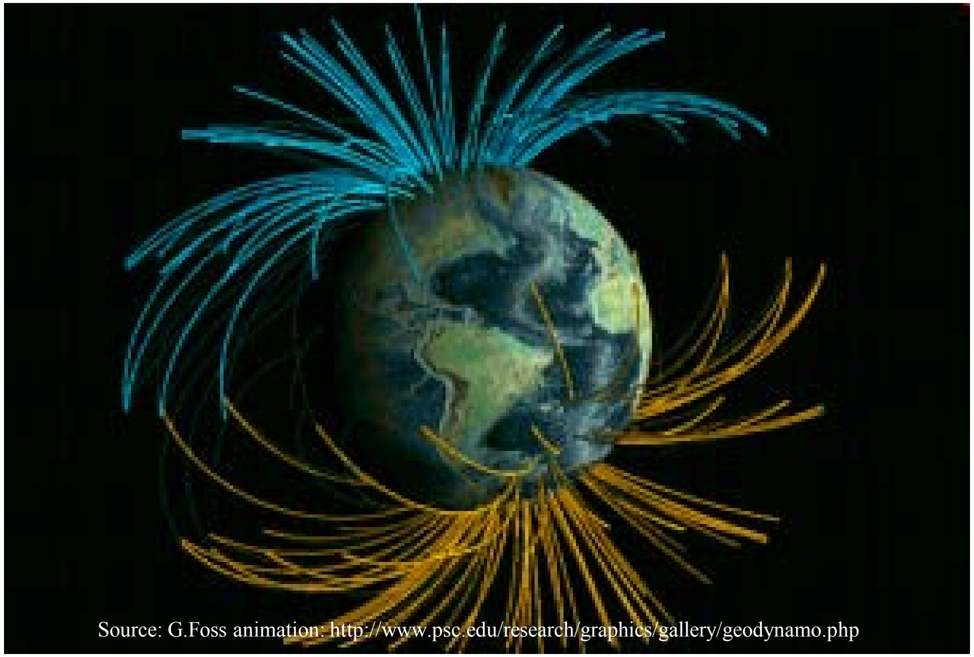
- Quantifies *<u>disturbances</u>* in the horizontal component of earth's magnetic field
  - Numeric value 0 (quiet) to 9 (major storm)
  - Measured every 3 hours
  - Low = good
- Disturbances usually caused by variations in the solar wind
  - Symptom of charge injected into the ionosphere
  - Can close polar paths

K-index	Boulder, CO observatory measurement (nT)
0	0-5
1	5-10
2	10-20
3	20-40
4	40-70
5	70-120
6	120-200
7	200-330
8	330-500
9	>500

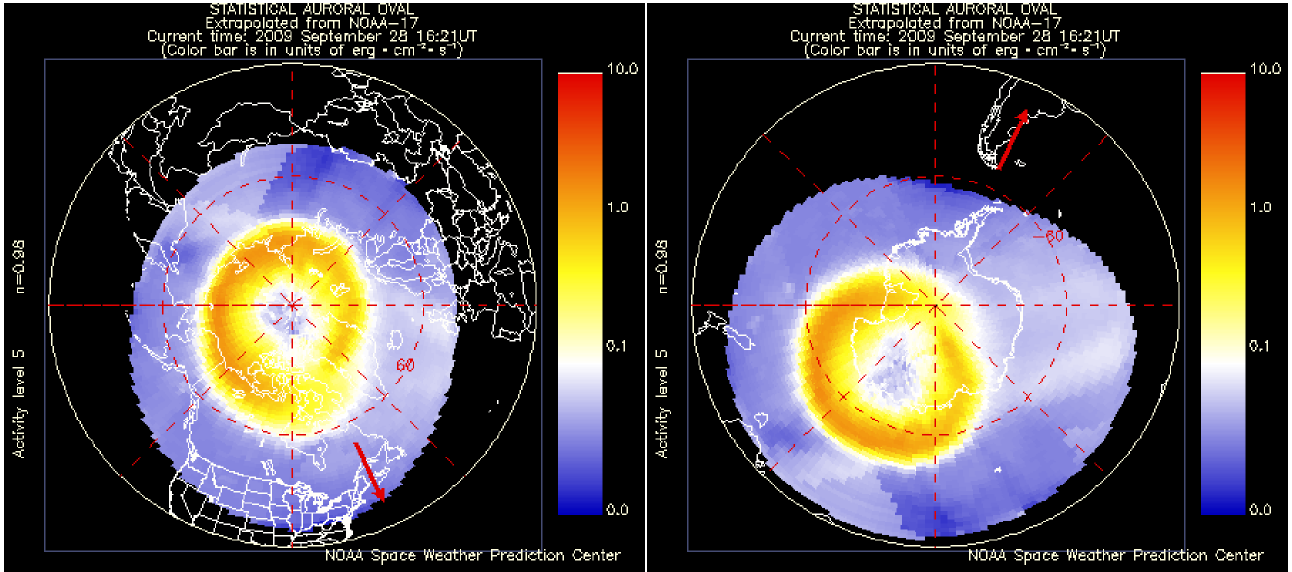


Polar Paths

- The Earth’s magnetic field reaches the ground near the poles
- Charged particles spiraling along magnetic field lines enter the atmosphere in a ring around each magnetic pole
- This produces a “shield” that attenuates and distorts RF signals passing over the poles.



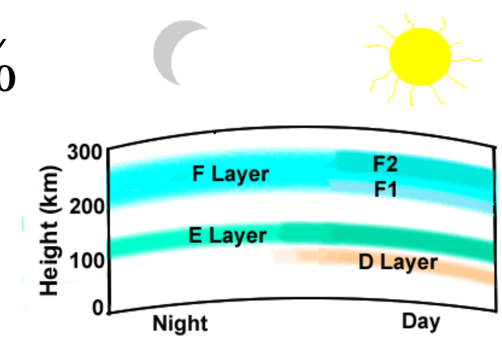
Source: G.Foss animation: http://www.psc.edu/research/graphics/gallery/geodynamo.php



Mythbusting #3

- The daily sunspot number is ***not*** a major predictor of daily f_oF_2
  - "the most widely held incorrect belief among radio amateurs"
- f_oF_2 typically varies by 20% in a given month
  - Solar ionizing radiation: 3%
  - Solar wind/geomagnetic activity: 13%
  - Neutral atmosphere (e.g., winds): 15%

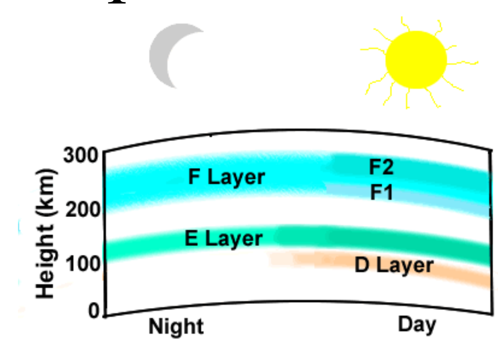
$(3\%)^2 + (13\%)^2 + (15\%)^2 = (20\%)^2$



H. Rishbeth and M. Mendillo, "Patterns of F2-layer variability," *Journal of Atmospheric and Solar-Terrestrial Physics*, Volume 63, 2001, pp 1661-1680.

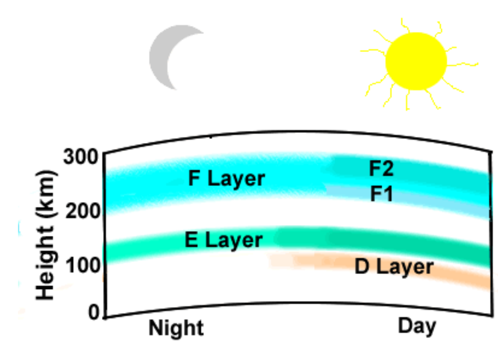
Daily Variations

- Since solar radiation is highest on the daylight side of the Earth, the higher bands are best in daylight (f_oF_2 is highest)
- Recombination effects are typically slower than ionization effects, so the higher bands typically stay open into the evening
  - Relevant point is the sunlight on the ionosphere, not the ends of the link
- Lower bands best at night



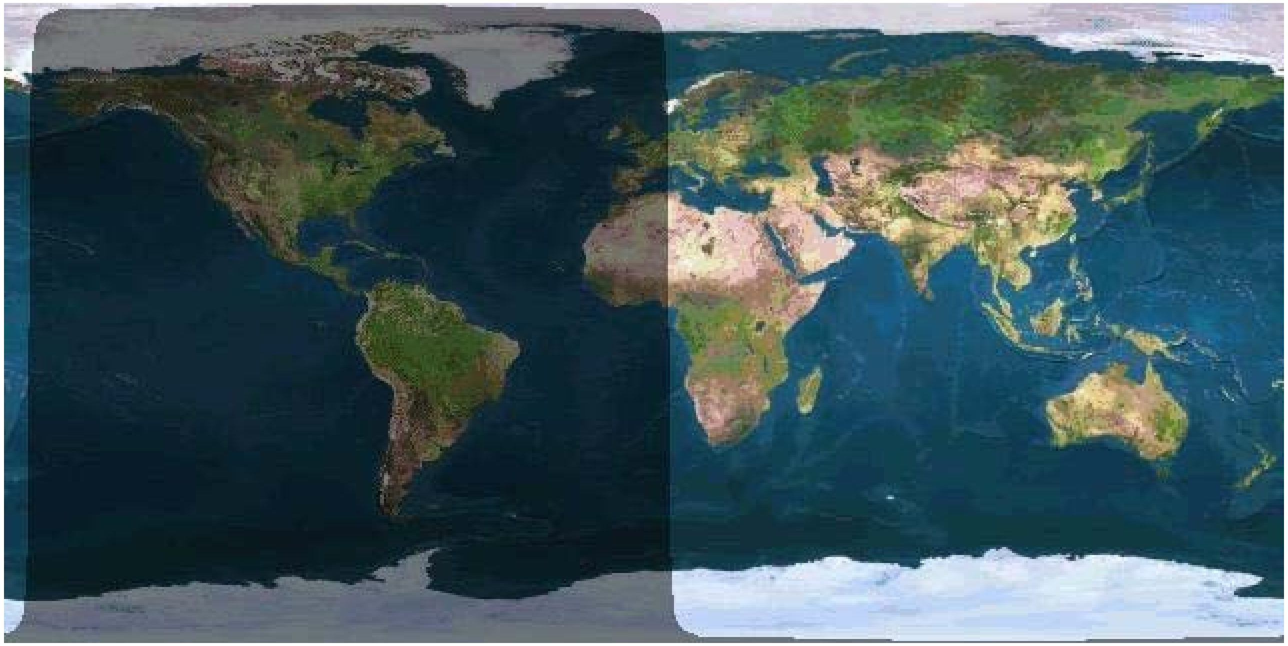
Seasonal Variations

- Since insolation of the ionosphere is important to us, and the sun angle varies with the seasons, we can expect seasonal HF propagation variations
  - Long winter nights → longer nighttime paths on the low bands
    - Noise-making thunderstorms largely far away
  - Cross-hemispheric DX best at the equinoxes



H. Rishbeth and M. Mendillo, "Patterns of F2-layer variability," *Journal of Atmospheric and Solar-Terrestrial Physics*, Volume 63, 2001, pp 1661-1680.

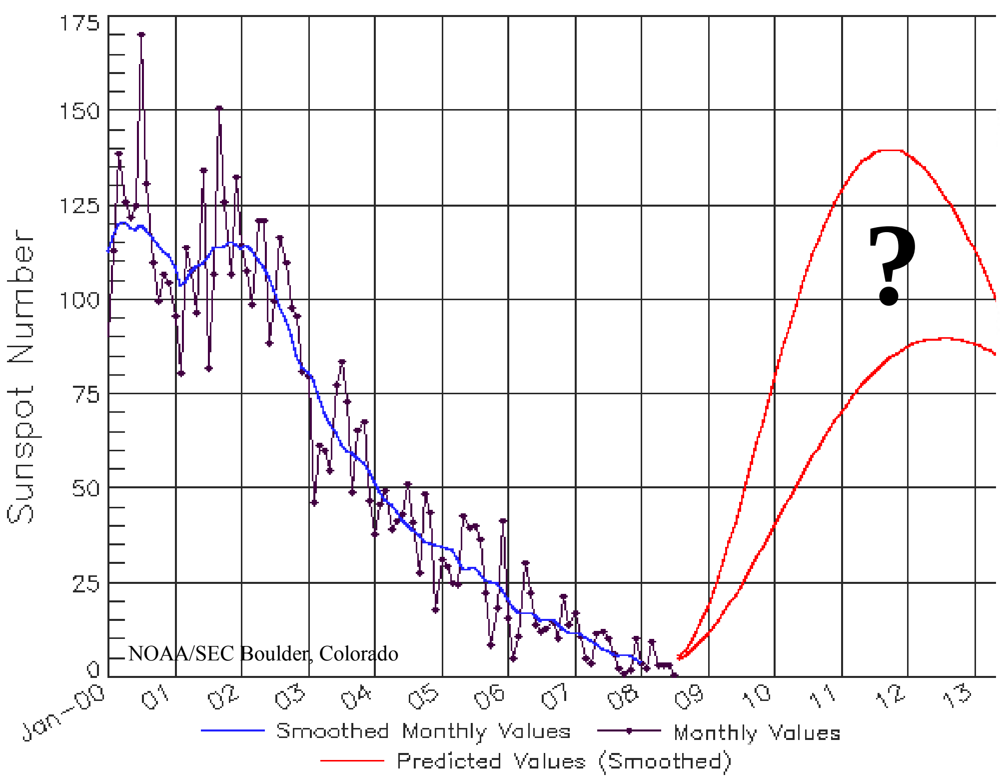
The Equinox

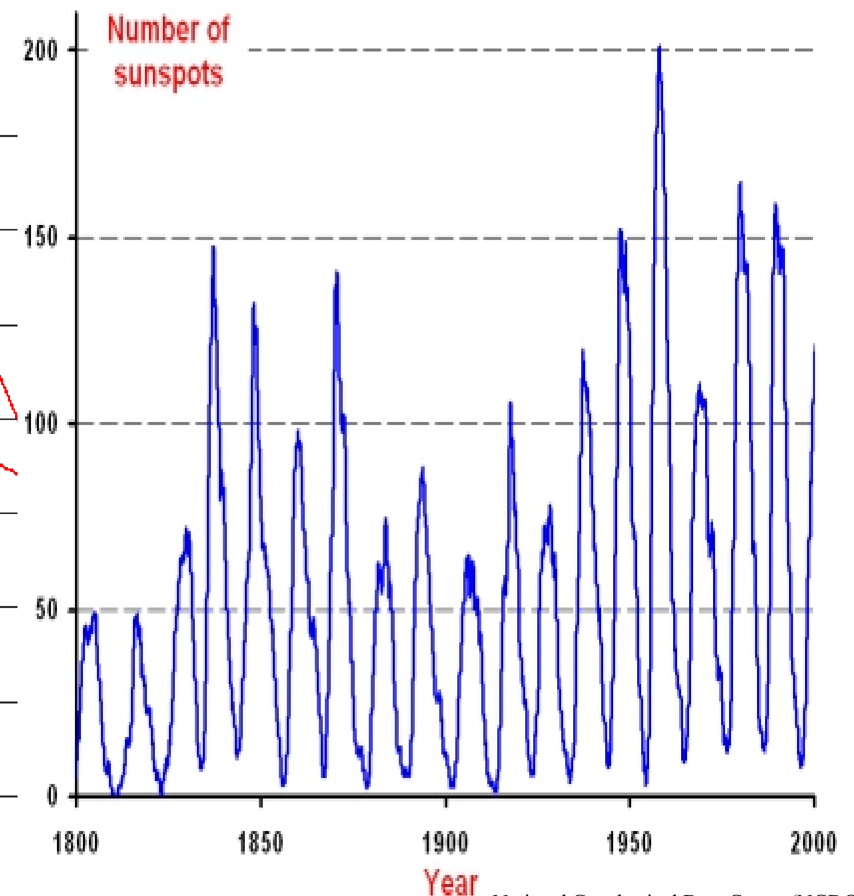


Sun evenly split between northern and southern hemispheres

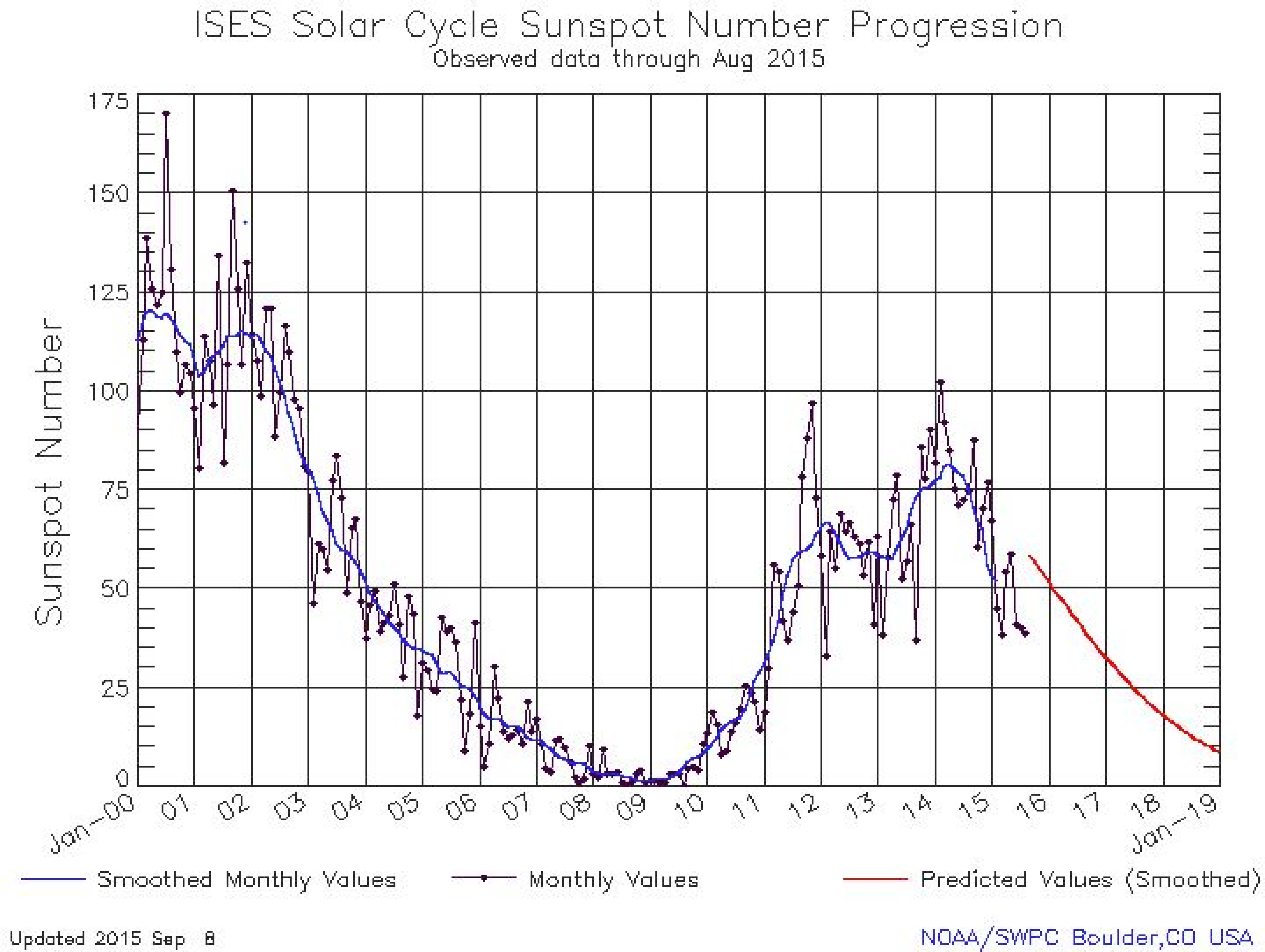
The Sunspot Cycle

- Really a 22-year cycle
  - Magnetic field reverses every 11 years
  - You, too, can be a sunspot cycle predictor!





National Geophysical Data Center (NGDC)

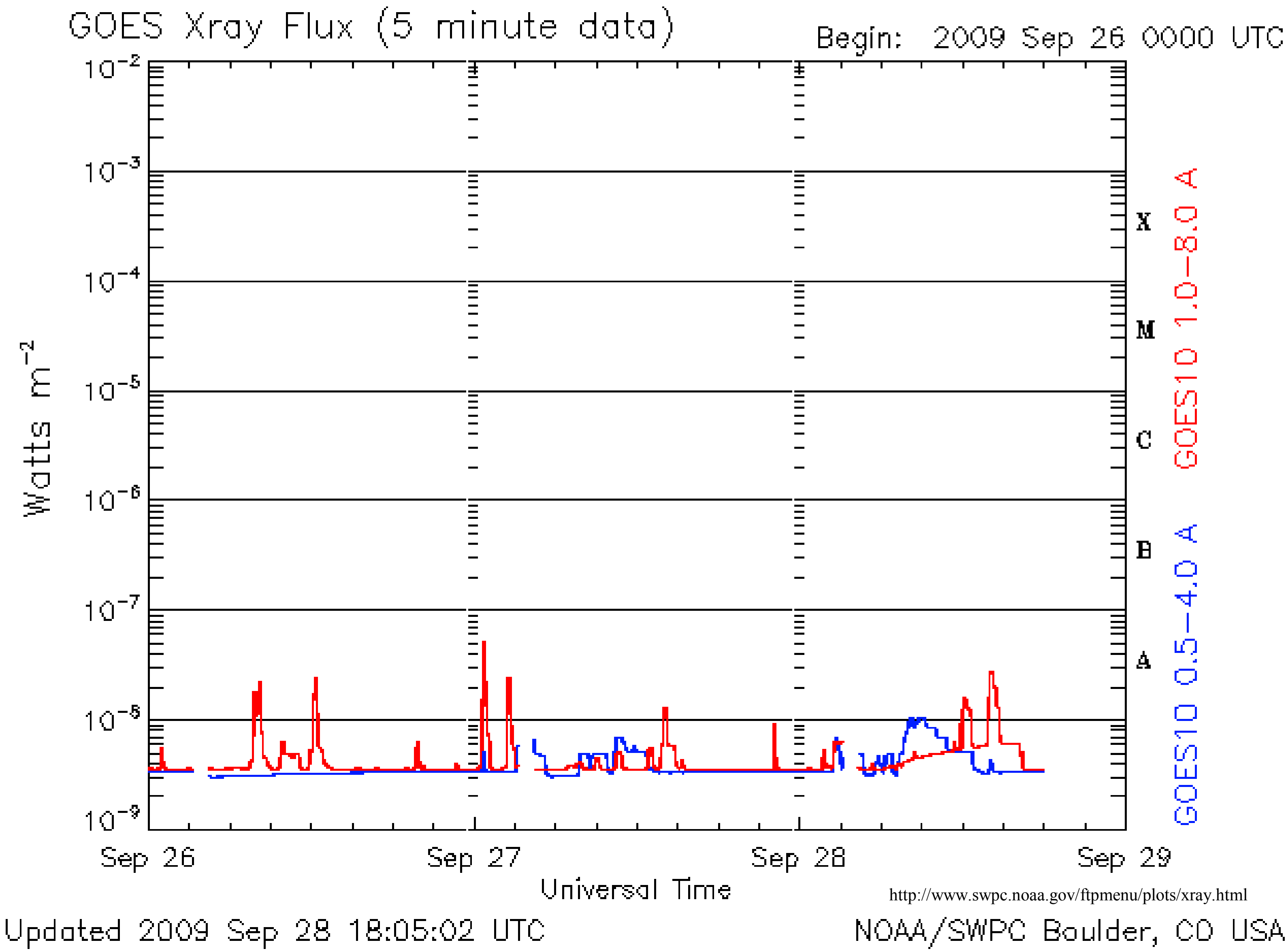

ISES Solar Cycle Sunspot Number Progression
Observed data through Aug 2015
Sunspot Number
175
150
125
100
75
50
25
0
Jan-00
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
Jan-19
Smoothed Monthly Values
Monthly Values
Predicted Values (Smoothed)
Updated 2015 Sep 8
NOAA/SWPC Boulder,CO USA

Information and Propagation Prediction Software

Real-Time Information

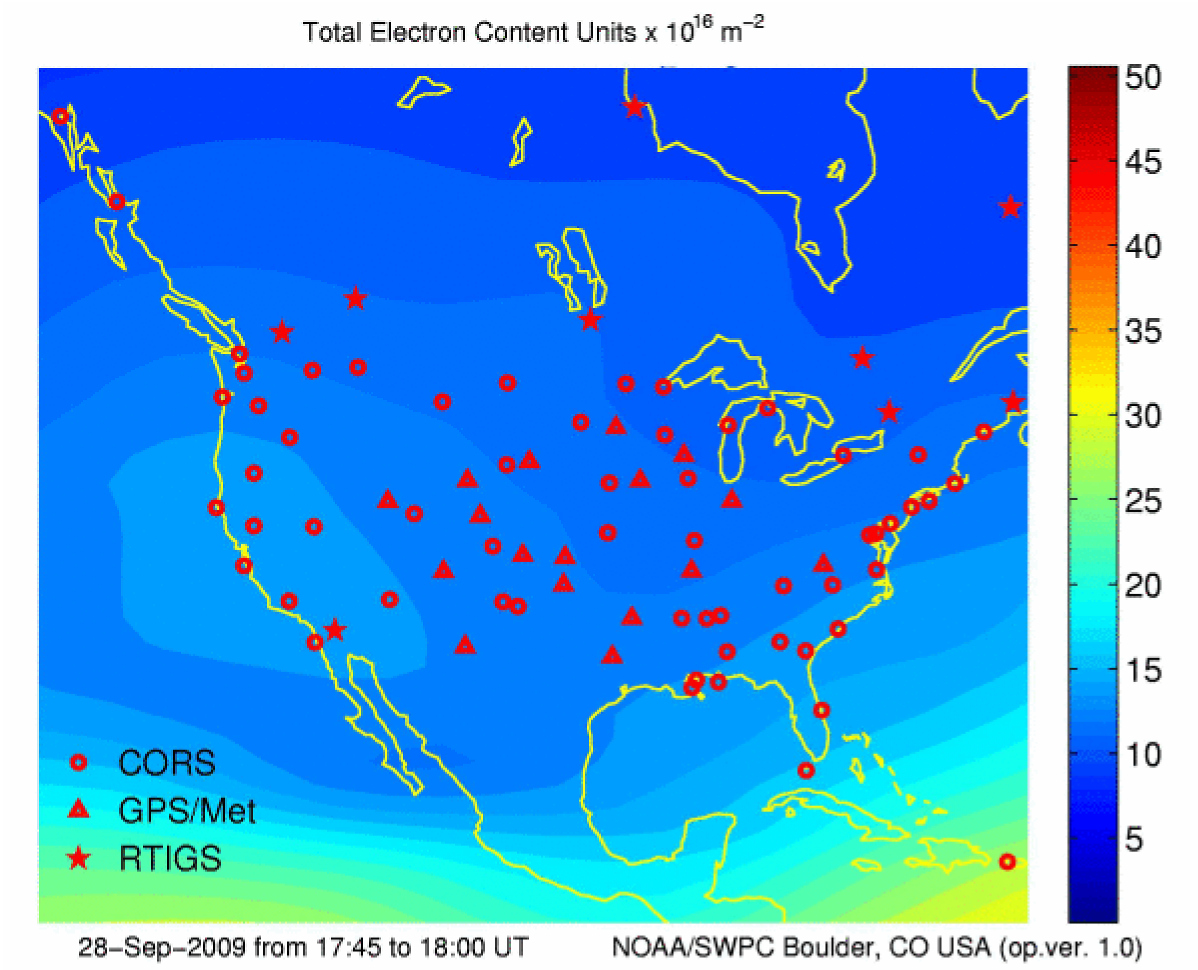
- Space probes have revolutionized our understanding of the Earth-Sun relationship, and the web brings the information to us
- http://dx.qsl.net/propagation/index.html
  - Compilation of much propagation information
- http://www.spaceweather.com/
  - Just what it sounds like
- http://www.swpc.noaa.gov/SWN/
  - NOAA Space Weather Now

GOES X-Ray Flux Data



http://www.swpc.noaa.gov/ftpmenu/plots/xray.html

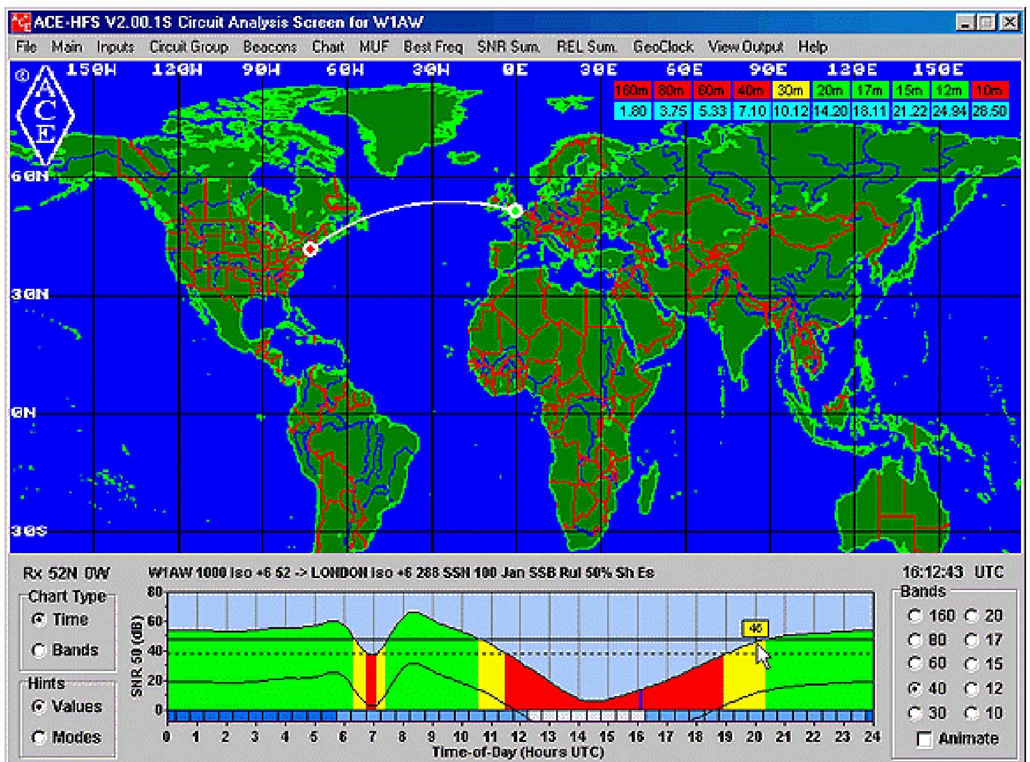
US Total Electron Content (USTEC)



http://www.swpc.noaa.gov/ustec/

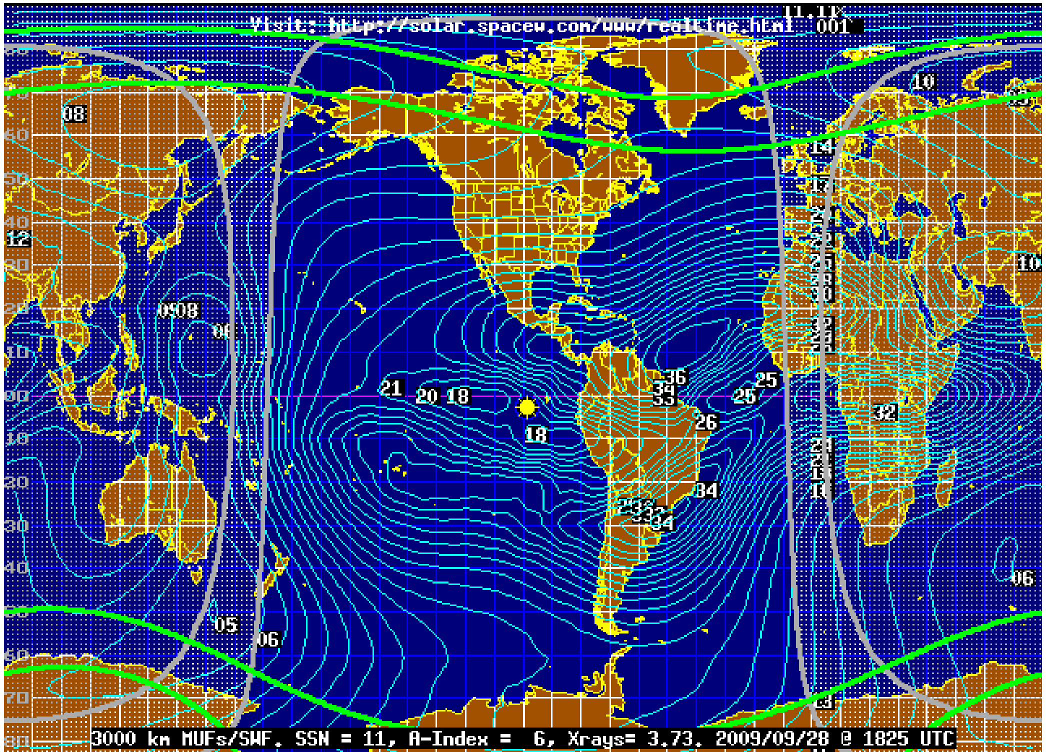
Propagation Prediction Software

- Nearly all based on VOACAP, with better UI
  - Voice of America's HF prediction program
  - Ace-HF (http://home.att.net/~acehf/) my favorite
  - Many others



Ray-Tracing Software

- Not based on VOACAP, but rather sophisticated new ray-tracing algorithms
  - PropLab-Pro; http://www.spacew.com
  - Not inexpensive, but probably my next purchase



http://www.spacew.com/www/realtime.php

Questions?