High Frequency Propagation

(and a little about NVIS)

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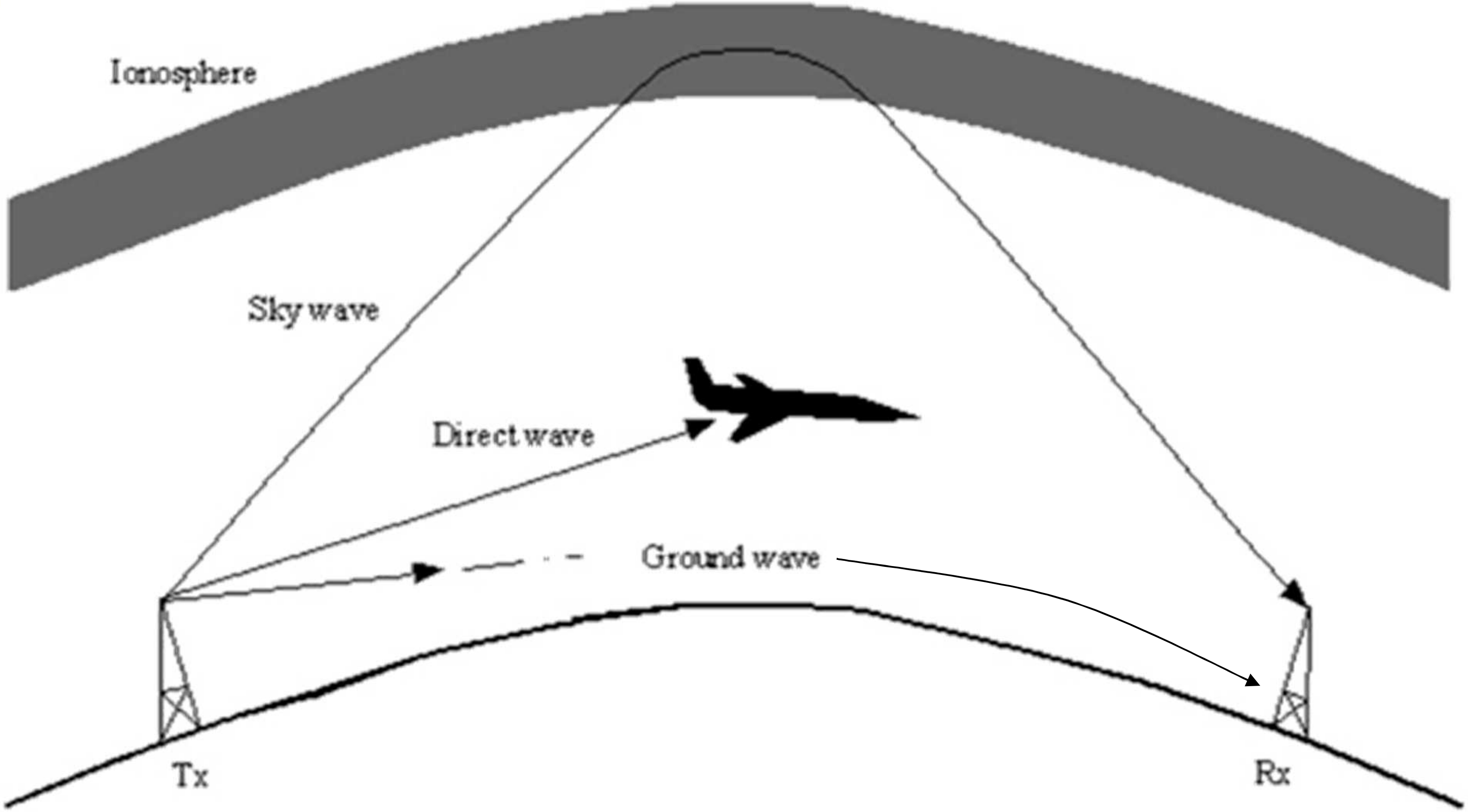
The problem

- Radio waves, like light waves, travel in ~straight lines.
- How do we communicate with someone far away – hidden by the curvature of the earth?
- Use satelites, repeaters, base stations and fiber optics – ‘cell phones, VoIP, etc.’
- What happens when the power goes out, the towers are damaged, the base stations are down, or we’re out of range?
- How do we communicate when there’s no infrastructure?

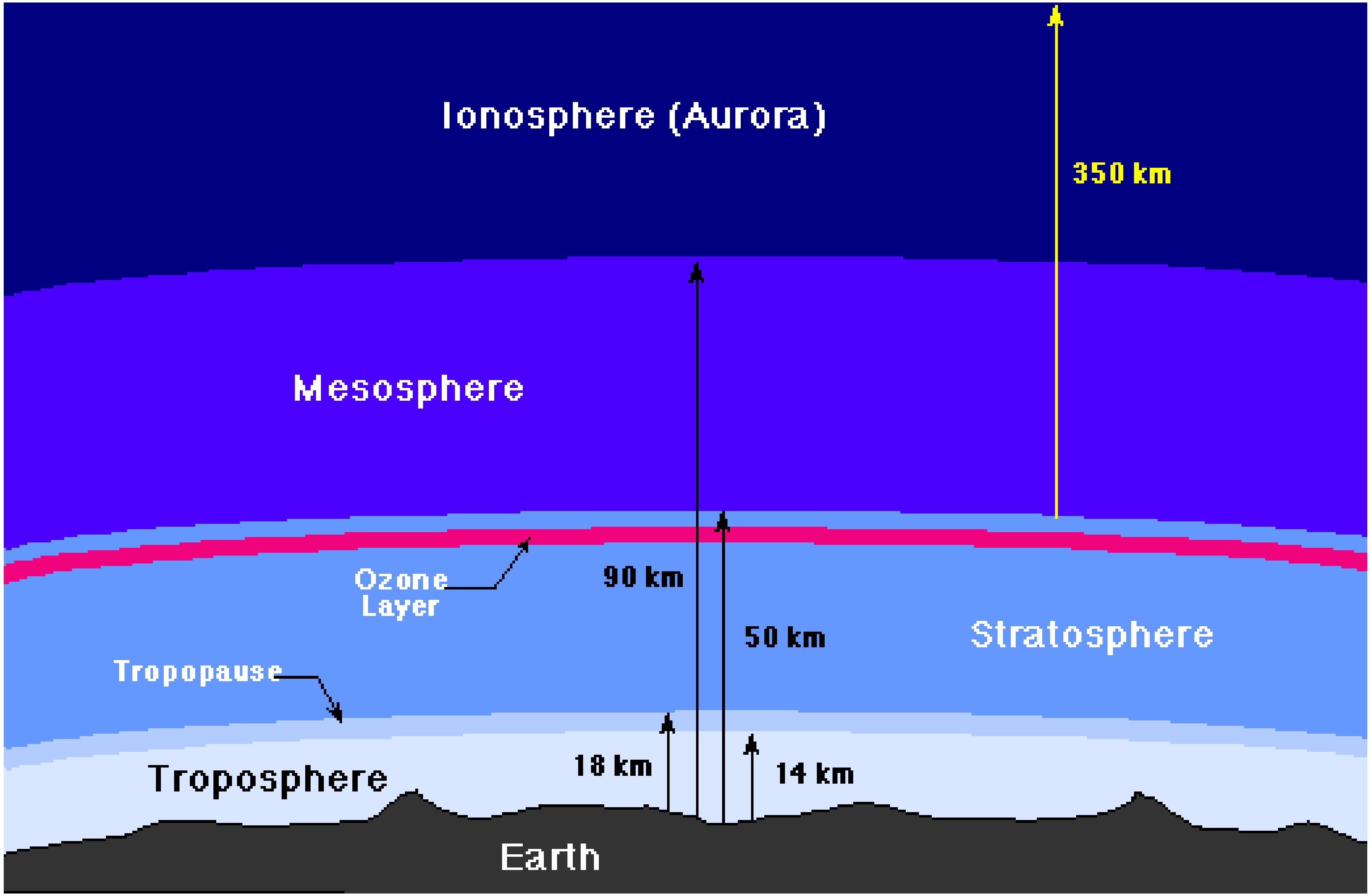
A Solution

- The earth's ionosphere acts as a radio wave reflector
  - It's high above the ground.
- The ground itself can reflect radio waves.
- Between those two – we can communicate around the world.
  - With some restrictions.
  - Frequencies from about 1.8 MHz to about 30 MHz.
  - Depends on time-of-day, sunspots, effective antennas, efficient modulation.

Different Propagation types



The Ionosphere



What ionizes the atmosphere?

- Ultra-violet and X-ray radiation from the sun.
  - About half the ionization comes from He^{+2} 30.4 nm line.
- Energetic UV photon ‘kicks’ outer electron free from an oxygen or nitrogen atom – ionizing it.
- It’s the *free electrons* that are responsible for refracting our radio signals.
- Free electrons eventually bump into another ion and recombine.
- Upper ionosphere – lots of UV radiation available. Very few atoms – low density & pressure.
  - Result: only a few ions created but they live a long life. Net result is greatest quantity of free electrons.
  - When the sun sets, they recombine slowly through the night.
- Lower ionosphere – less UV radiation available (absorbed above). Many atoms available – higher density & pressure.
  - Result: moderate number of ions created but they live a short life. Net result is lesser quantity of free electrons.
  - When the sun sets they recombine (disappear) quickly.

Ionization & Recombination

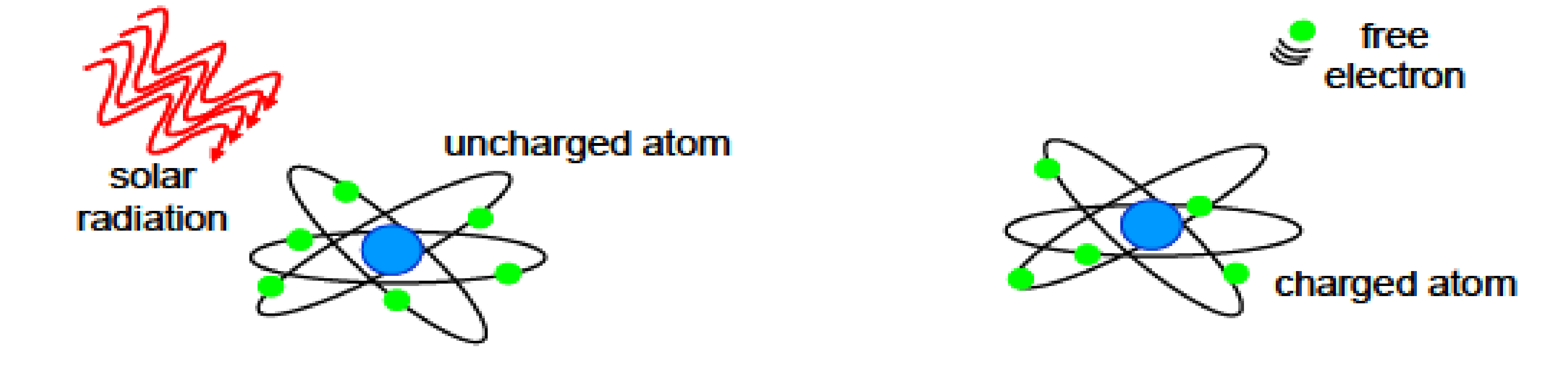


Figure 1.2 *Free electron production in the ionosphere*

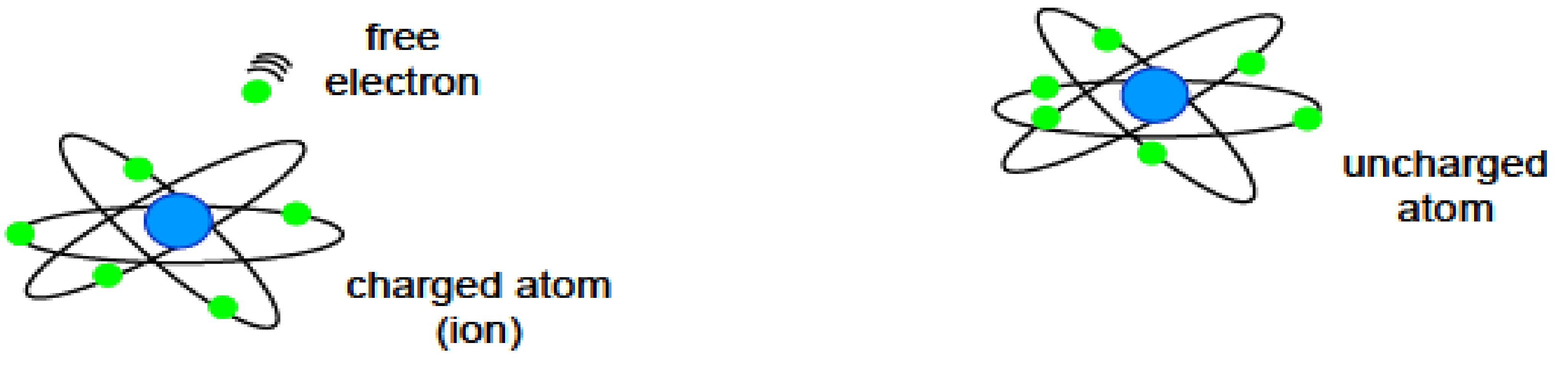
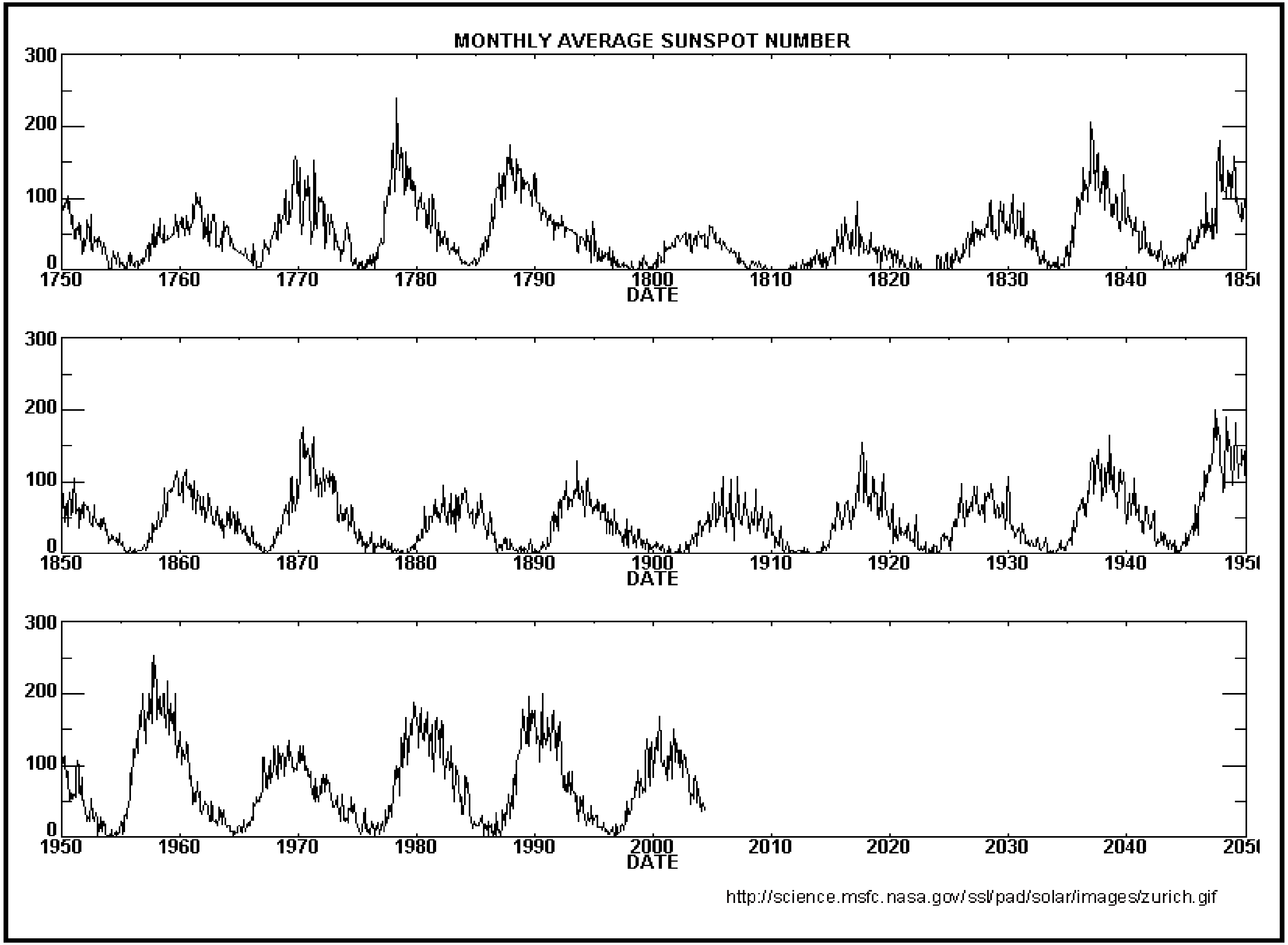


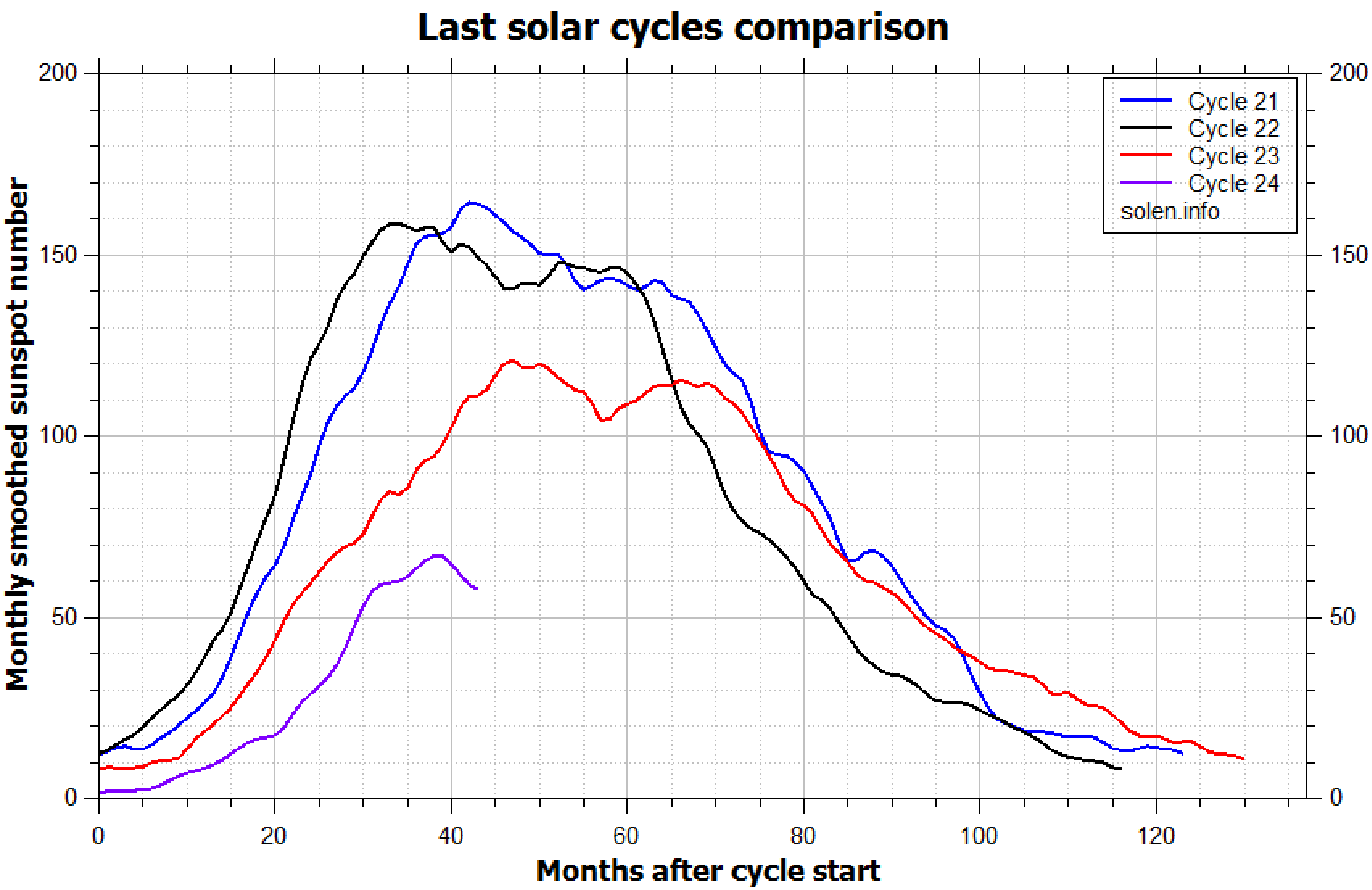
Figure 1.3 *Loss of free-electrons in the ionosphere.*

Ionization depends on sunspots

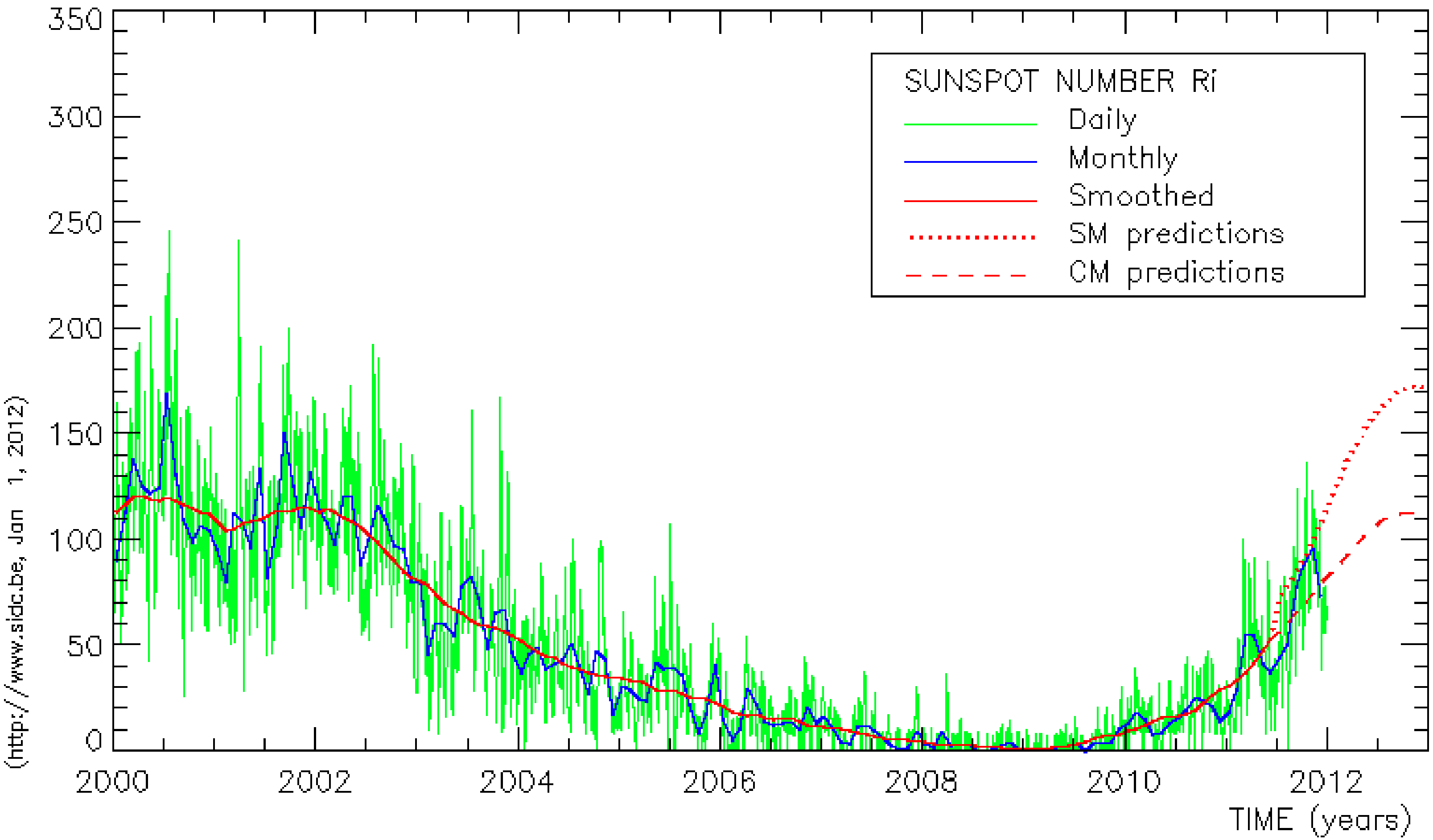
More sunspots → ‘roughly’ more UV radiation



Last 4 Sunspot Cycles - smoothed



2000-2012 Sunspot Number: Daily, Monthly, and Smoothed



Day and Night Ionosphere

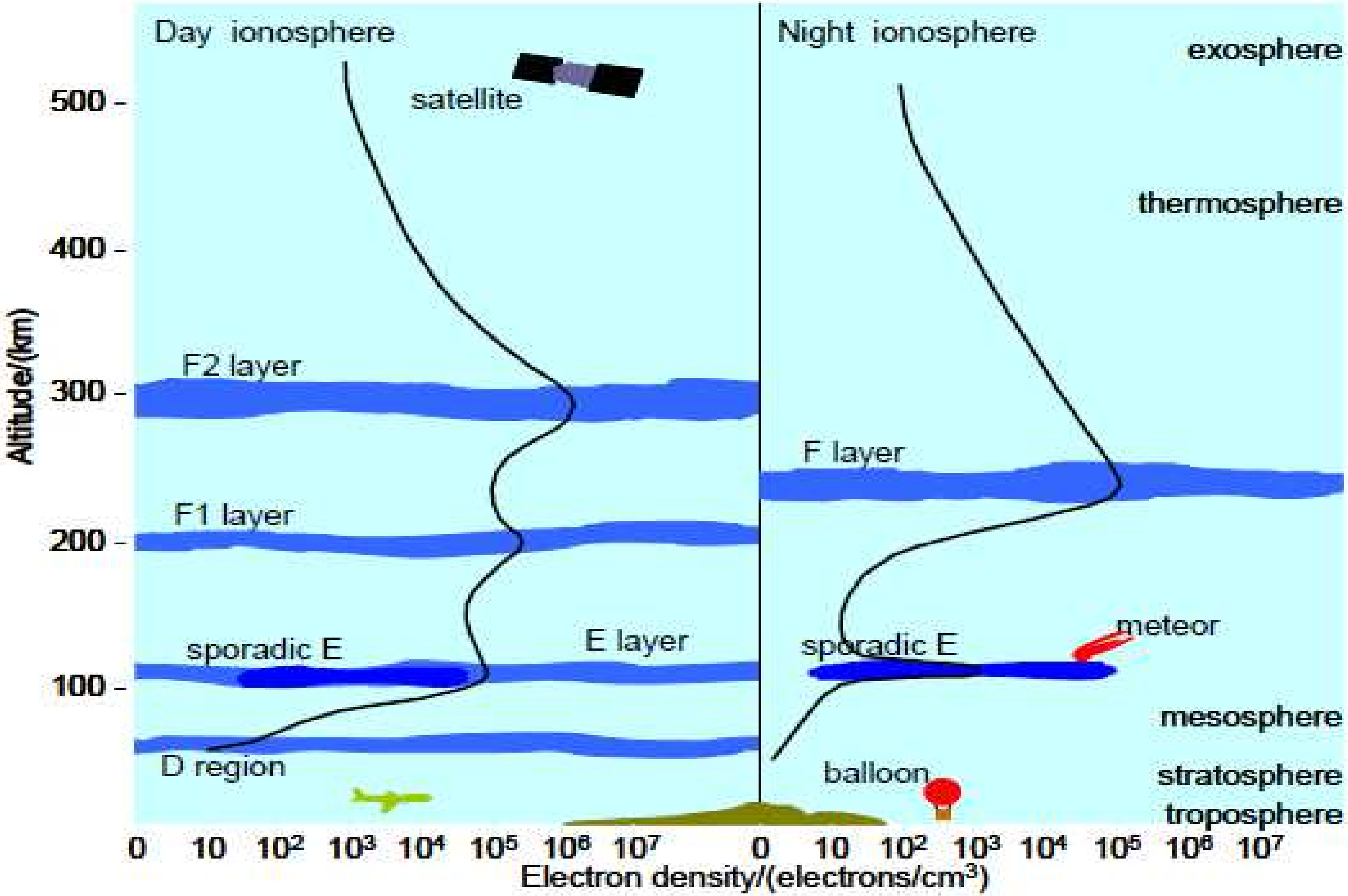
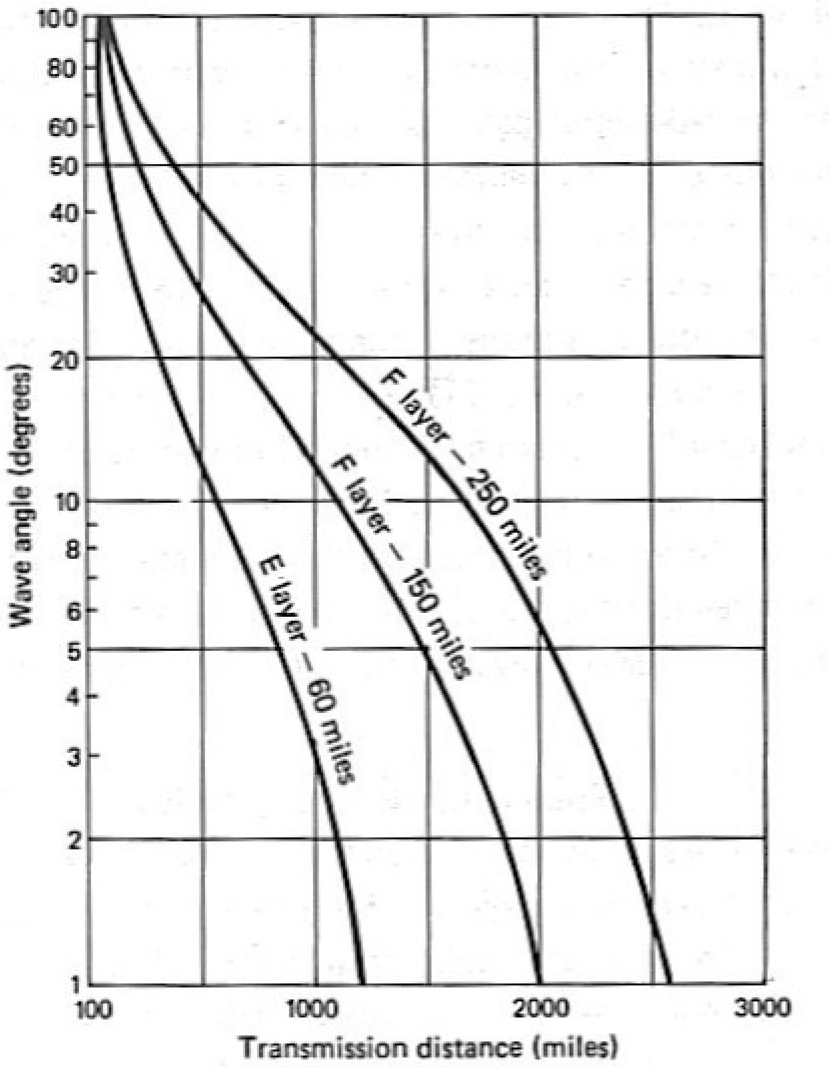


Figure 1.1 *Day and night structure of the ionosphere.*

Hop Length vs. Elevation Angle



F-layer: longer distances
E-layer: shorter distances

Example of different modes

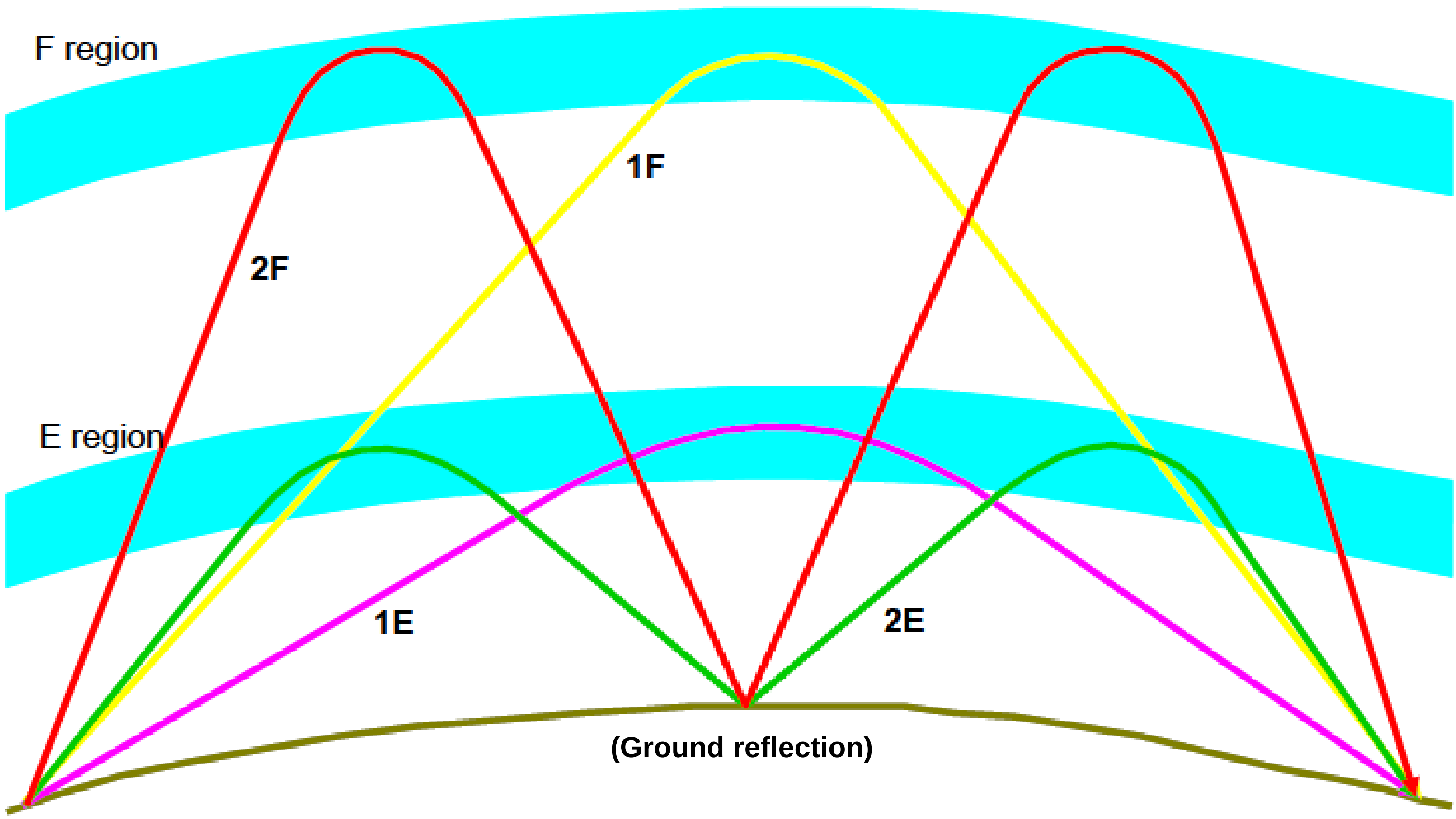


Figure 2.4 *Examples of simple propagation modes.*

Ionospheric refraction depends on the frequency.

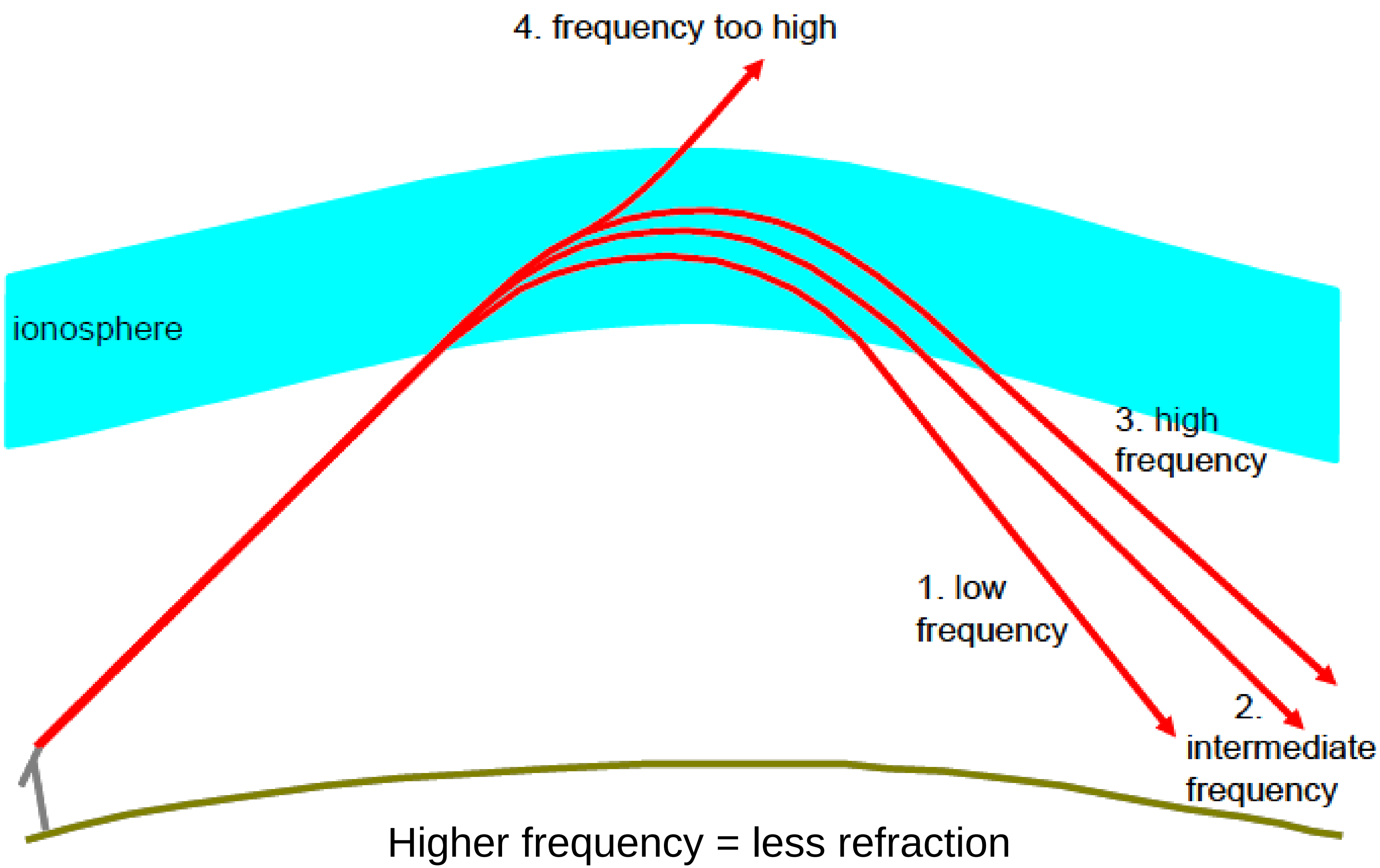
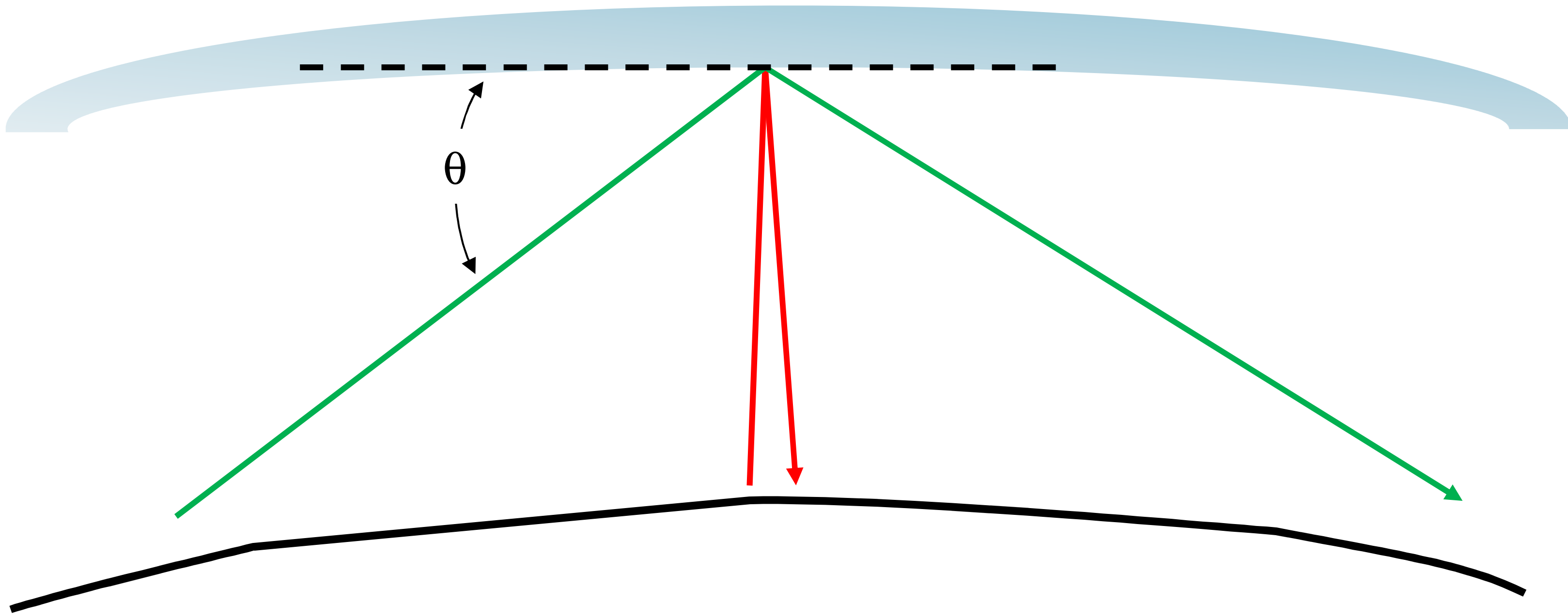


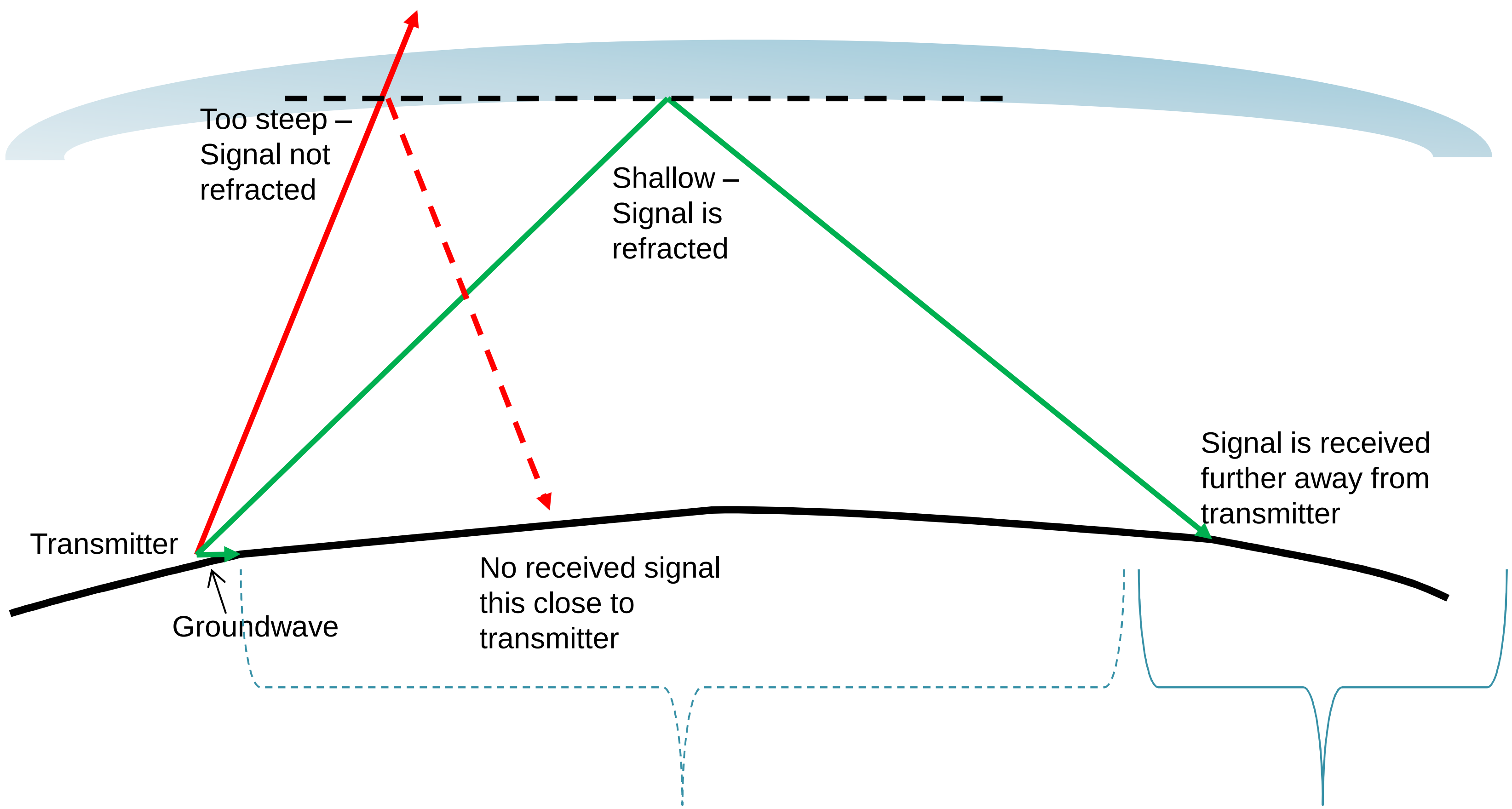
Figure 2.7 *Elevation angle fixed.*

Ionospheric refraction depends on the angle of incidence.



Steep incidence = poor refraction
Grazing incidence = better refraction

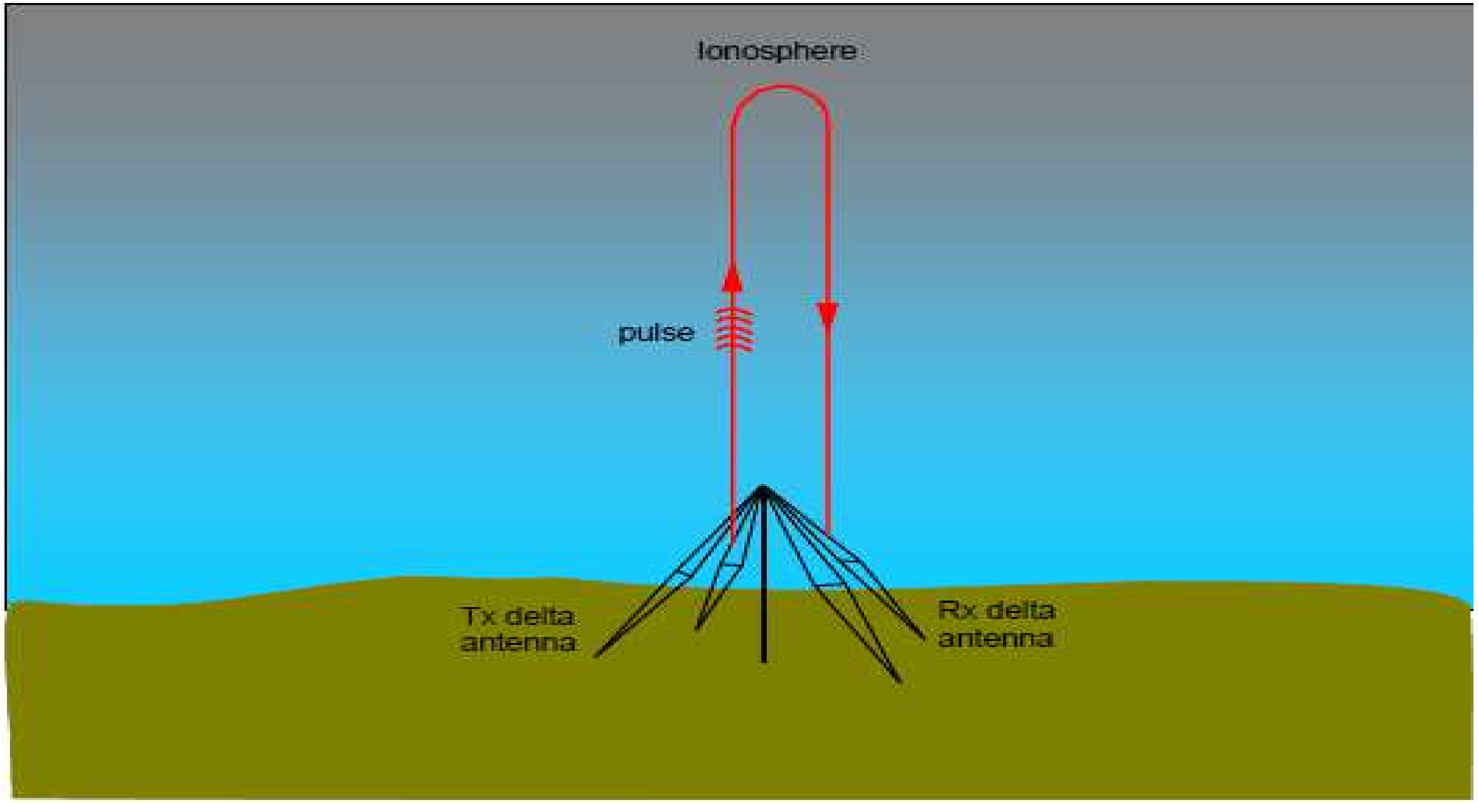
Skip Zone



Range where the signal is not received is called the 'skip zone'

Range where signal is received

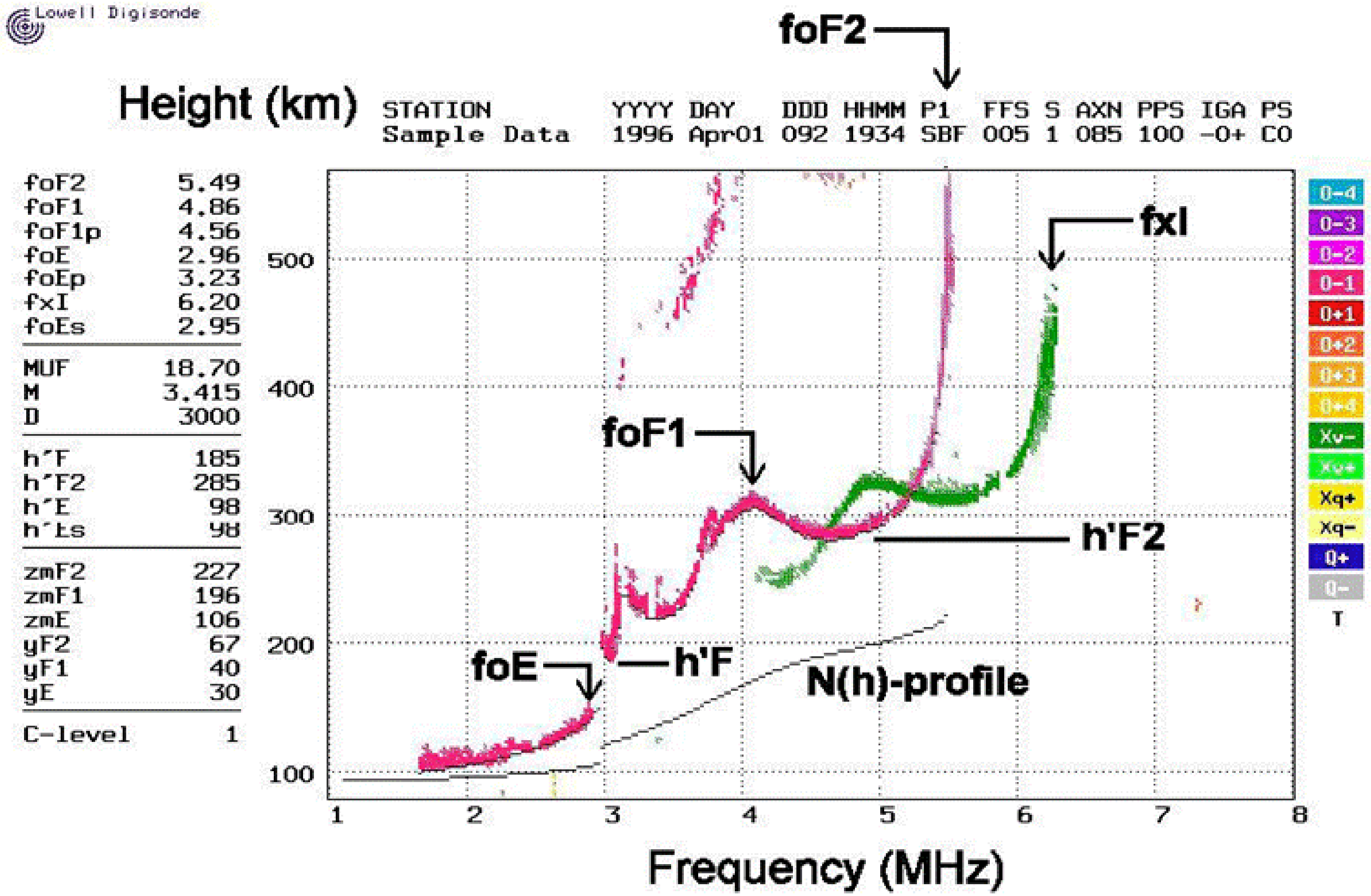
Measuring the Critical Frequency of the Ionosphere – "Ionosonde"



1. Set the frequency of the transmitter and receiver.
2. Launch short vertical pulse. Measure the time-to-return. Time → 2 * Height.
3. Increment the frequency and repeat.
4. Measures vertical incidence – worst MUF. Compute path MUF = Muf90/sin θ

Ionogram

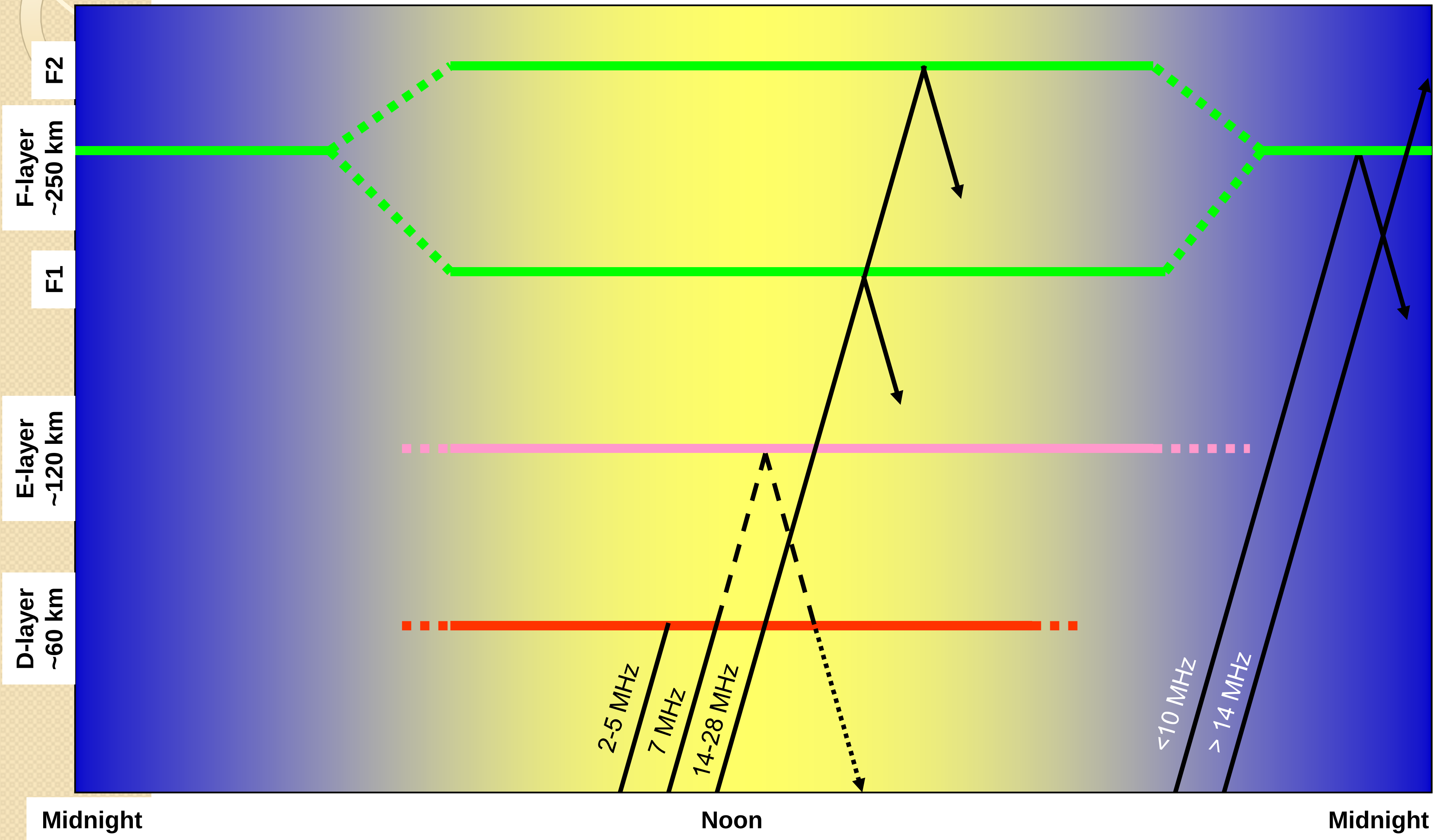
MUF at 90 degrees (vertical) incidence. ‘Critical Frequency’



Some notes

- During the day – lower ionosphere attenuates lower frequency signals. Thus 3.5 MHz is poor.
- After sunset, lower ionosphere disappears due to recombination – 3.5 MHz is much better.
- The higher the frequency the less the attenuation – until the ionosphere *stops refracting*. This is called the Maximum Usable Frequency – “MUF”.
- The MUF depends on the path.
  - High incidence angle = low MUF
  - Grazing incidence angle = higher MUF.
- As the ionization level drops:
  - We lose close-in communication (250 miles) first.
  - Longer distance communication (1000 miles) holds up longer.
    - The band has ‘gone long’.

Summary of HF Effects



Path Prediction

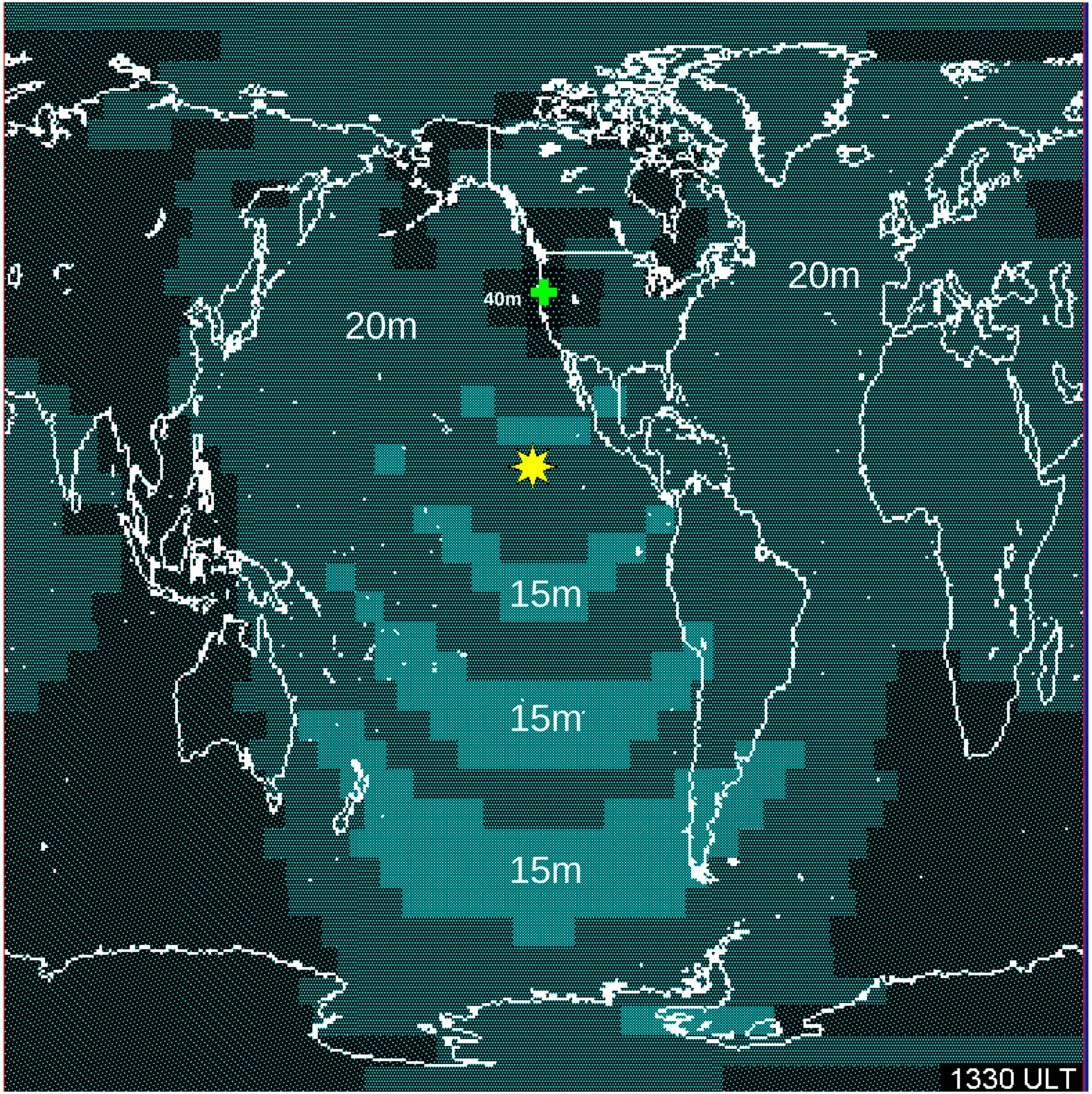
- Things we know well:
  - MUF versus ion density – how waves interact with ionosphere.
  - How the radio waves propagate.
  - Time & Date / The season.
  - Latitude and Longitude of the two end stations.
- Things we don't know well:
  - The amount of solar UV radiation. Only well correlated with smoothed sunspot number. We only have averages.
  - Heating and cooling of the ionosphere → convective currents.
  - Unexpected sudden particle storms and X-ray events
- Approximate the behavior of the ionosphere with known science, plus *statistical data* from prior observations.
- Compute MUF with a probability of success.
- Free software available: W6ELPROP

MUF Map

- August
- Solar Flux = 80
- K = 2

Notice 'skip zones' on 15m.

80m propagates close-in.

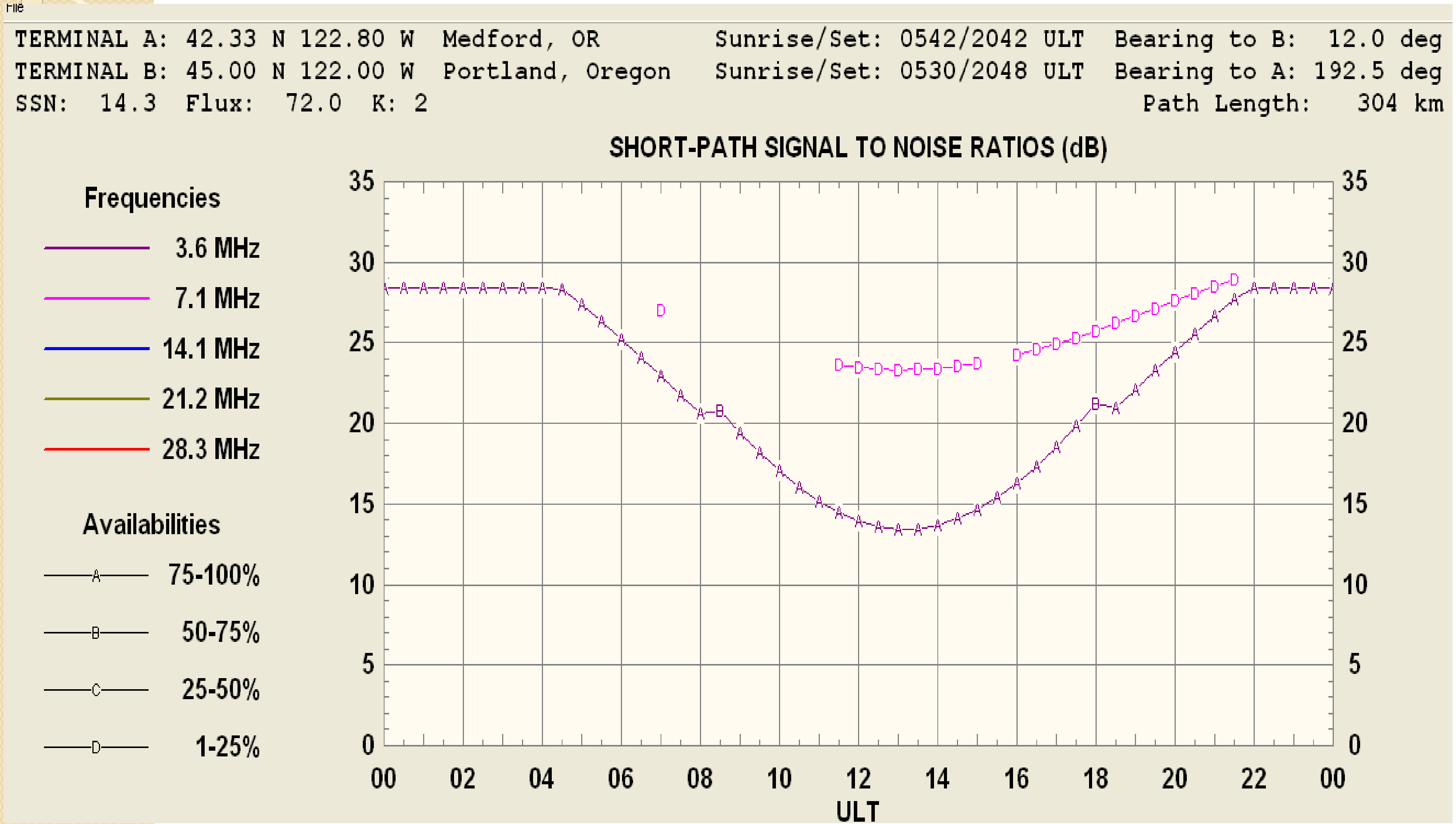


NVIS

- Near-Vertical Incidence Signal
- It’s how we communicate over 200 mile path. High incidence-angle signals.
  - Medford, OR to Portland, OR: 57 degree elevation. 304 km path.
- 160m / 80m / 60m / 40m can support NVIS mode at certain times of the day.
- Antenna pattern should work well for higher-angle signals.

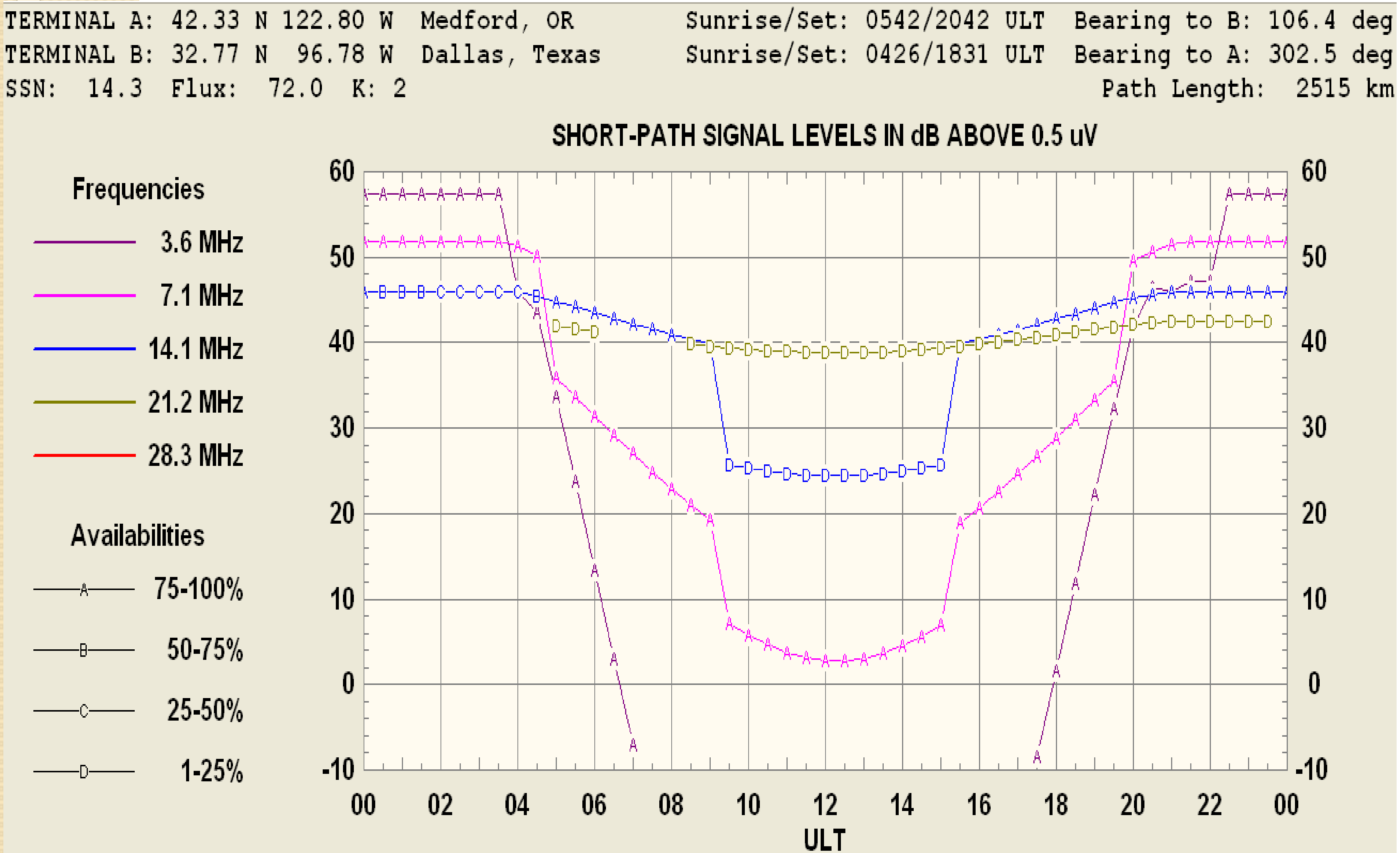
Medford → Portland

June 18. Solar flux = 72



Medford → Dallas, TX

June 18, Solar flux = 72

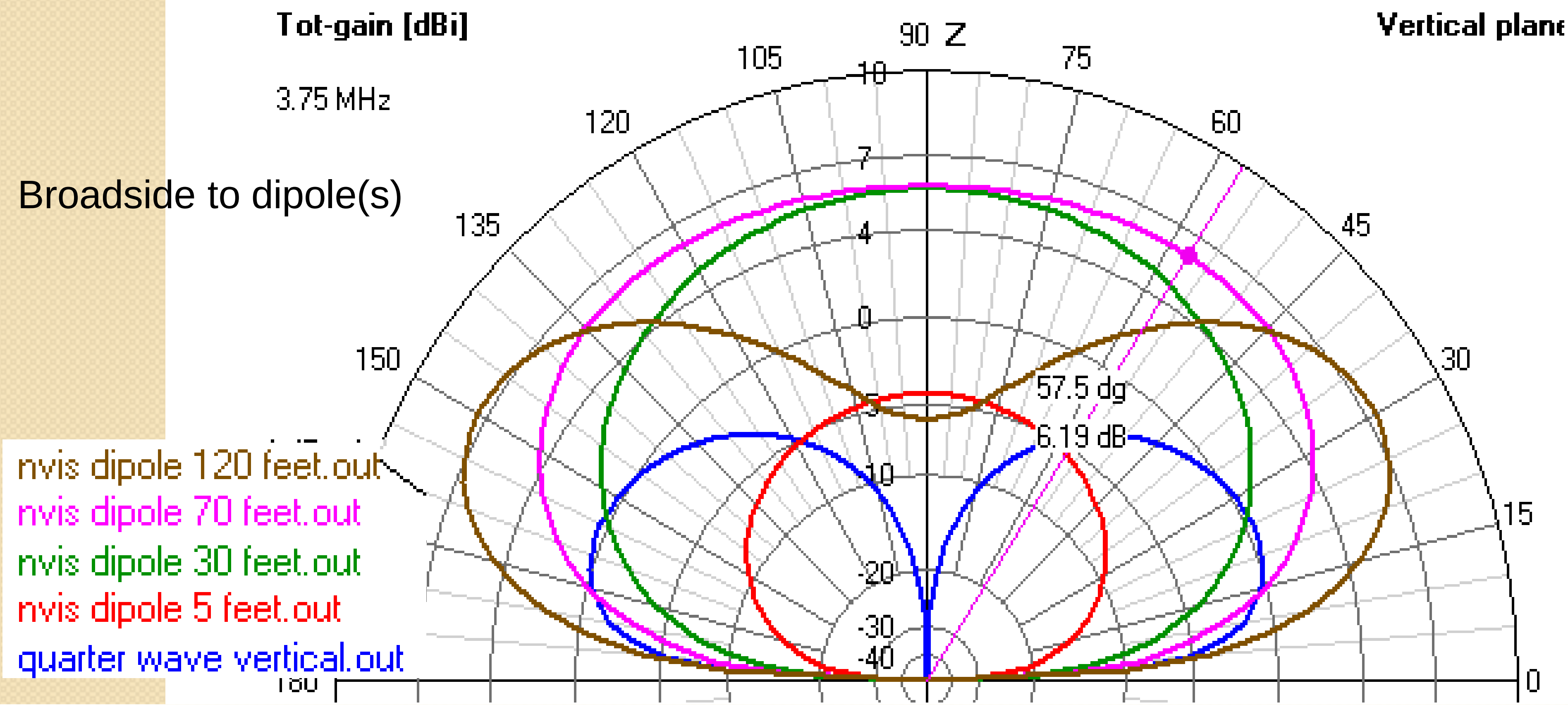


NVIS Antenna Comparison

Medford → Portland, OR – 80 meters

- 57 degree elevation angle for one-hop F-layer propagation.
- 80 meter 5-ft dipole is 13 dB worse than 70-ft dipole for this path (average ground) – primarily ground and antenna loss.
  - Low antenna is earth-warmer (*NOT* cloud burner).

Broadside to dipole(s)



Summary

- UV radiation from the sun creates *free electrons* in the ionosphere.
- Free electrons refract HF radio signals.
- Frequency, incidence angle, sunspot number, latitude and longitude all impact the probability and strength of refraction.
- Result is a very complex relationship.
- We can predict signal strength & probability on a path if:
  - We have a good guess for solar flux & K index.
  - We know all the path parameters.

References

- “Introduction to HF Radio Propagation” Australian Government – IPS Radio and Space Services.

  http://www.ips.gov.au/
- Sheldon Shallon, W6EL propagation prediction program ‘W6ELPROP’ (free)

  http://www.qsl.net/w6elprop/
- Carl Luetzelschwab, K9LA webpage

  http://mysite.ncnetwork.net/k9la/
- Solar Terrestrial Dispatch (real-time MUF and F2 maps)

  http://spacew.com/
- NW7US propagation webpage

  http://prop.hfradio.org/
- This Presentation

  http://www.tapr.org/~n5eg