Thinking in 3-D
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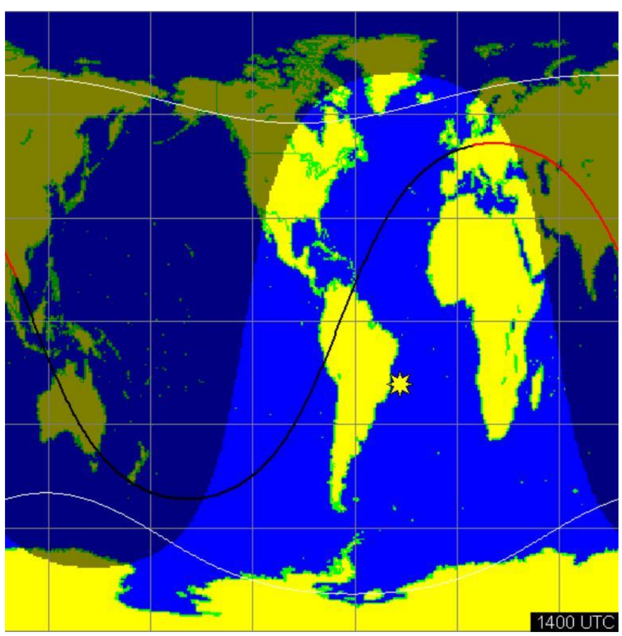
That's an interesting title, isn't it? What does it mean and what's the relevance to propagation?

You may have correctly guessed that 3-D is short for three dimensions. Similarly, 2-D is short for two dimensions. Most of the time we think of the ionosphere as being 2-D. In other words, an electromagnetic wave can go up to the ionosphere and back down to Earth (as in an ionosonde taking data). It can also go forward to a target location (as in working DX). That's the ionosphere in 2-D thinking – up/down in the z direction and forward (and reverse) in a straight line in the x direction (along a great circle path).

In 3-D thinking, we acknowledge that an electromagnetic wave can also deviate from a straight line – it can go in the y direction. We call this a non-great circle path. To be able to do this, the electromagnetic wave must encounter a sufficient horizontal gradient in the electron density (as opposed to the more well-known vertical gradient that refracts signals back to Earth), and then be refracted, reflected or scattered off the straight line path.

Now that we know what 'Thinking in 3-D' means, let's tie this to propagation. We'll do this by looking at an e-mail I received from Charly HSØZCW. His observations over many years led him to conclude that short path signals from HS on 20-Meters end up in Europe and North America stronger than signals going the other way. He reports the difference to be several S-units. The following map from W6ELProp shows the short path (in red) between HS and a European country (Germany) in the middle of November at the best time (around 1400 UTC from VOACAP). We'll use this scenario for further study.



When you think about HSØZCW's comment, his observations are in between two extremes: fully reciprocal propagation in which the signal strengths going both ways are equal, and one-way propagation in which the signal is readable one way but not the other way.

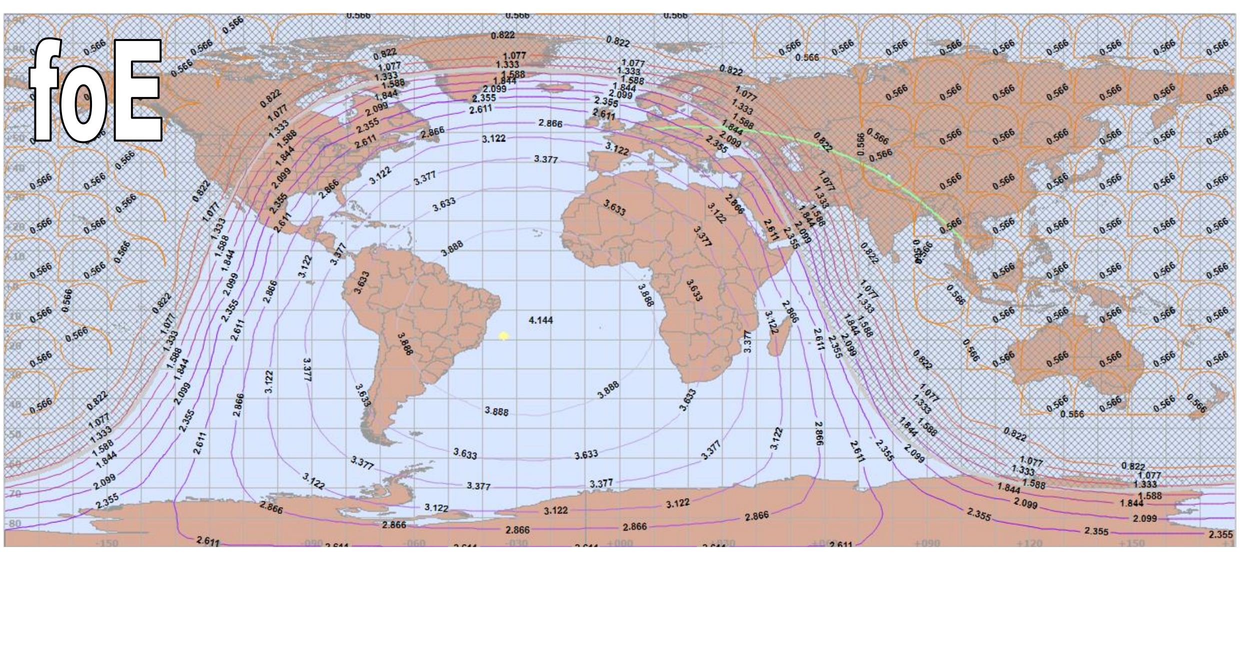
Normally we assume fully reciprocal propagation, but if you've operated for a while you probably can give an example of one-way propagation where you heard a station but he didn't hear you (or vice versa – the other station advised that he heard you but you didn't hear him). Many have written about this one-way condition – including me.

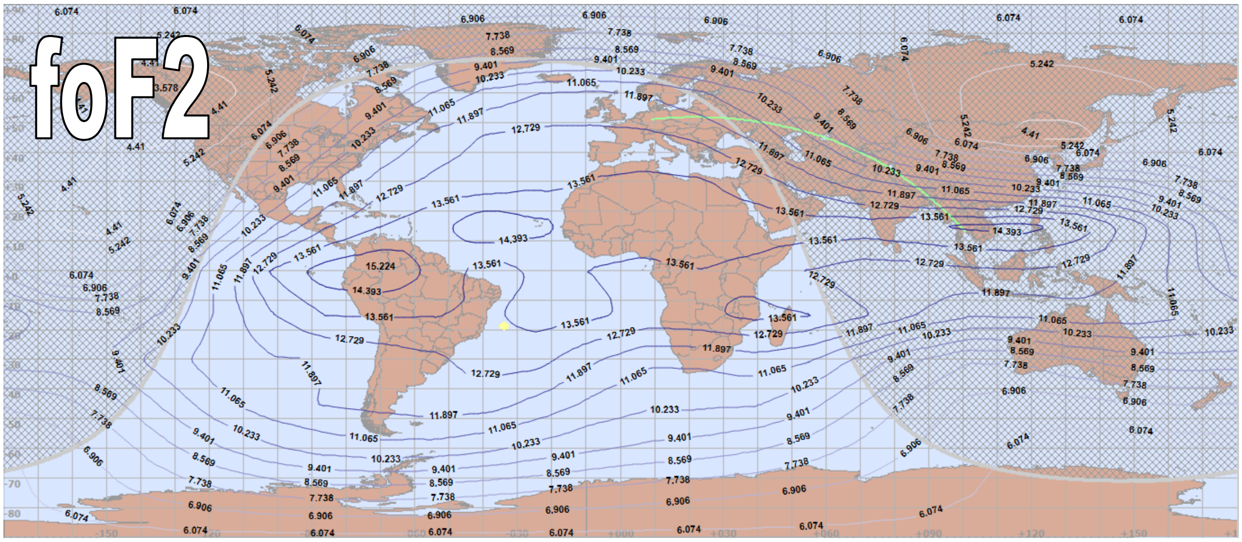
My first article on this was my August 1998 WorldRadio column. I tried to work a station in Florida in the ARRL 10-Meter Contest, but he never heard me answering his CQs. I reviewed possible explanations for this: receiver sensitivity, transmit power, atmospheric noise, man-made noise and a directive antenna pointed in the wrong direction. I also looked at elevation angles in detail on two 20-Meter paths – from W9 to 9A and from W9 to KH6. Regardless of the direction, transmit and receive elevation angles were quite similar.

In my February 2015 Monthly Feature, I again wrote about one-way propagation. I looked at East-West and North-South one-hop paths on 160-Meters to assess the impact of the electron gyro-frequency on 1.8 MHz. The N-S path had less absorption (by about 3 dB) than the E-W path, but whether the direction was N-S versus S-N or E-W versus W-E didn't matter. I went through this exercise on 7 MHz, too, and 40-Meters didn't show any bias towards N-S versus E-W. Again there was no real "aha!" moment to fully explain one-way propagation.

These two articles have one thing in common – they assumed the ionosphere was 2-D. In other words, I looked at what I thought was everything – except non-great circle paths due to horizontal electron density gradients. So let's do a full 3-D analysis of the HS-to-DL path shown in the earlier W6ELProp map. What we're looking for is a scenario where skewing takes the RF away from the great circle path, and pointing our antenna along the great circle path results in a signal strength that is many dB down from where the signal is really coming.

Let's first look at the worldwide ionosphere in the middle of November at 1400 UTC. I'll assume sunspot maximum for a large cycle (R_{12} = 150), which should provide large horizontal electron density gradients. The first map is foE values (E region critical frequencies), and the second map is foF2 values (F2 region critical frequencies).

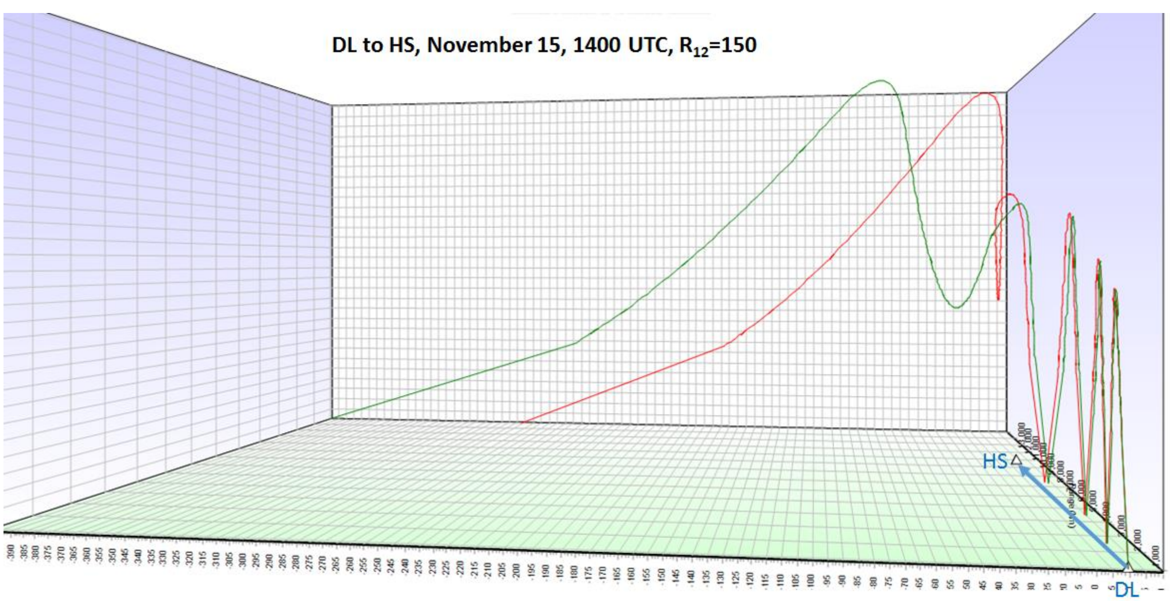




For both maps, the path between HS and DL is the green line. The DL end has the highest values of foE (around 2.3 MHz where the RF would encounter the E region) as the DL end is still in daylight. With the E region MUF (maximum useable frequency) at low elevation angles about 5 times foE, the 20-Meter electromagnetic wave out of (or into) DL will not be affected by the E region. On the HS end, the E region is definitely out of the picture since it's in the dark ionosphere. Thus the E region shouldn't affect this 20-Meter path.

The F2 region is another story. With the F2 region MUF at low elevation angles about 3 times foF2, the MUFs along and near the path are above 30 MHz. This will definitely affect 20-Meters. There are also horizontal electron density gradients present, with the HS end having the steepest gradients (contour lines closest together). The signal could be skewed more northward (to the left out of DL and to the right out of HS) due to the gradients decreasing to the north.

Doing ray traces with PropLab Pro V3 shows this. This plot is from DL to HS.

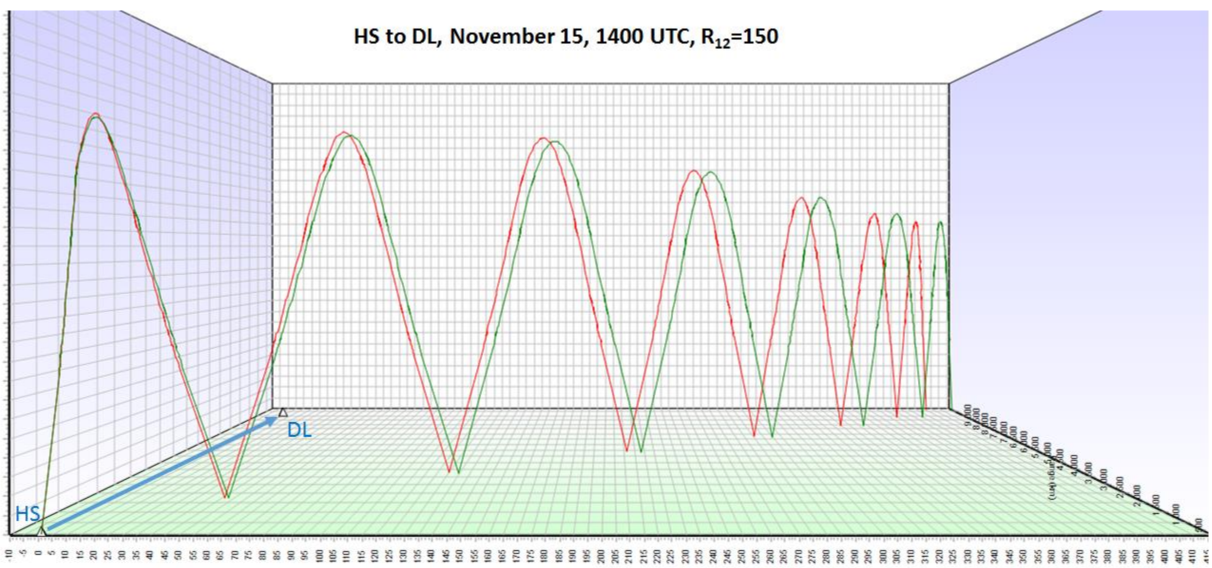


The red trace is the ordinary wave, and the green trace is the extraordinary wave. The blue arrow line is the great circle path from DL to HS (80.2 degrees). The horizontal axis is the lateral distance (in km) off the great circle path. The rays are at an elevation angle of 10 degrees.

Both waves pretty much follow the great circle path out of DL, indicating that the E region and F2 region gradients on the DL end of the path do not affect the RF's path. But on the HS end, where the steepest F2 region gradients occur, both waves skew to the left (to the north) as speculated earlier from the worldwide map of the F2 region critical frequencies.

The extraordinary wave skews a bit more, indicating that the index of refraction it sees (due to the Earth's magnetic field) is a bit smaller than the index of refraction that the ordinary wave sees. Due to the view presented, the altitude scale is not seen – the first three hops and the apex of the fourth hop are indeed at F2 region heights. And there's a hint of ducting between the E and F2 regions right at the end.

This next plot is from HS to DL.



Again, the red trace is the ordinary wave, and the green trace is the extraordinary wave. The blue arrow line is the great circle path from HS to DL (320.5 degrees). The elevation angle for both traces is 10 degrees.

Due to the HS end having the steepest F2 region gradients, both the ordinary and extraordinary waves immediately skew to the right (to the north) and then don't skew very much anymore. And again we see a slight difference between the indices of refraction of the ordinary and extraordinary waves. The altitude reached by both waves is the F2 region.

Both ray traces (DL to HS and HS to DL) make it look like there's major skewing taking place. But if you look at a signal traveling 9025 km (the distance between HS and DL) and ending up something like 400 km off target (from the worst case lateral distance of the HS to DL trace), you'll see that this is only 3.6 degrees off the true great circle path. Thus the electromagnetic wave out of HS that gets to DL would be several degrees to the left of the great circle path (to compensate for skewing to the right). That isn't much, and even a big 20-Meter antenna (like a 6-element monobander) couldn't tell the difference between the great circle path and this magnitude of a skewed path.

For the record, I also looked at other elevation angles – from 5 degrees to 20 degrees. My results at 10 degrees appear to be the worst case. I also looked at smaller smoothed sunspot values – less skewing occurred (as expected) as the sunspot number decreased.

So where are we with this investigation? I have to admit that nothing positive came out of this to explain HSØZCW's observations. My efforts were interesting (and certainly time consuming), but the fat lady still hasn't sung on this topic.

Finally, I would be remiss if I didn't say that I thought about the accuracy of HSØZCW's observations. There really isn't any strict standard nowadays for calibrating S-meters. Sure, Collins had a standard way back when, but my measurements of modern receivers show S-meter readings to vary quite a bit. For example, here's a table of S9 versus signal power on three receivers I own.

S-meter reading	TS-180	FT-747	OMNI-VI
S9	-72 dBm	-80 dBm	-66 dBm

The receivers are different by a bit more than one S-unit, which is less than what HSØZCW reported. This suggests that his observations are likely valid. Having calibrated S-meters on each end would certainly resolve this issue for good.

In conclusion, assuming HSØZCW's observations are true (and I see no major reason why they aren't), skewing doesn't appear to be the answer.