Using Auroral-E Propagation to Explain an HF QSO

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Remember the movie *Star Trek IV – The Voyage Home*? Captain Kirk and the crew went back in time to 1986 to get a humpback whale. They needed the whale to respond to an alien probe that was destroying the Earth in the 23rd century (whales were extinct in the 23rd century). After beaming up the whale (along with tons of water), Bones (Dr. McCoy) noticed that Spock had a perplexed look on his face. Bones asked what was wrong, and Spock said he didn't know the exact weight of the whale and water to use in his time-travel calculations to get back to the 23rd century. Bones, knowing that Spock was the extreme scientific type, told him that sometimes you just have to take your best shot.

There's a parallel in ionospheric matters to this fictional story – it's trying to understand how an every-once-in-a-while event happened. Without a daily model of the ionosphere and without the exact data we need, sometimes we also have to just take our best shot at explaining what happened.

A good example of this is an e-mail I received long ago from Jim K5RX. He mentioned a QSO with SM2EKM in the February 2004 ARRL International DX Contest (the CW weekend). The QSO was on February 22, 2004 at 2047 UTC on 10m. Around that time he didn't work any other Scandinavian stations, nor did he work any other Europeans. He also didn't hear any East Coast stations on the direct short path (W1s, VEs, etc). How did this happen?

A First Look

Let's start with the 'big picture'. Figure 1 is a great circle map (also known as an azimuthal equidistant map) for the K5RX-to-SM2EKM QSO with a K index of 3 (from the Ottawa observatory at the time of the QSO). The center of the map is K5RX, and the thick dark line is the great circle short path between Jim and SM2EKM. Note the arrow to the right of the path indicating 3500 km out of K5RX (more on this later). This map comes from Oldfield's DXAID software, with additional annotations added.

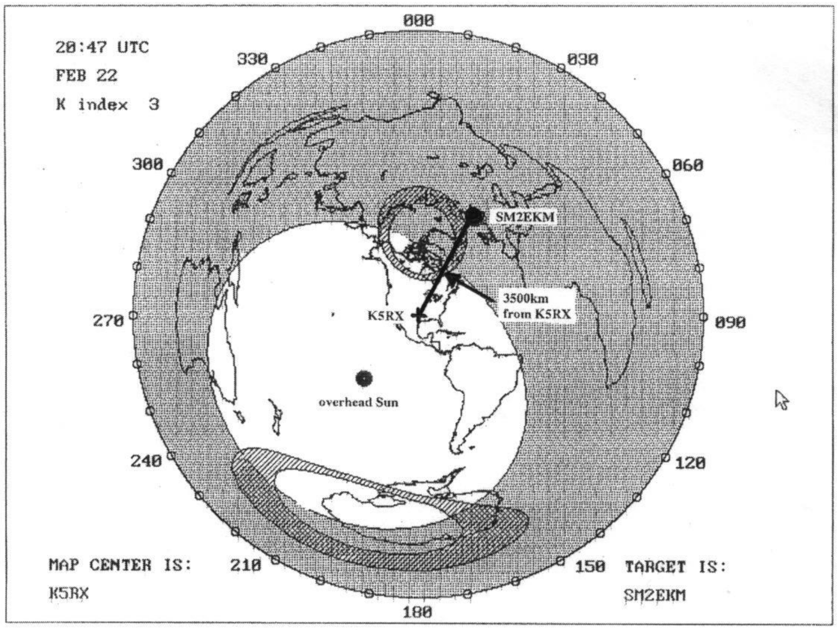

Figure 1 K5RX to SM2EKM – the big picture

The first half of the path (the K5RX end) was in daylight. The last half of the path (the SM2EKM end) was in darkness, and went through the auroral oval tangentially.

The Hypothesis

Based on Jim's comments about not hearing the East Coast and based on the SM2EKM end of the path being in darkness and going through the auroral oval tangentially, my hypothesis is that a very long F2 hop out of K5RX got the signal near the auroral oval (long enough to over fly the East Coast). Then auroral E hops (two or three of them) took it the rest of the way into SM. Let's see if we can test my hypothesis of a very long F2 hop coupled with auroral E by using basic ionospheric concepts and ionosonde data.

Testing for a Long F2 Hop

Cycle 23 was on the decline in 2004, with the February 2004 smoothed sunspot number at 49.3. That's getting low enough so that there might not be enough ionization to refract higher angle (closer in) 10m RF back to Earth.

The distance from K5RX to the East Coast is at most about 2500 km, and that requires an elevation angle of about 6 degrees when the height of the F2 region peak electron density is about 260 km (what it was around the time of the QSO over the area in question). Let's assume that there's not enough ionization to refract this elevation angle back to Earth on 10m – it goes through the ionosphere. But what happens to lower elevation angles? With the F2 region MUF inversely proportional to the sine of the angle of incidence on the ionosphere, a lower elevation angle could be refracted back to Earth on 10m – and it would be a longer hop, too.

The thought here is that the ionosphere could only support a very long (very low angle) 10m F2 hop at this point in Cycle 23 – maybe something on the order of 3500 km (the arrow in Figure 1), which would put the mid point just northeast of the Great Lakes and the end point way up in Canada and in the vicinity of the auroral oval to take advantage of auroral E. Now let's look at the F2 region ionosonde data from Millstone Hill (MA), which is the closest ionosonde to the mid point of this path. For the record, Millstone Hill is about 1000 km southeast of the mid point. Figure 2 shows the data.

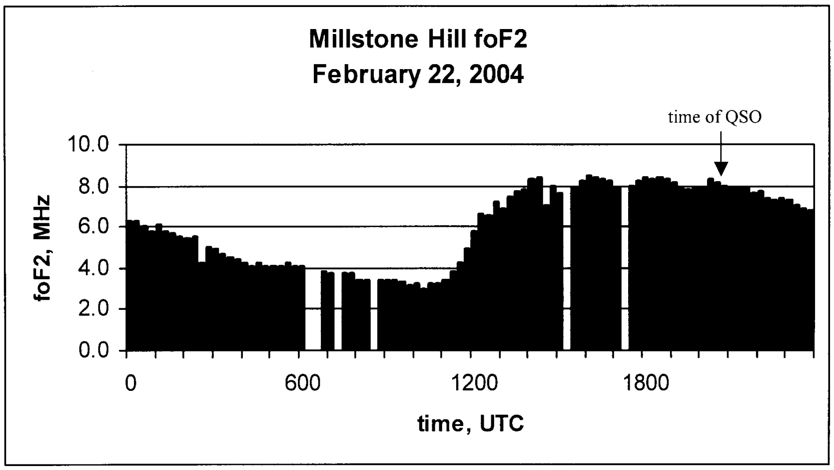

Figure 2 Millstone Hill foF2 data

At the time of the QSO, Millstone Hill was reporting an F2 region critical frequency foF2 of around 8 MHz. The 3000 km M-factor (what you multiply foF2 by to get the 3000 km MUF) was reported to be around 3.4. So the F2 region MUF for a 3000 km path, if Millstone Hill was at the mid point, would have been 27.2MHz.

For a 3500 km path with a lower elevation angle (our hypothesis), the MUF would be slightly higher at about 29.4 MHz. For a 2500km path with a higher elevation angle (K5RX to the East Coast), the MUF would be slightly lower at about 25.9 MHz. So K5RX couldn't work the East Coast at 2500 km (or anything shorter) due to not enough ionization, but he could work longer distances at 3500 km. As can be seen in Figure 1, 3500 km out of K5RX is for all intents and purposes in a very unpopulated area of Canada – there's no one around to QSO K5RX.

It'd be nice to have an ionosonde closer to the midpoint of this 3500 km path, but we're simply out of luck here. All we can say is that the magnetic latitude of the midpoint of the 3500 km path is a little farther north than the magnetic latitude of Millstone Hill (57 degrees N compared to 52 degrees N, respectively) and that the solar illumination is about the same, so the ionosphere over the midpoint was probably just a wee bit less ionized compared to what Millstone Hill measured and reported. Thus the MUF values given in the previous paragraph, which are over Millstone Hill, would be several tenths of a MHz lower if they were over the midpoint of the 3500 km path – which still says the hypothesis of a very long (very low angle) F2 hop is valid.

Testing for Auroral E

From my April 1997 Propagation column in WorldRadio, the important characteristic of auroral E is that during a winter month auroral E occurs on about 35% of the days of the month at that portion of the auroral oval at local midnight. The probability of occurrence decreases as you get farther away from the midnight portion so that it's a low probability at 6 hours on either side of local midnight.

In Figure 1, local midnight is where the auroral oval is thickest, which is on the line from the overhead Sun through the center of the polar cap. Where K5RX's RF would encounter the auroral oval after the very long F2 hop is about 5 hours prior to local midnight. This is within the statistical occurrence pattern of auroral E.

Now let's look at E region ionosonde data from the Narssarssuaq ionosonde (at the southern tip of OX), which is the ionosonde closest to the path. For the record, Narssarssuaq is about 500 km south of the path.

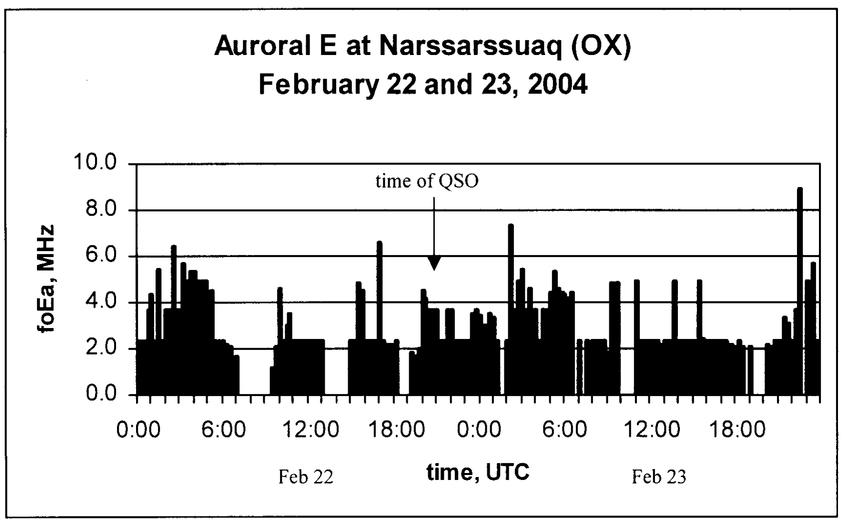

Figure 3 Narssarssuaq Auroral E data

Since Narssarssuaq isn't directly under the K5RX-to-SM2EKM path, we really can't say anything definite about what was happening in the E region along the path at the time of the QSO. All we can say is that it is highly likely that sufficient auroral E activity was going on in the area based on the K index, the auroral E activity over Narssarssuaq (as seen by foE values way above the normal nighttime value of about 0.5 MHz), and several of the Narssarssuaq foE values being high enough to refract 10m back to Earth (since the E region MUF is about 5 times foE).

Other Mechanisms

It's always interesting to consider other mechanisms explaining how an every-once-in-a-while event occurred. Regardless of the hypothesis, the first question to answer is "can the physics of the ionosphere support the hypothesis?" If it can, then the second question to answer is "do the observations match the statistical pattern of the ionosphere?"

Conclusion

The hypothesis of a very long F2 hop coupled with auroral E hops is statistically possible, albeit at a low probability, and offers the most likely explanation. This hypothesis also matches Jim's observations, and the ionospheric physics is there to support it.

Note that the total probability of this path happening depends on the probability of the very long F2 hop times the probability of the auroral E hops. Since the F2 region is involved in the first half of the path, the total probability will depend on where we are in a solar cycle. This says this path was more likely on 10m prior to February 2004. It also says 15m should be more likely than 10m. But watch it here - we can't continue extrapolating higher probabilities as we go lower in frequency because absorption, which is inversely proportional to the square of the frequency, soon takes over.

Summary

The goal of this column wasn't to explain how this K5RX-to-SM2EKM QSO occurred – although we kind of ended up doing that. The real goal was to show how we're sometimes between the proverbial rock and hard place when trying to explain an every-once-in-a-while occurrence in propagation.

The problem is two-fold. Our model of the ionosphere is a monthly median model (an average of the ionosphere over a month's time frame, so to speak), so it's tough trying to determine what happened on a specific day (especially at high latitudes where the day-to-day variation of the ionosphere is much more dynamic). And when we look for ionosondes to get some real-time data, they're so few and far between that usually they're not in the right places (i.e., not along the path).

Thus all we can do to explain these every-once-in-a-while occurrences is understand the characteristics of the ionosphere, match the event to the statistical patterns of the ionosphere, and then go with the one that is most likely. Although we know a lot about the ionosphere, it's dynamic enough to realize that what Bones told Spock is sometimes very applicable to our endeavors.