Inferring 6m Propagation Modes from E_s and F_2 Probabilities

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In the summer of 2005, Scott N9AG operated as J68AS (St Lucia). From June 23 through July 2, he made 382 QSOs with EU on 6m. He said most everyone believed this to be propagation via 3 or 4 hop E_s (sporadic E). Let's try to confirm this with our knowledge of the statistical pattern of E_s. And if we don't succeed, we'll look at other possibilities.

QSO Data

Figure 1 plots the 6m EU QSOs for all the days when J68AS was active.

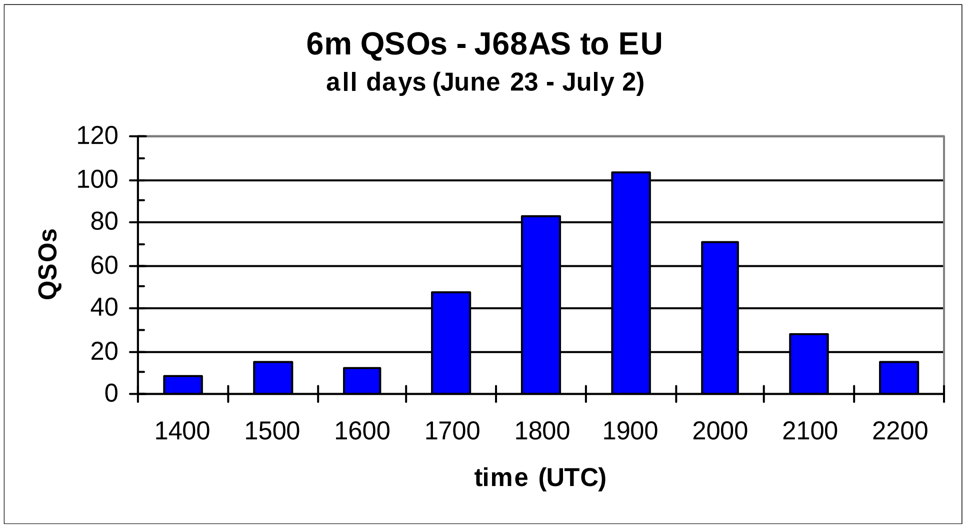

Figure 1 – J68AS 6m EU QSOs versus time of day

The most productive day was June 29, with almost 40% of the QSOs. The second most productive day was July 1, with almost 20% of the QSOs. July 2 took third place, with just over 10% of the QSOs.

In essence Figure 1 is a probability distribution, with the highest probability of 6m J6-to-EU QSOs centered on 1900 UTC for the late June through early July 2005 time period (the individual days cited in the previous paragraph follow the same general pattern as Figure 1). The question we'll try to answer is "does the statistical pattern of E_s between J6 and EU match this statistical pattern of the actual QSOs?"

E_s Methodology

To determine the statistical pattern of E_s propagation between J6 and EU, we'll use the plot of 50MHz E_s probabilities from the USAF Handbook of Geophysics [note 1]. Figure 2 shows this plot.

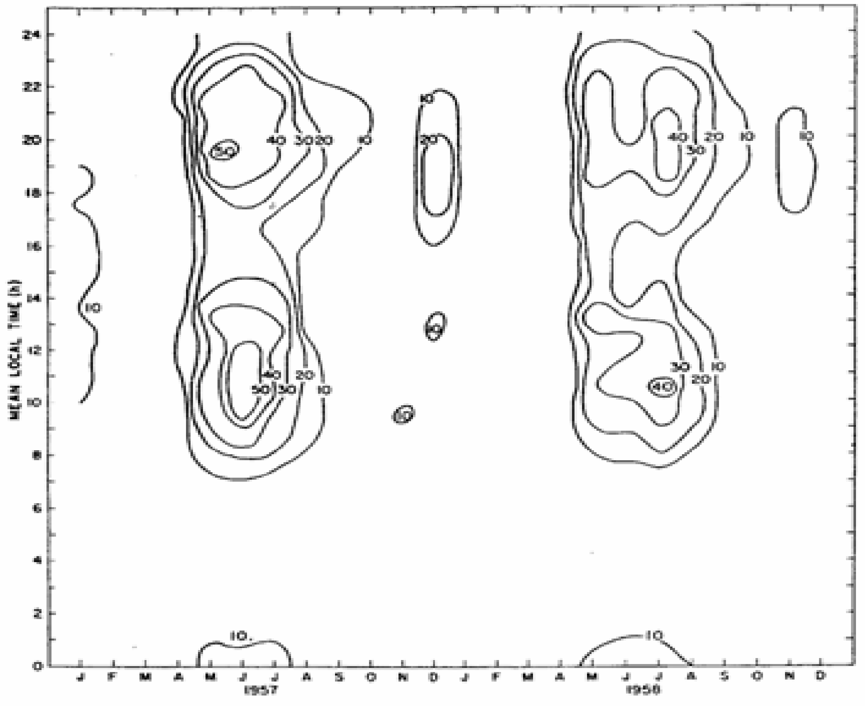

Figure 2 – 50MHz E_s probabilities

The plot gives the probability of 50MHz E_s for all months versus local time over a two year period, and is applicable to mid latitudes (roughly 30 to 60 degrees). The contour lines are percentages. For example, using the left-most data, the probability of 50MHz E_s at the beginning of June at 1PM local time is about 45%. The term 'local time' refers to the midpoint of the path. Thus we need to know the local time of the mid point of each hop along the J6-to-EU path.

E_s Analysis

For the analysis, we'll use a path between J6 and HB (7283 km). We'll assume this is a 4 hop path (each hop is 1820 km). This defines where the apogees (and mid points) of the four hops encountered E_s clouds: at 55°W longitude, at 41°W longitude, at 24°W longitude, and at 4°W longitude. Next the local times at these four encounter points were determined, and the left-most data of Figure 2 for the 1400 to 2200 UTC period was used for probabilities. The results of this exercise are in Table 1.

	55°W		**41°W**		**24°W**		**4°W**		**overall**
UTC	**local time**	**prob**	**local time**	**prob**	**local time**	**prob**	**local time**	**prob**	**prob (decimal)**
1400Z	10AM	40%	11AM	42%	Noon	42%	2PM	35%	.0247
1500Z	11AM	42%	Noon	42%	1PM	42%	3PM	27%	.0200
1600Z	Noon	42%	1PM	42%	2PM	35%	4PM	21%	.0130
1700Z	1PM	42%	2PM	35%	3PM	27%	5PM	20%	.0079
1800Z	2PM	35%	3PM	27%	4PM	21%	6PM	31%	.0062
1900Z	3PM	27%	4PM	21%	5PM	20%	7PM	42%	.0048
2000Z	4PM	21%	5PM	20%	6PM	31%	8PM	42%	.0055
2100Z	5PM	20%	6PM	31%	7PM	42%	9PM	42%	.0109
2200Z	6PM	31%	7PM	42%	8PM	42%	10PM	40%	.0219

Table 1 – Probabilities for 4 E_s hops

Assuming that the probability of each E_s cloud at each encounter is independent (in other words, a huge E_s patch did not occur along the entire path from J6 to EU), the four probabilities were multiplied together to give the overall probability of a 4-hop E_s path (the last column in Table 1). This probability is plotted in Figure 3 [note 2], which also includes the actual QSO data from Figure 1.

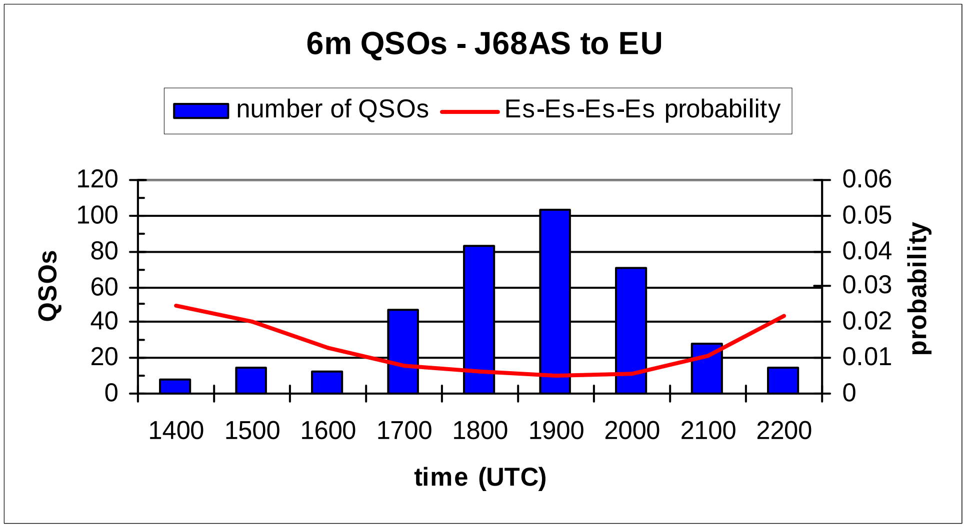

Figure 3 – Comparison of E_s-E_s-E_s-E_s probability with QSO data

It is quite obvious that the 4-hop E_s probability appears to be out of phase with the actual QSO data [note 3]. This suggests that the J68AS 6m QSOs with Europe may have involved more than just E_s modes. The obvious next step is to look at F_2 modes to see if there's a better fit between the distribution of actual QSOs and F_2 probabilities.

A Look at F_2

To see if we're on the right track with an F_2 mode, we'll look at the median MUF (maximum usable frequency) for a 3000km F_2 hop out of J6 towards EU. We'll do this using the worldwide MUF maps that can be generated in Proplab Pro (Solar Terrestrial Dispatch). Figure 4 shows the median MUF data at an effective sunspot number (SSNe) of 45 (from www.nwra-az.com/spawx/ssne.html) centered on June 29 – the mid point of N9AG's DXpedition.

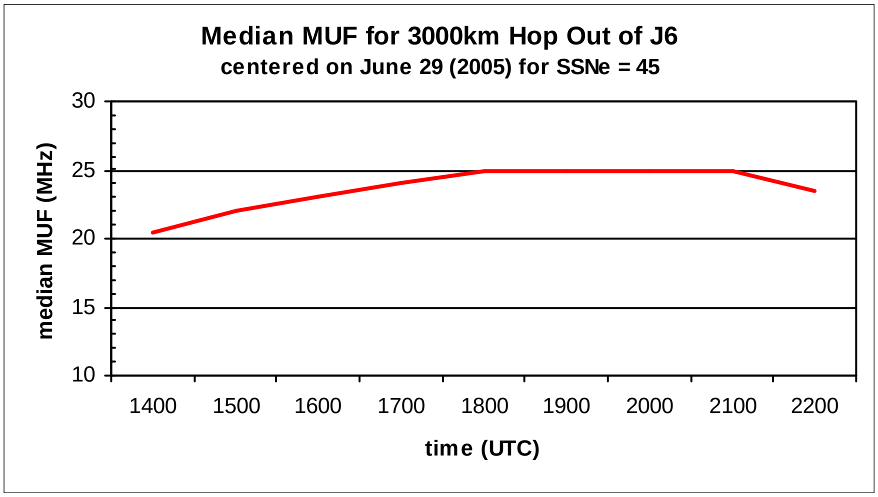

Figure 4 – Predicted 3000km median MUF

This data is very encouraging. It shows that for a 3000km path from J6 towards EU the F_2 region maximizes around the time of the QSOs [note 4]. But it's obvious we have a problem – and that is the median MUF is not close enough to 50MHz to predict any probability of propagation on 6m. Does this mean F_2 wasn't possible? Not necessarily – we need to consider three mechanisms that can increase the MUF.

Increasing the F_2 MUF

The first mechanism that may increase the F_2 region MUF is a hop longer than 3000km. As the hop length increases, the MUF increases because the wave needs to encounter the electron density at more of a grazing angle for a longer hop. A single F_2 region hop on 6m longer than 4000km (the accepted limit for HF propagation) may be possible. In fact, parabolic layer theory predicts this [note 5]. The caveat is that radiation at an extremely low launch angle is needed – which shouldn't be a problem on 6m due to typical antenna heights in terms of an electrical wavelength.

The second mechanism involves help from the underlying E region. The MUF for the F_2 region is a function of the electron density (measured in terms of the critical frequency f_oF_2) and the angle at which the electromagnetic wave encounters the F_2 region (which in turn is dependent on the height of the layer). Due to the spherical Earth-ionosphere geometry, the lowest angle at which a wave launched at a 0 degree elevation angle can normally encounter the F_2 region is around 20 degrees. This limits the MUF to approximately three times the f_oF_2 value (from one over the sine of the angle). To achieve a higher MUF, more of a grazing angle on the F_2 region is needed – which may be possible with some refraction help from the underlying E region.

The third mechanism is over-the-MUF propagation. Often signals are received at frequencies above the standard MUF (even taking into account the upper statistical bound of the median MUF). The F_2 region can be regarded as a number of separate patches of ionization with differing maximum electron densities, so that each patch has its own

MUF [note 6]. An over-the-MUF mode introduces more loss, but 6m is more tolerant of loss than the HF bands.

Applying estimates for these mechanisms (visit **http://mysite.verizon.net/k9la** for the detailed analysis, and click on the file "Increasing the F_2 MUF") to the Figure 4 data still results in a median MUF too low (just under 40MHz) to predict any probability of propagation on 6m. Are we dead in the water? No, not yet – it looks like we just need some help from the equatorial ionosphere.

A Skewed Path Hypothesis

The equatorial ionosphere is the most robust portion of the ionosphere in the world. Even at solar minimum, the MUFs at the crests of the equatorial ionosphere on either side of the geomagnetic equator can reach 30MHz at certain times of day during certain months. Figure 5 shows contours of median 3000km MUFs centered on June 29 (2005) at 1900 UTC at an SSNe of 45.

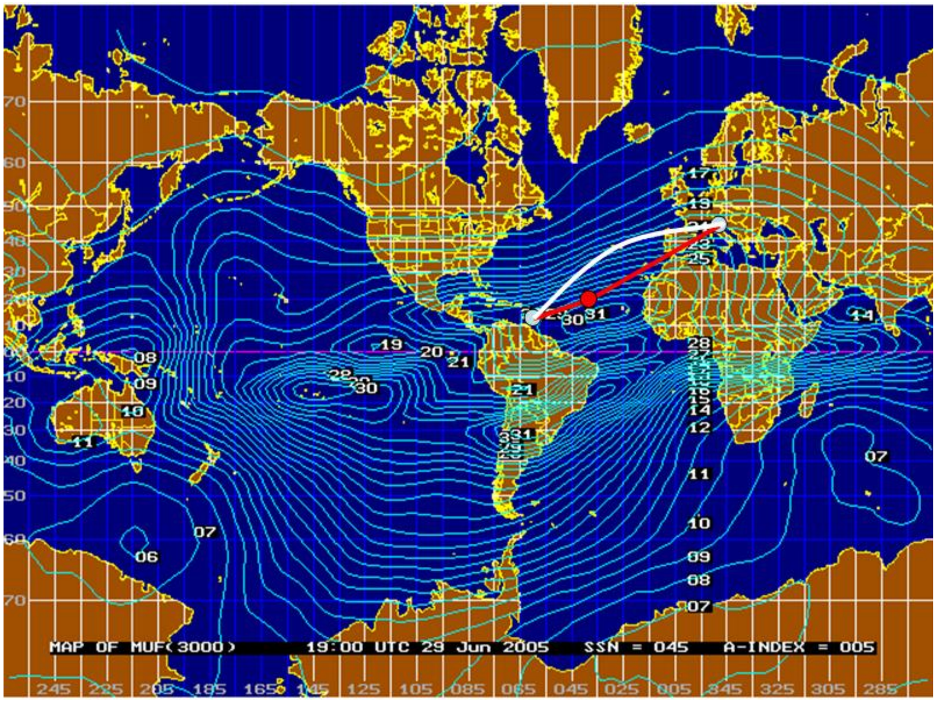

Figure 5 – Worldwide Map of 3000km MUF

The thick white line in Figure 5 is the true great circle path from J6 to HB (this is where the data in Figure 4 comes from). Also shown is a skewed path from J6 to the high MUFs of the northern extremity of the northern crest of the equatorial ionosphere and then into HB (the thick red line, with the red dot representing the skew point). The azimuth difference between the true great circle path and the skewed path on the J6 end of the path is 27 degrees, and it is 14 degrees on the HB end. This suggests a skewed path could occur without the necessity to move antennas on each end of the path off the true great circle path – in other words, N9AG and the operators in Europe may not have known a skewed path was happening.

This skewed path is the hypothesis for how these QSOs occurred – a long F_2 hop on the J6 end with refraction from the high MUFs at the northern crest of the equatorial ionosphere (the red dot), coupled with two E_s hops to get to HB. Note that the ionization gradient of the northern crest in the area is going the right way for this skewed path to happen (an electromagnetic wave refracts away from a higher electron density).

<u>F_2 Analysis</u>

Going through a similar analysis to what was done for the 4-hop Es mode in Table 1 and using the estimates in the previous *Increasing the F_2 MUF* section gives the results in Figure 6.

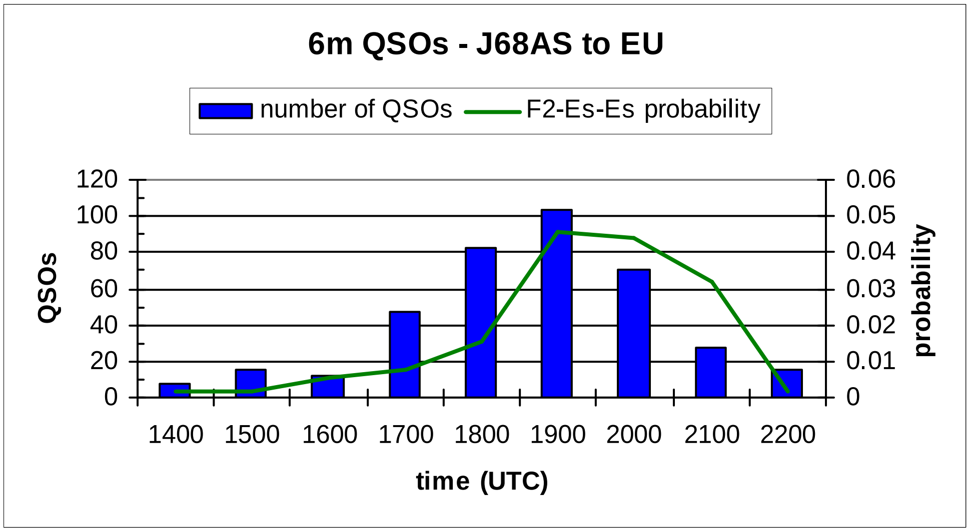

Figure 6 – Comparison of F_2-E_s-E_s probability with QSO data

The shape of the F_2-E_s-E_s probabilities agrees much more closely to the actual QSO data than the E_s-E_s-E_s-E_s results of Figure 3. To reiterate, the values of the probabilities are my best-guess estimate (and I'll readily admit that the analysis is crude – but it's the best I can do). Although the values are estimates, the <u>shape</u> of the statistical pattern versus time should be accurate.

<u>Summary</u>

A comparison of estimated E_s and F_2 probabilities to actual QSO data suggests that the F_2 region had more to do with the J6-to-EU QSOs experienced by Scott N9AG in late June 2005 than originally thought. I doubt if we'll ever know for sure what really happened, but it is interesting to estimate F_2 and E_s probabilities and compare them to QSO data to try to understand the propagation mode.

Notes:

1. Although the data is from 1957 and 1958, it compares favorably with more recent data such as that presented by Wu, et al, in a paper titled *Sporadic E morphology from GPS-CHAMP radio occultation* published in the **Journal of Geophysical Research** in January 2005.

2. Since Figure 2 is for latitudes between roughly 30 and 60 degrees, the probabilities on the J6 end of the path are a bit optimistic since the encounter with the E_s patch on the J6 end of the path is around 20 degrees. Correcting the first hop probability for this issue still results in the E_s probability being out of phase with the QSO data.

3. The exercise in Table 1 was also done for a 3-hop E_s mode, with the same results – the 3-hop E_s probability appears to be out of phase with the actual QSO data.

4. The normal E region, being under direct solar control, maximizes around noon local time. The F_2 region, although relying on solar illumination for ionization, maximizes later in the day due to the influence of additional factors (slower recombination at the higher F_2 region altitudes and diffusion of plasma due to winds).

5. See Figure 6.15 on page 175 in **Ionospheric Radio** (Davies, 1990). It shows one-hop F_2 region propagation out to 6000 km.

6. See section 6.5 starting on page 5 of **Propagation at Frequencies Above the Basic MUF** (Report ITU-R P.2011-1, International Telecommunications Union, 1997-1999). It discusses over-the-MUF modes. VOACAP uses an over-the-MUF algorithm in its assessment of F_2 region propagation.