

## A Model for Diurnal Effects in Multi-hop Six-Meter E<sub>s</sub>

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### Introduction

There are persistent patterns in the time of day during which sporadic E propagation (E<sub>s</sub>) occurs on six meters. Observations show that these "solar-time" correlations depend on the path that the signal takes, and in particular, the range of latitudes it traverses (see Kennedy, Mobile, and Magnani<sup>1</sup> in this volume).

Observations with radio ionospheric sounders clearly show that the characteristics of E-layer ionization can be segregated into at least three geomagnetic categories: Polar or *Auroral*, *Temperate*, and *Equatorial*. Each form of propagation has its own unique time-of-day signature<sup>2</sup>.

*Auroral E<sub>s</sub>* is a nighttime effect found near the magnetic poles. It is quite frequent and seems to occur regularly in all seasons. Near the equator, *Equatorial E<sub>s</sub>* is a daytime effect, and also largely independent of season. These two phenomena are related to the auroral and equatorial electrojets, respectively.

Most amateur operators are more familiar with Temperate Zone E<sub>s</sub>. Unlike Auroral and Equatorial E<sub>s</sub>, Temperate Zone E<sub>s</sub> has a strong seasonal dependence. It peaks in the May-July summer in the Northern Hemisphere, and has only a minor peak in December-January. This seasonal dependence is also found in the Southern Hemisphere, where again, summer is the predominant peak (now November-January, of course) with a minor peak in the Austral winter.

There is also a strong time-of-day dependence. For single-hop signals propagating entirely in the Temperate Zone, the strongest peak occurs at about 0900-1200 Local Standard Time (LST). There is a secondary peak about 1800-1900 LST and sometimes another about 2100-2200 LST.

As discussed in the accompanying paper by Kennedy, Mobile, and Magnani, in the case of multi-hop E<sub>s</sub>, unless the path is close to due east-west, even the reach of double hop can cause the signal to have reflections in more than one of the three E "zones". Triple hop and more will almost always traverse more than one zone. As a result, the diurnal effects observed over various multi-hop paths will be a complex combination of the dependencies of each zone involved.

Another important factor is that for such long paths, the signal is hitting skip points that are in different *time zones*. Thus, the time of day is most likely different at each skip point, by as much as ninety minutes. Obviously this is also a function of the path heading. The effect is most prominent for east-west paths.

While not really scientifically rigorous, this present paper is an attempt to show how these and other effects might interact to produce the observed time dependencies reported by Kennedy, Mobile, and Magnani, and others. A several-step model that uses simple assumptions about the time dependence of each zone, and such other things as how many stations are active, has been

developed to produce predictions for the paths presented in the previous paper. They are then compared to the observations actually made.

Two kinds of paths have been modeled and compared:

1. Two from North America, to either Europe or Alaska/Japan, that have skip points in both the Temperate Zone and the Auroral Zone, and
2. The path from North America to Hawaii, that has skip points in both the Temperate and Equatorial Zone.

*In this comparison, all times will be expressed in terms of the LST at the midpoint of the path.*

### **The Model**

Two basic factors were taken into account:

1. Ionogram measurements of the time variation for the E layer in each of the two latitude zones assumed for each of the paths,
2. An “operator function” that estimates the underlying operator activity as a function of time at each end of the circuit.

Each of these two characteristics gives two values for each 30-minute period during a 24-hour day: a value for the probability of skip for each of two zones, and a value for the probability there will be someone on the air at each end of the circuit. These four probabilities are all numbers between zero and one. The four numbers were then multiplied together to give the combined probability for the path for each 30-minute interval.

This approach assumes that there are two latitude zones involved, and then treats them as if all the paths are double hop – one in each zone. This is a simplification for computational purposes, and not actually the case for many of the actual observations made.

*Ionogram Data* – The data used to construct the ionospheric model were drawn from measurements made by Smith<sup>3</sup> for the Northern summer months of 1951 and 1952. These years were in the waning phase of the solar cycle prior to, but not at, minimum. (It should be noted that one of the less than fully rigorous aspects of the present paper is that there was no attempt to average data over a full solar cycle.)

The original ionosonde data were expressed in terms of the percentage of the time the E-layer critical frequency exceeded 5 MHz. These figures have been assumed to be at least proportional to the amount of time the MUF was above 50 MHz.

Figure 1 shows all three latitude-zone functions in terms of the local standard time *at the skip point*. Of course, in computing the model values, the functions do not overlay quite like this since each skip point is likely to be in a different time zone.

Something to note in Figure 1 is the time variation of the Temperate-Zone probability. The ionosonde data show essentially the same pattern that people have come to expect for US mainland east-west single-hop  $E_s$  – a midmorning peak and then a smaller late afternoon-mid-evening peak. It is interesting to compare this to the two plots in Figure 2 that show the two-zone paths. The other thing to notice in Figure 1 is that the behavior of the Auroral and Equatorial is relatively simple compared to the Temperate  $E_s$ .

*Operator Function* – This function is just a guesstimate (another less than rigorous aspect of the study). It assumes that in the time zone of each end of the circuit there are no operators on six meters between 0400 and 0600 LST. It then assumes a nearly linear increase in operators between 0600 and 0930, by which time all of the operators are active. All operators remain active until 0030 and then there is a linear decrease that reaches zero at 0400 LST. There is a three-hour time difference assumed for the operators at the two ends of the circuit (another one-size-fits-all simplification).

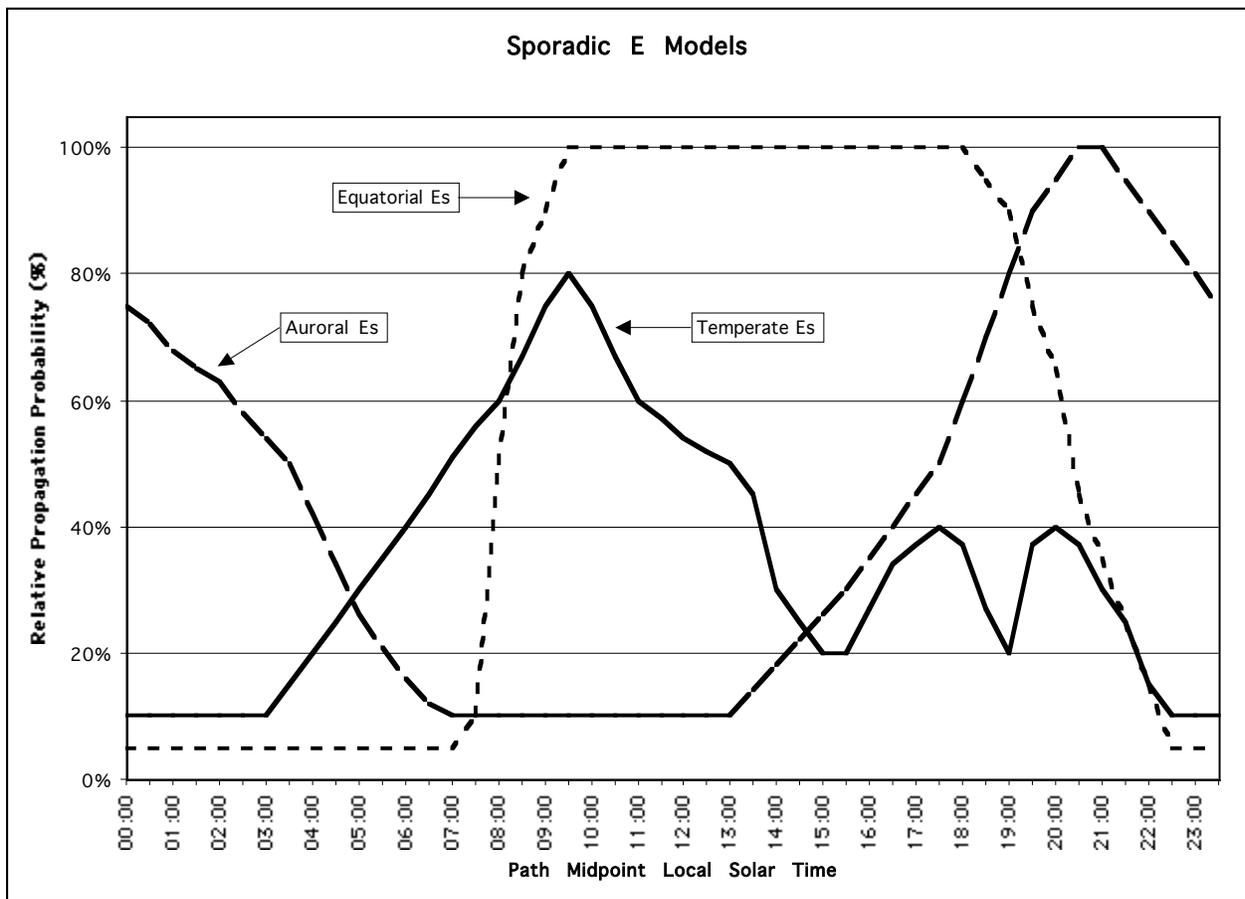
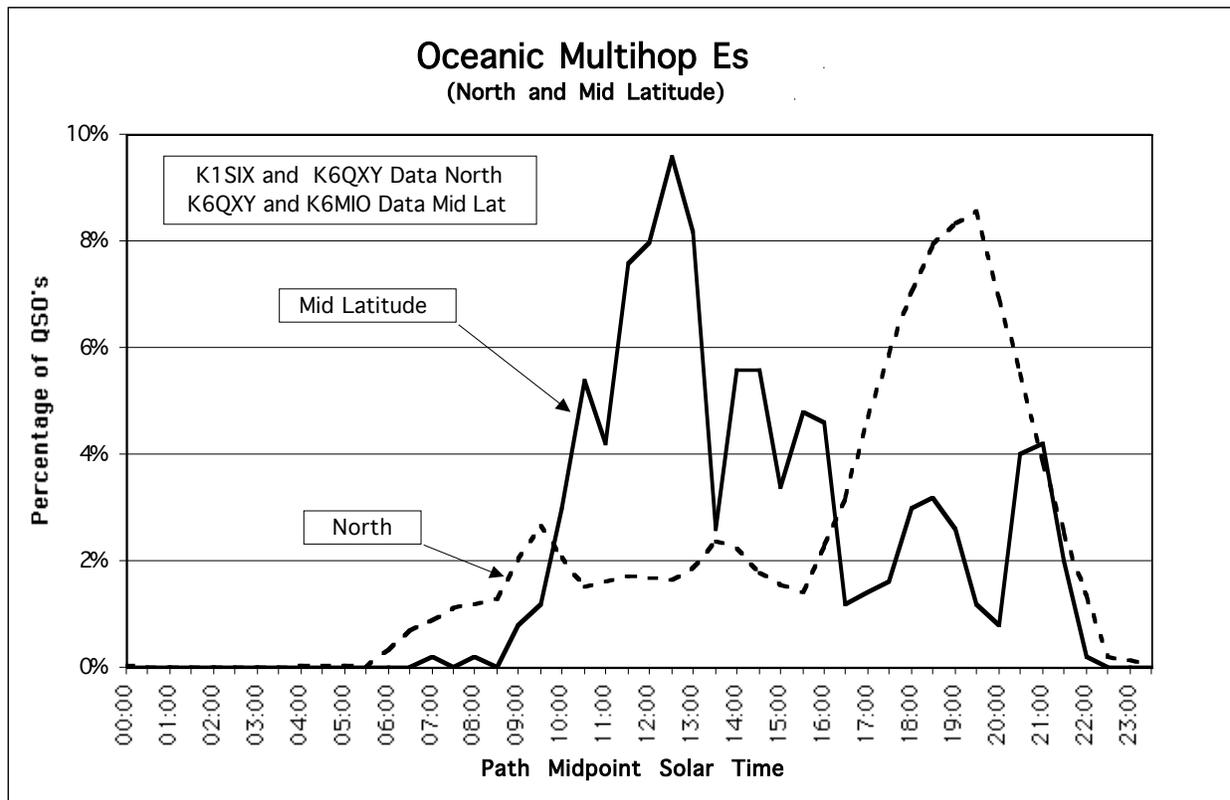


Figure 1. This plot shows an overlay of the Auroral, Temperate, and Equatorial ionospheric propagation functions interpreted from the published ionosonde data. The “probabilities” shown are only relative to each other, they are not expressed in absolute terms.

## The Observational Data

As noted, these data are from the companion paper, found in this volume. They are from the logs of K1SIX in New Hampshire, K6QXY in Northern California, and K6MIO/KH6 on the Big Island of Hawaii. K1SIX records 2,537 contacts or beacon observations with stations in Europe between the years 1985 and 2000. The K6QXY data provide 277 contacts with Japan, Alaska and northwestern Canada, and Hawaii from years 1979 to 2000. The K6MIO/KH6 data represent 390 contacts with stations across North America during only 1999 and 2000. All times are in terms of the path midpoint LST.



*Figure 2.* A composite of the Hawaii (Mid Latitude) and North Oceanic data shows the mirroring of the dominant and minor peaks between the northern and mid paths. It is clear that the effect of mixing two different pairs of latitude zones in a path produces substantially different time-of-day effects.

Both the model and the observations have been expressed in terms of the solar time at the midpoint of the path involved. This ensures that even though the paths may be between many different time zones, they may be directly compared in terms of their own local solar time.

The data for the Europe and Japan circuits were found to be very similar when each set is parsed in terms of its respective path-midpoint time, and so they have been combined to represent Northern Temperate-plus-Auroral paths.

The two data sets for the North America-Hawaii circuit were also combined in making overall comparisons. However, there are some caveats in this regard. The K6QXY data span some 20 years, while the K6MIO/KH6 data are from only two years near the peak of the solar cycle. Moreover, more than half of that data (196 QSO's) came from one single opening (2 July 2000). Consequently, they may not be completely typical. There will be further discussion of this and a related matter in a later section.

### Northern Oceanic – Temperate plus Auroral

The result of the comparison observations and the computer model for Temperate-plus-Auroral path is shown in Figure 3. It will be noted that the correlation is quite good, although no attempt has been made to estimate the correlation coefficient or confidence level.

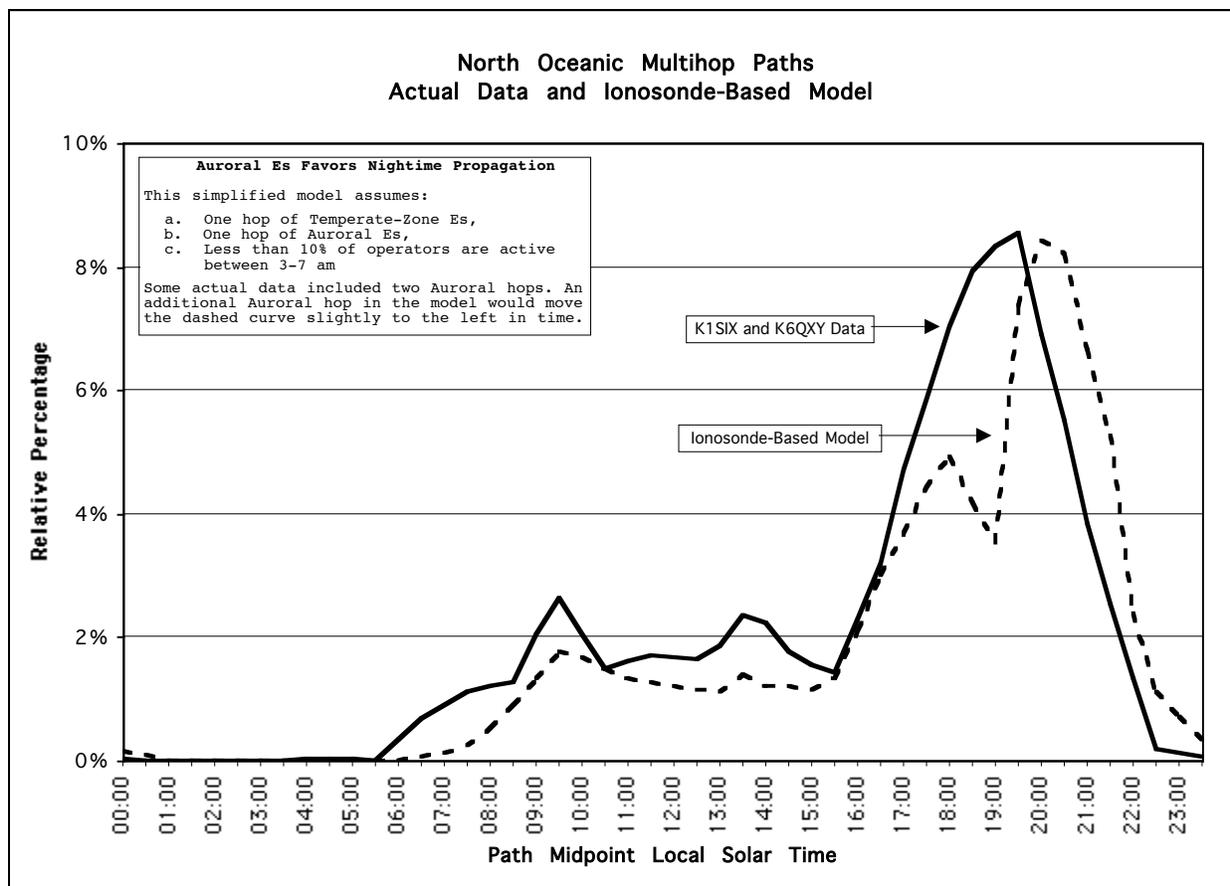


Figure 3. This plot shows the overlay of the observed data and model values for the Temperate-plus-Auroral link. There is good correspondence between the major features.

What seems to be happening is that the Temperate-Zone morning peak is almost completely knocked down by the fact that the Auroral ionization is almost always gone during the day. As a result, the contacts rely on the less-frequent minor evening peaks to connect to the Auroral Zone.

Thus, it should come as no surprise that these openings are relatively infrequent and difficult to work. They depend on the poorest “good” part of the regular Temperate E<sub>s</sub> in order to get across.

### Mid-Latitude Oceanic – Temperate plus Equatorial

This comparison and its analysis turn out to be a little more challenging than expected. As Figure 4 shows, the plots are similar, but the timing is off by quite a bit.

Ignoring the timing issue for the moment, what the ionospheric computer model shows is that the daytime Equatorial E<sub>s</sub> couples very well to the Temperate E<sub>s</sub> morning peak. However, the fading of the Equatorial E ionization in the evening hours dampens the late peak, but doesn't completely eliminate it. (By the way, that evening Equatorial E ionization is on its way to the F layer to try to make TEP, as a result of the Afternoon Fountain effect.)

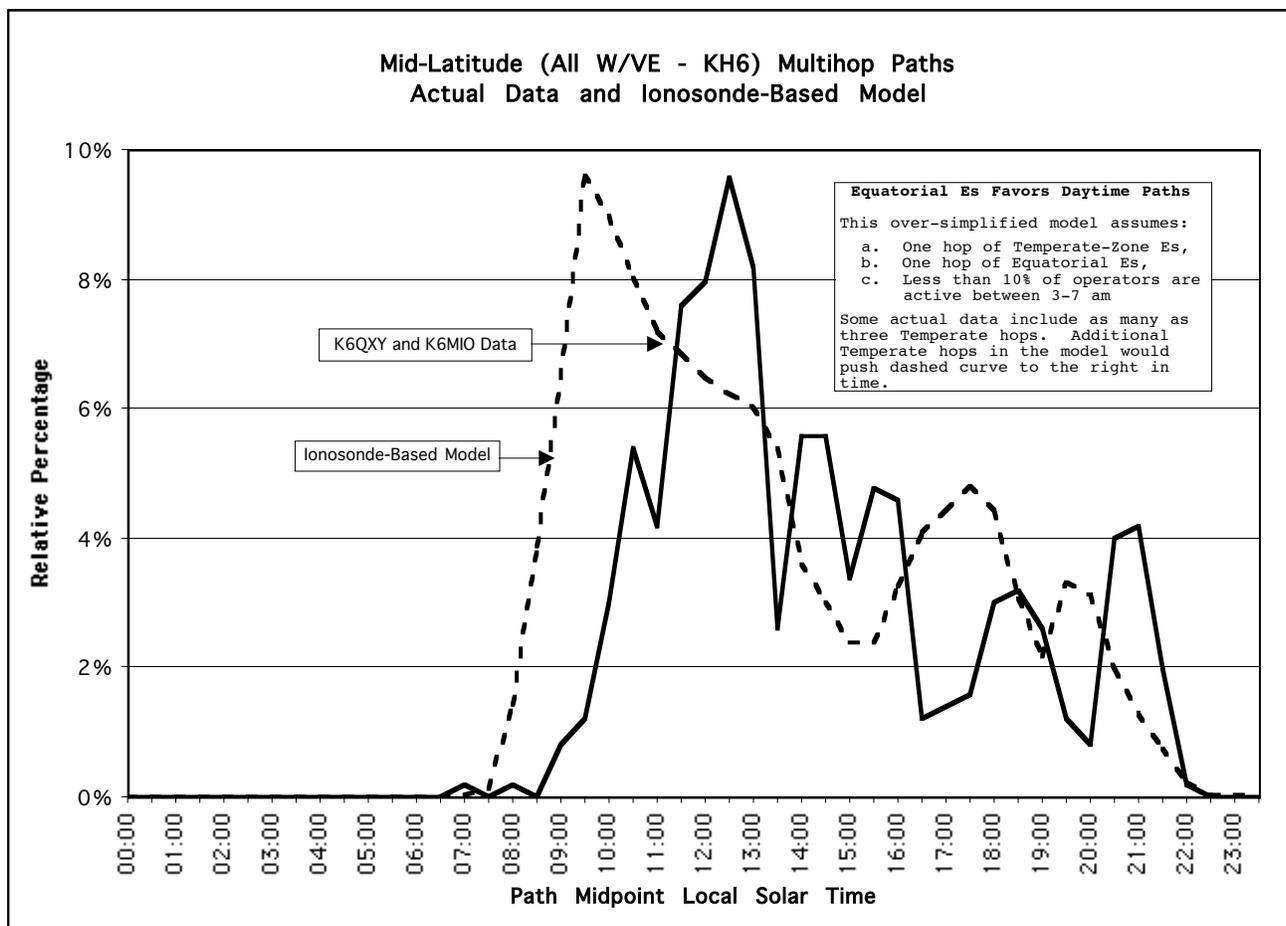


Figure 4. The comparison of the combined K6QXY-K6MIO/KH6 data shows many of the same features as the ionospheric model, but there is a distinct misalignment in the timing.

Returning to the matter of the timing mismatch: further, and more detailed, investigation showed that the assumption that everything could be modeled as if it was all double hop is the source of the problem. And the culprit is the K6MIO/KH6 data.

On the other hand, the K6QXY data *are* all double hop. Those paths were all from the San Francisco Bay area to a localized bunch of islands in Hawaii. The distance is about 2,400 miles. *However*, the K6MIO/KH6 data are from the islands back to the whole North American continent. The *shortest* path is the 2,400 double-hop path to the Bay Area. However, a sizable fraction of the contacts were made on three and four hops. The longest was probably to K1SIX for about 5,000 miles.

To test this hypothesis, the known-to-be double-hop data from K6QXY were plotted against the model data separately, with the results below. Figure 5 shows quite good agreement with the theoretical computer model. The major morning peak is where it was expected to be, with suggestions of some of the subtler features. The afternoon dip in activity and the evening peak are reasonably consistent with the model as well.

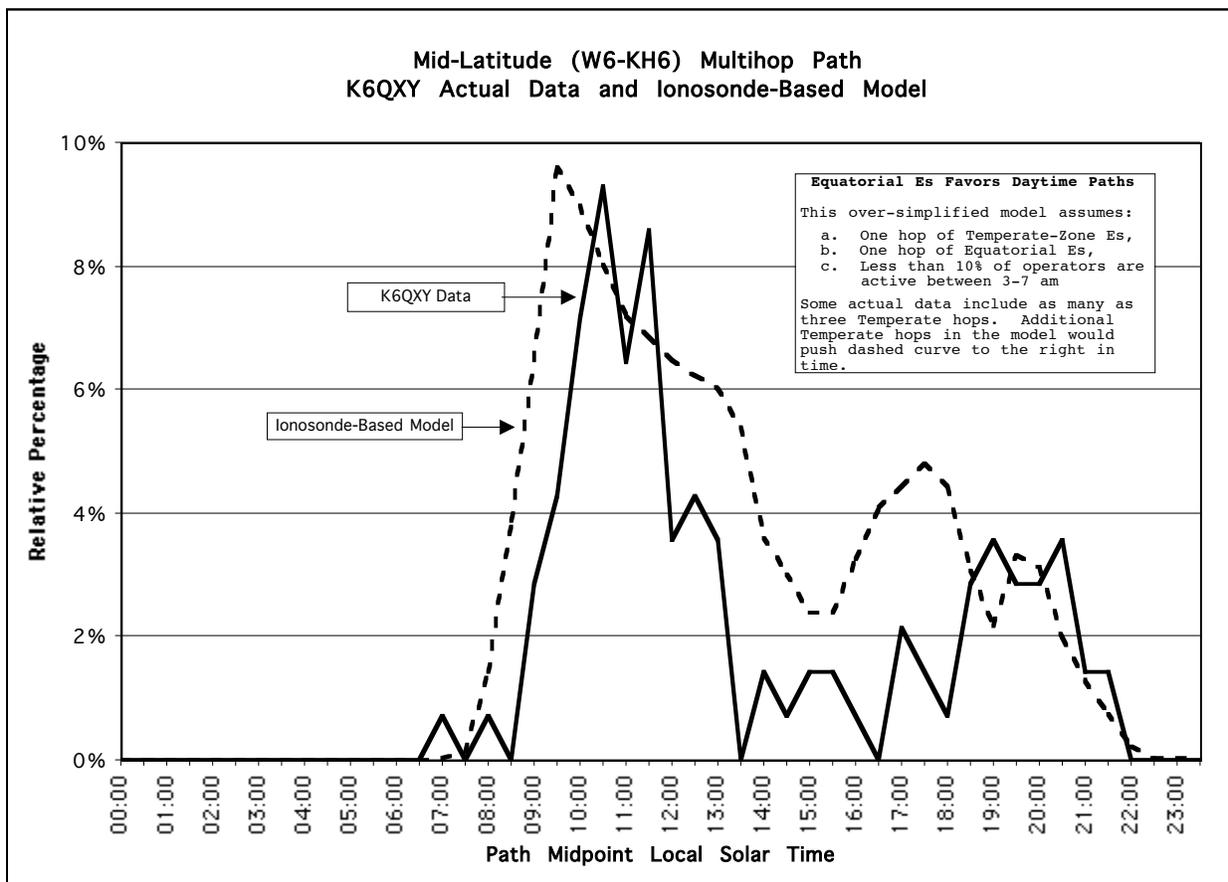


Figure 5. Plotting only the double-hop K6QXY data for the W6-KH6 path shows a fairly good agreement for both the timing and major features in the ionospheric model.

So what was the problem with the K6MIO/KH6 data, from the model's perspective? The answer seems to be that the model did not take into account the one or two (or even three) extra Temperate  $E_s$  hops – all of which occurred at skip points that were much later in their local solar day.

A separate model was constructed that looked just at the effect of two Temperate-Zone hops separated by various numbers of time zones. This auxiliary model showed that the partial overlapping of the morning peaks in skip points separated by two to three time zones had the effect of shifting the peak later (eastward) about 2.5 hours in terms of path midpoint time.

Thus, the Temperate-plus-Equatorial model was run again, but with the Temperate pattern shifted 2.5 hours east. The result is shown in Figure 6. It shows a surprisingly good correlation between the time and structural features of the major midday peak. At this point, there may not be enough data to distinguish between an Equatorial E to Temperate  $E_s$  link up, as opposed to simple two-hop Temperate  $E_s$ .

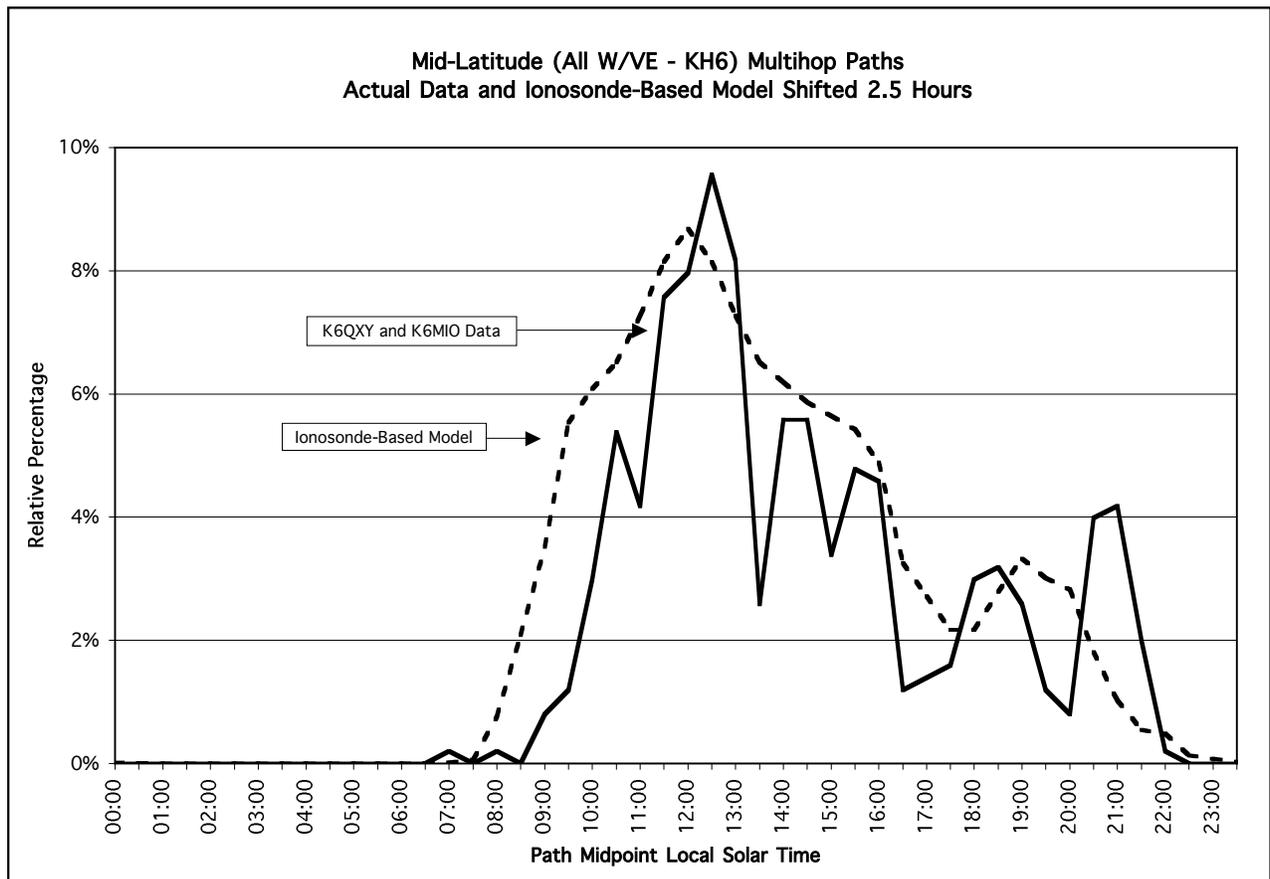


Figure 6. A crude adjustment for the effect of mixing 3 $E_s$  and 4 $E_s$  data with only 2-hop Temperate  $E_s$  data on the Hawaii to California path was achieved by shifting the Temperate-Zone data 2.5 hours eastward, resulting in a very good match to the combined K6MIO/KH6-K6QXY data.

## Summary and Conclusions

The observed behavior of E-layer propagation between the continental US and Europe on the one hand, and Japan and Alaska on the other shows that these have a much higher occurrence probability between about 1700 and 2030 LST at the path midpoint. This is in contrast to the usual Temperate E<sub>s</sub> pattern, which strongly favors the midmorning hours.

A simple model that assumes combining skip points in the Temperate E<sub>s</sub> zone with those in the Auroral E<sub>s</sub> zone accounts for the principal features seen in these paths. The main reason that the morning peak is virtually non-existent appears to be the absence of daytime ionization in the Auroral Zone.

Observations show that the path from Hawaii to North America looks more nearly like the Temperate E<sub>s</sub> pattern. This can be accounted for in either of two ways. Firstly, the path may be dominated by *only* multiple Temperate-Zone E<sub>s</sub> hops (*no* Equatorial). Secondly, it may be a combination of Equatorial E<sub>s</sub> *and* Temperate E<sub>s</sub>. It is actually hard to tell the two apart with the amount of data present. More observational data will help.

The Hawaii to eastern North America path, involving three and four total hops (and perhaps five in some cases), can be better accounted for by including the overlap of the probability functions for the extra Temperate E<sub>s</sub> hops. Curiously, this does *not* seem to be the case for the equally long hops to Europe and Japan. This may be due to the Auroral-Zone effect being the dominant influence in determining the propagation.

The author especially thanks Bob Mobile and Bob Magnani for so freely sharing their data and their thoughts, which made this effort possible.

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<sup>1</sup> Jim Kennedy, Bob Mobile, and Bob Magnani, 2001, 'Time-of-Day Effects in Six-Meter Multi-hop Sporadic E Propagation', *Proc. 35<sup>th</sup> Conf of the Central States VHF Society*, ARRL

<sup>2</sup> Kenneth Davies, 1990, *Ionospheric Radio*, Peter Peregrinus Ltd. pg. 145

<sup>3</sup> E.K. Smith, 1957, 'Worldwide occurrence of sporadic E', *Circular 582*, National Bureau of Standards.