This is the second in a series of articles (for the first, see “Extreme Range 50-MHz Eₘ —nEₘ or Chordal” in the Fall 2011 issue of CQ VHF) discussing the unusually long, yet still short-path, propagation events that continue to be seen on 6 meters in both the Northern and Southern Hemispheres. The first article mentioned above took a preliminary look at the essentially east-west path type, which is either entirely above, or entirely below, the equator. These paths are seen to reach out to about 11,000 km.

Han Higasa, JE1BMJ, originally labeled this as Short-path Summer Solstice Propagation (SSSP), in the belief that it was something other than Eₘ, due to its extremely long range (Higasa 2006 Japanese, 2008 English). However, the propagation seems to occur exclusively during the relevant hemisphere’s local summer, strongly suggesting that some form of Eₘ mechanism(s) plays an important role.

The first article concluded that the JA–US path was consistent with either five-hop Eₘ (5Eₘ) or a combination of multihop Eₘ hops together with mid-path chordal (cloud-to-cloud) hops. It also showed direct observational evidence that at the four-hop range, both 4Eₘ and multihop Eₘ with intermediate chordal hops do occur, at times with comparable signal levels.

In view of that evidence, it suggested that it might be more appropriate to call the phenomenon East-West Extreme Eₘ (EWEE), because, taken literally, “Short-path Summer Solstice Propagation” describes virtually any kind of local summer Eₘ. Such a change also helps differentiate EWEE from another related, although importantly different, type of propagation that goes generally north and south, always crossing the equator, on even longer paths out to beyond 15,000 km. (This north-south propagation will be the subject of the third article in this series.)

What follows here is a deeper discussion of east-west EWEE propagation, based on a broader range of observations and then some comparisons with data-driven models of the ionosphere.

**E-layer and Eₘ Review**

Since some detailed ionospheric conditions will be discussed involving Eₘ and E-layer ionization, it will be helpful to take a quick look at how radio propagation works in that region.

**The Sun and the Rain—of Meteors**

The E-region of the ionosphere is generally considered to be the altitude range between 90 and 130 km. The ionization found at these levels arises from two main sources—solar radiation (at ultraviolet (UV) and soft X-ray wavelengths), and the vaporization of incoming meteors.

Every day an estimated 1,000 tons of very small meteoric particles hit the Earth’s upper atmosphere. Most of these so-called sporadic meteors are smaller than a grain of sand. They do not appear to be connected with the larger swarms of meteors normally associated with the recurring meteor showers. Generally,
these particles are metal rich, containing nickel, iron, sodium, and a number of other elements.

Although the \( E \)-region atmosphere is very thin, it is dense enough for atmospheric friction to heat up and vaporize the incoming particles. The intense heat raises the particle temperature high enough to both vaporize the particles and also ionize them into positive metal ions and negative-free electrons.

Due to the electronic structure, greater mass, and high temperatures of the positive metal ion cores, the subsequent loss of free electrons due to recombination is a much slower process than that for the smaller, lighter background gases. As a result, the metal ions have longer lifetimes than those created by the Sun’s UV and X-rays by photoionization.

As noted, meteors are coming in and producing ions all the time, day and night. However, the Sun only produces ions during the day (roughly 0600–1800 LST [Local Solar Time]). As a result, at a given point in the \( E \)-layer the total ionization from both the Sun and meteors is highest during the day, but does not go to zero during the night; the meteor component remains.

What may be surprising is that even in the daytime the large-scale \( E \)-region ionization is fairly weak. The ordinary peak daytime \( E \)-layer maximum usable frequencies (MUFs) are on the order of 16–22 MHz. Thus, something else has to happen to increase the local electron density by a factor of ten or more in order to produce an MUF above 50 MHz.

While there really is no additional source of large-scale ionization, it will turn out the combination of daytime solar and all-the-time meteor ionization does provide the reservoir of electrons needed to produce sporadic-\( E \). Read on.

**Winds Aloft and Vertical Compression**

As is the case in the lower atmosphere, there are identifiable wind patterns in the \( E \)region. There are recognized flows in both the zonal directions (east to west and west to east) and in meridional directions (north to south and south to north).

For example, the zonal winds, in combination with the Earth’s magnetic field, seem to play a special role in enabling sporadic-\( E \) propagation below about 120 km. In the Temperate Zone, the Earth’s magnetic field has a significant component parallel to the Earth’s surface, and the zonal winds flow horizontally at roughly a 90° angle to that component of the field. As these winds blow, they try to carry both the neutral and ionized particles along with them. As the free electrons are dragged across the magnetic field, at roughly a 90° angle to the field, this produces a sideways electromagnetic force that bends the electron paths either upward or downward into orbits circling the field lines, rather than continuing to move along with the wind.

If the wind speed varies with altitude, there will be a wind shear at the boundary between the upper and lower flow. This produces net forces that push the electrons vertically into very thin sheets in the wind-shear region. The net effect is that the electrons, which originated in a rather large and weakly ionized volume of space, are then compressed vertically into thin sheets with much higher ion densities. This raises the local electron density (\( N_e \)), and with that, the MUF goes up—and \( E_s \) happens.

But then why doesn't this happen every day of the year?

**Seasons and Meteors**

Radar studies of incoming sporadic meteors have shown that there is a significant seasonal variation in the meteor counts at mid latitudes. In both the Northern and Southern Hemispheres the sporadic meteor count rates are three to six times higher in the hemisphere’s local summer. This is due to the 23° inclination of the Earth’s rotation axis to its orbital plane around the Sun (the tilt that causes the seasons in the first place). During the local summer, the hemisphere in question is aligned more directly with the plane of the Earth’s orbit, and thus it is more nearly aligned with the direction of the Earth’s orbital velocity, as it sweeps up the meteors, while moving around the Sun.

More importantly for radio propagation, there is a very strong positive correlation between the sporadic meteor counts and the \( E_s \) critical frequency (Haldoupis, et al., 2007): The higher the meteor count, the higher the MUF. The implication is that the enhancement of the general \( E \)-layer ionization, caused by the local-summer peak in sporadic meteors, increases the overall supply of electrons in the large-scale \( E \)-layer “reservoir.” Then, as a separate step, when local conditions are right to trigger the wind shear and its vertical-compression effect, \( E_s \) occurs with MUFs that are much higher than they might be during the other seasons of the year. This appears to explain the summertime major \( E_s \) peak.

In the study cited, the radars were at 54.6° N and 38° N. They show clear indi-
cations of a minor winter meteor peak in early January roughly corresponding to the winter $E_s$ peak, with the deepest minimum in mid February.

Another study (Younger, et al., 2009) shows strong summer meteor peaks at both 68°N and 68°S, with no winter meteor peak. Near the geographic equator (8°S), the seasonal meteor counts and seasonal variations are much less pronounced. Unlike the temperate region, there is a small meteor peak in both the summer and the winter.

With both studies taken together, the implication is that as one moves farther toward the equator from 68°, the summer meteor peak eventually begins to decline and the winter peak begins to emerge.

Atmospheric Tides and The Valley of Death

The Earth’s atmosphere is an ocean of air. Like the ocean of water, it sloshes around, and it is subject to tidal forces from outside influences. While there are a number of different tides in the atmosphere, one of the most prominent outside influences is the heating of the atmosphere caused by the Sun every day-time. During the day the Sun heats the surface of the Earth, which in turn heats the air in the lower atmosphere immediately...
above it. The heated air in that region expands, causing the dayside atmosphere to balloon upwards at all levels. The heating is more pronounced over land than it is over the ocean.

As the Earth turns under the Sun, this bulge follows the Sun, moving around the Earth once a day. In addition to this 24-hour tidal period, there also is a 12-hour tide and even an 8-hour tide (Haldoupis, et al., 2004). Of these, the 24-hour tide is the strongest, while the 12-hour one is next and the 8-hour somewhat weaker still. These tides produce systematic updrafts and downdrafts as they wax and wane. These vertical winds interact with the horizontal zonal and meridional winds to alternately enhance and diminish the vertical compression of the $E_s$-layer ionization.

The joint effect of these three tides seems to explain the well-known diurnal variations in the probability of $E_s$ propagation. The overlapping of these three signals produces a three-humped probability curve, shown schematically in figure 1. The morning peak is consistent with the overlap of all three of the 24-, 12-, and 8-hour peaks, while the double-humped afternoon-evening peak appears to be a result of the overlap of the 12- and 8-hour peaks. After the end of the late window, the disappearance of the solar component of $E$-layer ionization leaves only the meteoric component. Consequently, $E_s$ propagation above 50 MHz rarely occurs after midnight LST.

As was pointed out in the first article in this series, figure 1 can also be looked at in a different context, in which time is fixed at the location of the west-end station for a given family of propagation paths. If this is done, then the horizontal time axis in figure 1 can be reinterpreted as a corresponding distance axis, eastward from the west-end station.

Figure 2 shows what the propagation world would look like for the west-end station at 0700 LST. The MUF probability in figure 1 can be scaled as a proxy for the MUF itself. Figure 2 shows a schematic of the MUF to the east of the west-end station, now as a function of distance. In this example, the MUF minimum between the early window and the late window is shown dipping below 50 MHz. Evidence suggests that this is often the case. As a result, the only eastward stations accessible to the west-end station are those that are still in the same early window as the west-end station.

Much farther out, the stations within their late window can communicate with each other. However, the $N_e$ electron-density gap in the middle (the $N_e$ “Valley of Death”) stops ordinary $nE_s$ multihop propagation from going between the early and late windows.

That said, here are two obvious situations that would allow the early- and late-window stations to communicate with each other:

1. A chordal hop that bridges across the $N_e$ gap (they require a much lower electron density than $E_s$; see “M-Factor” below), or
2. The overall $E_s$ ionization is so high that the dip between the early and late windows never gets below 50 MHz anywhere (on a very good day, with very long $nE_s$).

As was noted in the first article, a key characteristic of EWEE is that the west-end station is almost always in its morn-
Chordal Hops, MUF, and the M Factor

The suggestion that EWEE may include chordal skip mechanisms was partly motivated by the fact that a chordal hop can skip successfully with a much lower level of ionization, N_e. This is because the value of the MUF depends on both N_e and the angle between the signal ray path and the bottomside of the reflecting layer at the skip point. Expressed in MHz, the MUF is given by:

\[ MUF = \sqrt{N_e \times (9 \times 10^{-6})} \]

where N_e is electrons/m^3

M is the so-called M Factor, which is the cosecant of angle between the signal path and the plane of the skipping layer. As the angle gets smaller, M gets bigger. One gets a higher MUF without a change in N_e. (If N_e is expressed as electrons/cm^3, the value of the constant is 9 \times 10^{-3}).

The M factor seriously comes into play when one considers any of the chordal-hop variations. All of these involve signal ray paths that have been modified from normal nE_s angles into very shallow (“grazing incidence”) angles, which can greatly increase the M factor, leading to a higher MUF for that hop than would be possible for nE_s. Put in different terms, in principle, chordal signals can skip successfully with a lot lower N_e than can nE_s.

It is fairly common for E_s clouds to be tilted with respect to the ground, sometimes as much as 60° (Whitehead 1997). Typically, what happens in a chordal situation is that the upcoming signal ray from the antenna on the ground first hits a tilted or curved cloud at what is now a shallow angle and is bounced off, more or less parallel to the ground. From there it might skip off of one or more flat E_s clouds and still not come to the ground until it finds another tilted cloud that points it back down again. All of these hops would require much less N_e than a traditional nE_s path.

Some Other E_s Important Characteristics

Sporadic-E has a number of features that make it rather distinct from F2. It occurs at a height of about 90 to about 150 km (most commonly below 130 km), while F2 is around 250 km and above. The lower E-layer height leads to shallower angles of attack for an upcoming wave, leading to higher values of the M Factor and thus higher MUFs than F2 with the same levels of ionization.

The ionization formation process for E_s clouds is both very different and less well understood, compared to F2. A consequence of this different ionization mechanism is that the morphology of E_s clouds is also quite different from F2. These complex processes lead to a variety of strange circumstances:

- Cloud layers are very thin, tens of meters to a few kilometers.
- Clouds are smaller in horizontal extent than in F2 region, averaging around 100 km.
- Large areas of ionization are composed of swarms of individual clouds.

Figure 6. USU-GAIM N_e rendition for 0300 UTC 02/20/2010 at Lat –30, Lon 180. The E-layer peaks at 105 km, then drops by about 25% by 118 km, and then resumes increasing, going upward toward the F-layer.

- Clouds in the swarm are in motion horizontally and vertically (usually descending).
- Vertical stacks of two, three, or more layers are fairly common.
- Tilted layers are common, at times by as much as 60° with respect to vertical.
- The underside of an individual cloud can be curved or rippled, rather than flat.

EWEE 2010

The first article in the series explored just the JA–NA paths. Since that time, a fairly large amount of 2010 northern summer data were compiled on both the JA–NA and NA–EU paths in order to characterize and compare these two different paths in more detail. Propagation reports were gathered from a variety of sources, including web-reflector postings and direct reports from the operators themselves.

In the end, the strategy was to select two different NA stations that had a lot of activity, one to JA (KOH1A) and the other to EU (W7MEM), in an effort to get a coherent picture of paths radiating from one single starting point. In both cases, the data used for this report were from the openings of 19–20 June 2010. The intention was to establish a balanced view of what was taking place over essentially the same paths to those two remote destinations. As with the previous study, the idea was to look for evidence of chordal versus nE_s hops, and see if the diurnal “early peak on late peak” timing was indeed a persistent feature.

It must be pointed out that unequivocally demonstrating that a given 10,000-km path is the result of every hop coming to
Earth is a “hard” problem. The distances involved, the realities of geography, climate zones, human infrastructure, and human population demographics would make it a challenge to design an experiment where Earth could happen and there would be a suitable population of radio operators in place and on the air at every hop footprint; oceans and polar regions are bound to get in the way.

JA–NA Path Ranges
Figure 3 shows a comparison of the JA and EU path data sets. The JA path result is much like the previous study. Except for a single KL7 at about 4,500 km, there is no other evidence of intermediate hops reaching the ground between NA and JA.

On that great circle path, the population of radio operators at all of the intermediate skip footprints (western Canada, Alaska, the Bering Sea, and the Pacific Ocean) is either very low or nonexistent. Consequently, it is still unclear whether these paths are nEₜ or chordal Eₜ.

NA–EU Path Ranges
This is the first time the NA-EU path has been explored using the current techniques. Fortunately, this path’s deeper end-point provides a bit more information. There is clear evidence of hops two, four, and five reaching the ground. Single hop was ignored in the study; direct hops two and three land in the vicinity of Hudson’s Bay and central Greenland and Iceland before making landfall in Europe. Looking more closely at figure 3, one can see at least two distinct populations of contacts at the four- and five-hop ranges, separated by what appears to be a skip-distance gap at about 8,500 km—where one would expect it—between hops four and five.
Figure 4 shows a great circle map centered on the average path midpoint. It shows the range of path tracks over the wilder-ness to finally reach the hops four and five footprints. Another interesting feature is the presence of multiple contacts from about 9,000 km to about 10,000 km, as hop five opened inland to central Europe and the Mediterranean. These are clearly at distances comparable to those required for the JA–NA path, and here those last two hops (at least) look very much like nE s. Of course, there is nothing to say some hops might be chordal and others nE s.

Early-on-Late Diurnals

The remaining measureables here are the details of the time-of-day relationships between the west-end and east-end station in each individual contact for both the JA and EU paths. The E s morning probability peak is from about 0630 to 1230 LST, and the afternoon/evening peak is from about 1530 to 2030 LST (see figure 1). Figure 5 dramatically shows that both the JA–NA and the NA–EU contacts were made exclusively within this west-end east-end window overlap.

The LST time difference (9 to 10 hours on average) is set by the difference in longitude between the east-end and west-end stations. However, the absolute time of day is a free parameter. The fact that the actual LST at each end fits within the E s peak probability times also strongly suggests that some kind of E s mechanism is at work.

It also means that if a contact is in the LST early-on-late box, and if there is a Valley of Death, then the Valley lies somewhere in between the two stations.

ZL/VK–SA EWEE

The 2009–2010 southern summer provided a number of what appear to have been east-west EWEE contacts between ZL/VK and the SA west coast. Their characteristics seem to mirror those of the Northern Hemisphere effect. Only two or three such contacts have come to light in the 2010–2011 southern summer.

What Was Going on in the Ionosphere?

Clearly there are ionospheric processes going on that led to these uncommon forms of propagation. In order to explore this in more depth, an effort has been made to recreate the state of the ionosphere as it may have been while these events were occurring.

Ionospheric Models

Unfortunately, directly doing this in any detail, in three dimensions, by making measurements of the free-electron density, N e, everywhere, is not currently possible. However, there are a large number of measurements of other relevant quantities that are made on an ongoing basis. So, while it is by no means trivial, it is possible to input those data into the known equations of the physics of the ionosphere to do a three-dimen-sional recreation, with generally good fidelity. There are a number of ionospheric modeling programs that do precisely that.

The model used here is called the Global Assimilation of Ionospheric Measurements model (USU-GAIM). It was developed at Utah State University (Schunk, et al. 2004). The ionospheric model was run for the entire day on the dates of the first event. It produced a snapshot of the global ionosphere in three dimensions from 92 km to over 1,000 km for each 15-minute period through the day. The models were run at the Community
Coordinated Modeling Center hosted at NASA’s Goddard Space Flight Center.

Although the USU-GAIM model is quite good, it is a large-scale, global model. It calculates values for every 4.66° of latitude and 15° of longitude. As a consequence, it cannot recreate small-scale or rapidly occurring events. This includes the many manifestations of \( E_s \). The spatial features of typical \( E_s \) are made up of many relatively small clouds, which are often in rapid motion. As a result, the USU-GAIM model is used only to show the location and size of the \( E \)-layer electron “reservoir,” and the approximate value of its electron supply. It cannot show when and where the \( E_s \) occurs, but only where it likely could be, if the vertical compressionion mechanism goes to work.

**E-Layer Valley**

As a general rule, if one plots the value of \( N_e \) starting at the surface going upwards, \( N_e \) increases with altitude until after the \( F \)-layer peak. However, there is an exception in the \( E \)-layer, which may turn out to be important to the discussion. \( E \)-layer \( N_e \) does increase with height, but only to a point (about 105 km in Figure 6) and then it actually goes down for a bit, before it begins to climb again. This feature is referred to as the \( E \)-layer Valley (Davies, 1990).

It demonstrates that there can be, in effect, at least two \( E \)-layer reservoirs to feed the formation of \( E_s \). One corresponds to the region of the \( E \)-layer “peak” (here about 105 km), and another region of equal or higher \( N_e \) 10 to 40 km above the “peak” (here about 32 km).

It is an observational fact that \( E_s \) most often tends to be seen around 105 km. However, one or two additional layers above the lowest one are seen at times.

**20 June 2010**

This is a first look at a study in progress. A lot of the avail-

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**Figure 8.** Upper: At the opening midpoint time, note that there is a “finger” of \( F_2 \) ionization overlaying the central portion of the path region, with lower fringes reaching from south-central Canada to east of Iceland. The main \( F_2 \) region is seen building south of 40N. Lower: At the same time, the \( E \)-layer at 105 km shows a broad area of available electron reservoir at good levels to feed \( E_s \).
able detailed data have not yet been fully explored. However, samples from various dates indicate that they may have many characteristics in common.

The 20 June 2010 date was selected as the first for a more extensive review because from NA the band opened to EU in the morning around 0700 LST. As the Earth turned that same day, in the afternoon it opened from NA to JA at about 1600 LST (about 0800 JA). This suggested an opportunity to look at the evolution of the ionosphere over a roughly 13-hour period, where, perhaps, the same or similar conditions may have persisted.

NA–EU Path

Figure 7 shows the range of course lines for the W7MEM to EU paths, and the latitudes and longitudes covered. In latitude, the paths extend from about 40N to about 76N, and in longitude, from about 120W to 20E. There are also two longitude scales. The upper one is in the more common longitude east and west format, here running from 120W (−120) to 020E. The lower scale is an “East only” scale used in many of the USU-GAIM displays. It simply measures everything going eastward, from 000 through 360. This scheme will be used in most of the remaining maps.

E-Layer Reservoir

Figure 8 (lower) is a contour map of the modeled daytime E-layer reservoir, showing its broad expanse. Though Ne levels are decreasing to the north, they are adequate for formation of over the path in question.

Arctic F-Layer Finger

The contour map of the F2 region in figure 8 (upper) shows that there was a separate F2 finger centered over Greenland at 69N and 275 km (top half of frame). It is quite separate from the main daytime equatorial-anomaly F2 ionization lobe (out of frame at bottom). This structure was centered very close to the figure 7 path midpoint, and it was elongated in the east-west direction.

While this discussion is not about F2 propagation, hold on to the thought that this enhanced F2 ionization generally overlays the main portion of the E paths between W7MEM and EU.

USU-GAIM is a 3D model. Figure 9 shows a vertical north-south slice down through the F2 structure along longitude 310E. It shows how this structure dominates the region from about 55N to past 80N.

E-Layer Valley Again

Figure 9 also shows the F2 high-density peaks around 250 km are pushing higher levels of ionization all the way down into the E layer. This shows that the
upper ridge of the E-layer valley, in Figure 6, is just the long, low-side tail of the F-layer ionization.

Much of the east-west path was near latitude 70N. Figure 10 shows an east-west cut through only the E-layer valley portion of the ionosphere (92–135 km). The west end of the path is on the far right and the east end is on, or just past, the far left. Figure 11 shows a north-south cut along the mid-path longitude.

These show an E-layer reservoir peak near 103 km, then a valley, and starting about 115 km, there is a steadily increasing reservoir that, near 128 km, reaches the same N_e levels as the lower 103 km peak. The N_e values were on the order of 100,000/cm –3. These are normal summertime values corresponding to MUFs greater than 15 MHz.

The point is that these conditions existed in two places in the valley that were only 25 km apart in the vertical direction. The elevated F2 conditions above the E-layer brought the upper side of the valley closer to the lower side, so that if wind shear was around, then the opportunity for both the upper and lower level to participate was enhanced. More importantly, this condition existed over much of the entire NA-EU path.

JA–NA Path

Consider the conditions later that afternoon, looking now from NA toward JA. Figure 12 shows the path tracks. JA is a rather small target compared to all of EU. The paths are all very similar. The real difference is in how far south the paths go on the west end.

These paths don’t go as far north as the EU paths. Some of those went nearly to 80N; here they all peak at about 60N. The other difference is the ionosphere, and the F-layer in particular. The persistent ridge-like F2 peaks tend to track 10°–20° north and south of the magnetic equator. Due to the magnetic equator’s inclination to the geographic equator, the angles of these ridges are somewhat different over the Pacific than over the Atlantic.

Arctic F-Layer Finger

Figure 13 (upper) shows that there is also a northern finger or ridge-like F2 feature of locally enhanced ionization that seems disassociated with the persistent diurnal F2 equatorial anomaly ionization maximum farther south. Unlike the NA-EU case, where the ridge overlaid almost the entire path, the Pacific ridge was south and west of the optimum location and was only associated with about the eastern half of the path.

E-Layer Reservoir

Figure 13 (lower) shows that the shape of the normal E-layer ionization patch, which provides electrons for E_s, was shaped and centered in the northern Pacific in such a way that it produced a nearly constant of reservoir ionization on the path from western Canada until Japan.

Figure 14 indicates that despite the less than optimal alignment of the F2 ridge, the F-layer ionization is apparently enhancing the upper edge of the E ionization valley.

Figure 15 is a close-up look at the east-west ionization along the path as seen at
It will be noted from figure 12 that the path remains in that general latitude vicinity for quite some distance. It shows that, like the NA-EU case, there is a second region of enhanced $E$-layer ionization of the upper side of the valley that is only 10–15 km away. In the east-west direction this seems to provide a channel for the development of $E_s$ both around 105 km and 125 km.

Finally, Figure 16 shows a north-south cut near the path midpoint, along latitude 190E. Here again, there is a resemblance to the NA-EU case in that it also shows that the north-south dimension of the channel region is quite extensive.

What Might Be Happening?

In order to address this question, the first step is to focus on defining the problem.

Why Shouldn't These Paths Work?

The initial concern was that the paths were so long that ordinary $nE_s$ would be so attenuated by absorption and scattering after so many sky and ground encounters that there would not be enough signal left at the far end. This led to suggestions that tilted-layer chordal hops, chordal skip ducting between layers, or even progressive refraction during long passages through ionized regions might preserve the signal strength sufficiently.

Though arguments have been advanced, it has never been conclusively shown that it could not be $nE_s$. Nevertheless, some amazing propagation involving chordal modes (Kennedy 2003) have shown up in the $F$-layer, so it is reasonable to explore them in the $E$-layer.

There is another issue that has emerged in looking at this problem, and that is the matter of the long-known diurnal pattern of $E_s$, as discussed and diagramed in figures 1 and 2. What is seen is that paths such as JA–NA and NA–EU seem only to work consistently when the west-end early and east-end late probability peaks overlap. It suggests that something must be happening in the middle of the path to get over the hump.

Why Do They Work?

The answer to that is still unknown, but the limited work on this so far suggests a couple of hypotheses:

**$F$-Layer Ionization Above and Channels in the $E$-Layer Valley Below**

Proceeding from the following observations:

- There is a known $E$-layer valley.
Es has been observed at least as high as 150 km, although it is rare that high. Multiple Es clouds between 100 km and about 135 km are more common. Wind shears and vertical motions are all associated with the actual occurrence of Es.

Though the diurnal Es probability is lower at the path midpoint LST, the N_e reservoir is maximum there. Consider the following scenario:

It is plausible that Es occurrences in a given region would be enhanced if the upper branch of the valley (fed by the F-layer) were squeezed down, physically closer, to the normal E-layer peak. If the two comparable levels of ionization were closer together, they could more easily participate in the available wind-shear engines at about the same time. This would lead to Es clouds at, say, both 110 and 125 km, more or less simultaneously. If this were the case, then an important factor in these unusually long Es links might be the positive influence of having a well-ionized F region above the E-layer path.

Only two openings have been examined in this detail as of now, so the statistics are very shaky. Nevertheless, there are a couple of apparent possibilities. In both the NA–EU and JA–NA openings, it appears that there was a channeled E-layer (not a single layer) at 105 km, about 25 km high, and 3,000–4,000 km wide that extended over much, or all, of the path. This could have led to a couple of things beyond just good conditions. All the “old” ideas are still on the table, perhaps even enhanced by the following conjectures:

Doubling the Odds. Much of the time Es is not composed of a single sheet of intense ionization thousands of kilometers wide and long. Most Es is made up a conglomerate of many, relatively small (up to 100 km horizontally), very thin clouds (tens of meters to a few kilometers vertically). Usually they are in motion, with the E-layer winds. As a result, Es is usually porous; the signal not only hits the clouds and maybe skips, but also passes through the spaces in between them and keeps going up. If there were two (or three) set of cloud producers, one above the other, the odds of getting an nEs hop, or an ordinary chordal hop, would go up.

Bottomside–Topside Ducting. This physical configuration may also set up the between-layers ducting situation mentioned earlier. There is no way to tell for sure, but if bottom–top ducting were to happen, it would appear that this “channel” structure would be the ideal setting for it.

Discussion and Conclusions

The intention of this study was to look further into the east-west EWEE phenomenon to see how it behaved at different longitudes. In the Northern Hemisphere, it reviewed the well-known JA–NA path with more and new data, and added a comparable study of the NA–EU path. It would be useful to look at the EU–JA path, but at the time there were insufficient data available to do it justice. Perhaps this will be possible in the future.

One concern that has been raised in the past has been whether there could be an Es path behaving according to mid-latitude “rules,” if it involved latitudes as far north as 60N to 76N. It is common to talk about the transition from mid-latitude Es to auroral Es being at about 60N. However, this boundary actually has a wide range, depending on whether it is day or night and whether the geomagnetic field is quiet or active.
On the daytime side of the Earth the auroral oval is pushed rather far to the north, perhaps as far 80N. In the present case, the path midpoints were all on the daylight side. Moreover, during quiet geomagnetic times, such as have prevailed these last few years, the ionosphere south of the (northern) auroral circle has the same seasonal and diurnal rules at ordinary “mid-latitude” $E_s$ (Hunsucker and Hargreaves, 2003). Thus, it may well be that the unusually long quiet Sun may have something to do with the amount of this propagation seen in recent years.

East-west EWEE propagation still has all the earmarks of an $E_s$ propagation mode, or modes. The biggest clues are the fact that it is a local summer-season event, and it exhibits a quite rigid adherence to the diurnal $E_s$ early-on-late effect. Almost without exception, the west-end stations are in their morning peak $E_s$ probability window, while the east-end stations are in their afternoon-evening $E_s$ probability window. The maximum range of any path by EWEE probably will be constrained by the geographic limitations of the early-on-late overlap. In detail, this distance varies with station latitude. Lower latitudes have longer geographically possible early-on-late distances going out beyond 14,000 km. Typical maximum values at mid latitudes are in the neighborhood of 11,000 km.

Conclusions
The findings regarding EWEE from this more extended study are:
1. The evidence remains strong that these events are some form of $E_s$;
2. It is not clear whether some of these hops were chordal $E_s$ modes;
3. Like the 2010 study, there is good evidence for $nE_s$ playing a role for at least some of the hops;
4. The character of the JA–NA and NA–EU phenomena seem to be essentially the same;
5. F-layer enhancement of the $E$-layer valley may play a role.

A Final Caveat
Although the studied openings and paths appeared representative of other known similar events, the detailed comparison to the ionospheric model was restricted to this one 24-hour period. While the characteristics, such as the diurnal patterns, were essentially the same as many other observed events, one must be cautious about assuming that the conclusions here are generally valid until more samples are studied.

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Note 1. The $2E_s$ was from W1 and W2 and 40°–50° east of the great-circle path to EU, probably not good indicators here.

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Figure 16. This is a north-south slice through the $E$ valley at the northernmost path point at about 190°E. It shows that the north-south extent of the valley walls is over 3,000 km.

Correction:

“A Homebrew AZ/EL Rotor Controller”
By James Kocsis, WA9PYH
Summer 2011 CQ VHF

This article described an AZ-EL rotor controller system (see page 24 of the Summer 2011 issue). The author makes the following correction and clarification:

“One of the parts in the electronics is rather rare, and in the parts list I specified a part number and source. However, the part specified was a DC capacitor, which will not work, and the part needed is an AC capacitor for C4 and CS. The good news is that there is a simple and inexpensive way to build a substitute part. I checked the circuit shown here and it works perfectly. The parts are available from many sources places and at very low cost.

“The capacitance value should be twice the value of an AC capacitor and voltage rating greater than 1.414 times the RMS voltage in the circuit. Therefore, two of the following rated DC capacitors are needed: 100 µF at 50 VDC.”