# Es Over Very-Long Water Paths

Jim Kennedy, KH6/K6MIO

**Introduction** – The 50 MHz band (6m) can often be an interesting place to study ionospheric radio propagation. One reason is that, at VHF, one is usually seeing only one, or perhaps two, propagation modes at the same time. This can help make untangling the multiple skip possibilities a bit easier.

Normally, long distance paths are usually associated with the solar activity maximum years. However, the following discussion is all about unusually long "short-path" propagation (say 8000 km and more, but less than half way around the planet), which showed up during periods of *very weak* solar activity. It explores two, every similar, sets of extended paths that occurred, first, near the end of the previous solar Cycle 23; and second, during similarly weak conditions nearing the end of the current solar Cycle 24, as shown in Figure 1. It may surprise many that these events actually occurred, and further, that it appears to mostly be a result Sporadic E propagation (Es).

For example, during the period of very low solar activity that occurred in the deep, waning days of Cycle 23 and then leading into the earliest days of Cycle 24 (2006-2010), quite a number of very long "short-path" six-meter openings occurred. Granted, these were weak-signal paths. Nonetheless, they remarkably spanned distances in the 8,000-12,000 km range on a number of occasions.

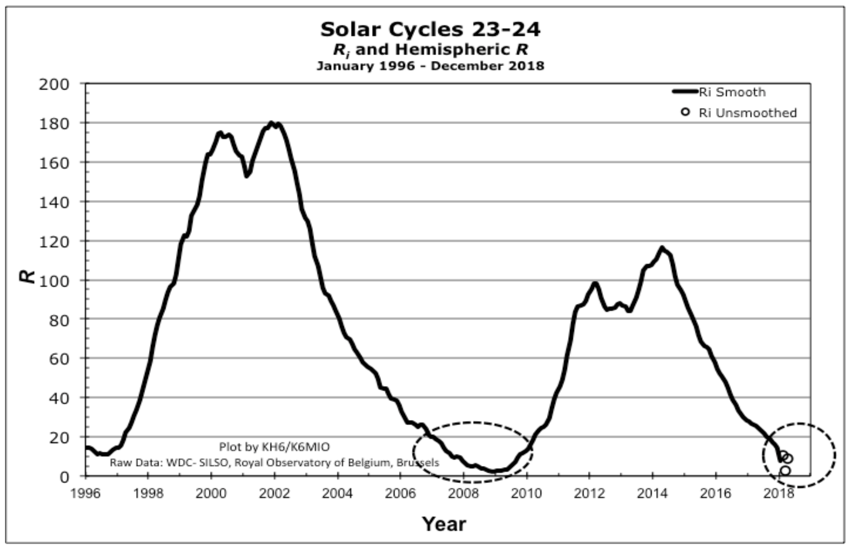


*Figure 1*: The two dashed ovals indicate the periods of lowest solar activity for Cycle 23 and the still evolving Cycle 24. The open circles in Cycle 24 are *unsmoothed* individual monthly values. *Data: SILSO*

These included substantial over-water paths between Pacific Asia and eastern North America, during the *northern*-summer Es season. On other occasions, there were paths between VK/ZL and South America, in the *southern*-summer Es season. More remarkably, it also included paths between VK/ZL and the west and central regions of the US – during the *southern* Es season [1]. (Of course, this was also the weak northern-winter Es period). Interestingly, the same paths did *not* appear when the summer-winter seasons were reversed north and south. Examples of the Cycle 23 openings are shown in Figure 2, on the next page.

More recently, during the same general range of very-low-level solar activity, this scenario has occurred again. The Southern Hemisphere summer of December 2017 - February 2018 also produced some truly remarkable long short-path six-meter propagation between Australia, New Zealand, and the islands a bit further east, then going all the way to South America, and North America – but first, let's consider a bit of technical background.

**Ionosphere** – Broadly speaking, the Earth's ionosphere supports HF and VHF radio-wave refraction in two height ranges: The E Region and the F Region. As a practical matter, at frequencies higher than about 10 MHz, the regions of most interest are generally restricted to the E Region (90-140 km) and the F2 Region (220 km and up).

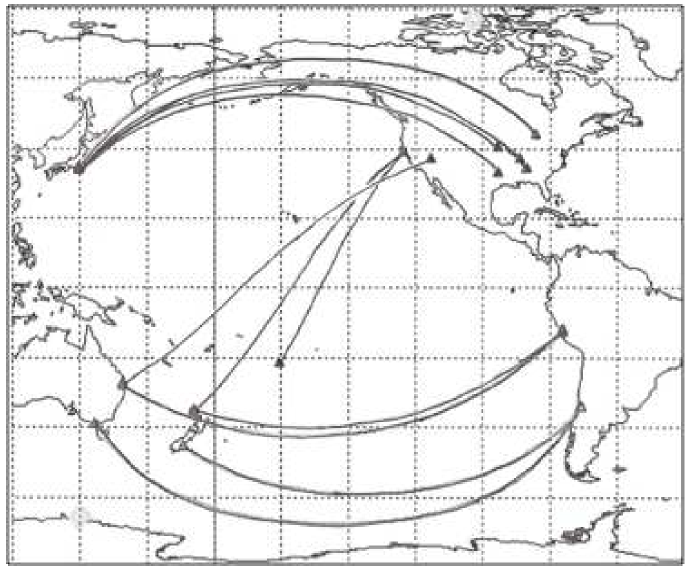

*Figure 2*: These are examples of three extreme "short" paths that showed up during the northern and southern summer Es seasons, in the very low 2006-2010 solar activity period near the end of Cycle 23. *Data*: *DX Maps. Plots*: *G.Projector.*

The higher one goes, the atmospheric *density* gets progressively smaller rather rapidly. For example, half of the Earth's atmosphere lies below 16,000 ft. At typical E-Region heights (say 105 km), the air pressure is only $3x10^{-7}$ that of sea level, while at typical F2 Region heights (say 300 km), it is only $2.5x10^{19}$ that of sea level. Comparing these E- and F-Region pressure values, note that the *E-Region* pressure is more than $10^{12}$ *greater* than for the *F Region*. Needless to say, that is a huge difference. Compared to the F Region, the E region is a seething soup of atoms, positive ions, and free electrons.

There are also several other important height-related effects. For example, looking *outwards* from the Earth's surface, as the air gets thinner, the percentages of the different gasses change. At the same time, their temperatures change (both down and up) with greater height. On the other hand, if one looks *inward* from the Sun – going deeper into the atmosphere – the thickening atmosphere progressively blocks out more and more of the Sun's high-energy radiation. Of course, the solar radiation is a central key to the ionization process, and the amounts and wavelengths of the radiation change with height.

***MUF Depends on Lifetimes*** – Along the way, these *differences* in the pressure and density, and in the amounts of incoming solar radiation and their specific wavelengths at each of the F and E Regions, all lead to dramatically different ways that the ionization can first occur, and finally, be *sustained* over long periods of time, in these two different regions.

Once an electron is ionized, there always is a heavy positive ion, somewhere, waiting to grab it back. Generally speaking, the lower the air density, the less often an electron and positive ion are likely to be close enough to recombine. In the *F Region*, the ion-electron recombination time can be tens of hours to more than a day, due to the large particle separations. This long delay means that there is *time* for the *total* ionization to *accumulate* to much higher total levels, thus producing higher MUFs.

On the other hand, the much-lower E Region situation is quite different. Here, the much higher pressure and density also means that the collisions – and resulting *recombinations* – occur very much faster. As a result, the lifetimes of individual E-Region free electrons drop very significantly – down to tens of seconds to a few minutes. This directly leads to very short ionization *accumulation* times, and much lower MUFs. As a result, "ordinary" E skip (*not* Es) rarely produces daytime MUFs much higher than 22 MHz, and rarely exceeds 3 MHz at night.

**Es is a Different Beast** – On the *other hand*, the most meteors burn up in the E Region. These vaporizing meteoroids leave behind a variety of atomic metals (mostly iron, some magnesium, and others). The metal atoms produce Es – together with the Es-cloud vertical compression from the Earth's magnetic field and the E-Region winds. This results from complex process that allows the meteoric metals to "protect" a fraction of the originally *solar-created* free electrons, by keeping them from immediate recapture, thus giving them much longer lifetimes – as much as tens of hours. This much longer ionization accumulation and much higher MUFs – results in Es.

The key here is that the E Region has a vastly larger neutral particle density than the F Region – even during low solar activity. So, the Sun directly produces huge amounts of the *very* short-lived free E-Region electrons every day. Importantly, since the Es process only needs to capture a very small fraction of the Sun's much larger *reservoir* of available electrons, the solar activity fluctuations don't seem to have much impact on the amount of available, protected, *Es* electrons. On the other hand, Es *is* very dependent on the amount of *meteoric metals* available to enhance the capture process.

Long-term studies of *ordinary* E MUFs, over many solar cycles, have shown that:

1. From cycle to cycle, the E-Region ordinary MUF actually increases slightly during solar minima.
2. For groups of several related weak cycles, the long-term average of the ordinary E-Region MUF tends to decrease slightly, despite much larger changes in the F-Region MUFs [2].

Of course, the ordinary E MUF is not the same as the Es value, but one expects Es would show similar effects. The net result of Es propagation observations seems to support the notion that the amount of long-term, year-after-year, solar activity doesn't have a noticeable impact on the Es MUF[1].

**Southern Summer 2017-2018** – Going back to the main subject: Though things had been fairly quiet for the last few years, things changed over the 2017 year-end, at least for a while. During this late-Cycle-24, low solar activity period, there was a burst of extended 6-m propagation across the Pacific Ocean, very much like what happened at the bottom of Cycle 23. It began to take shape in early December 2017, reached a peak in early January 2018, and then started downward slowly, ending in late February.

During that time, the west-end South-Pacific stations made contacts eastward across the Pacific – *below* the Equator – with the southern half of South America. They also made contacts *across* the Equator into Hawai`i, western US, and northern Mexico. In both cases, the longest propagation ranged from about less than 8,000 km out to more than 15,000 km, as shown in Figure 3. The characteristics were virtually identical of the late Cycle 23 episode, for the southern east-west paths and the north-south paths across the equator, as shown earlier in Figure 1.

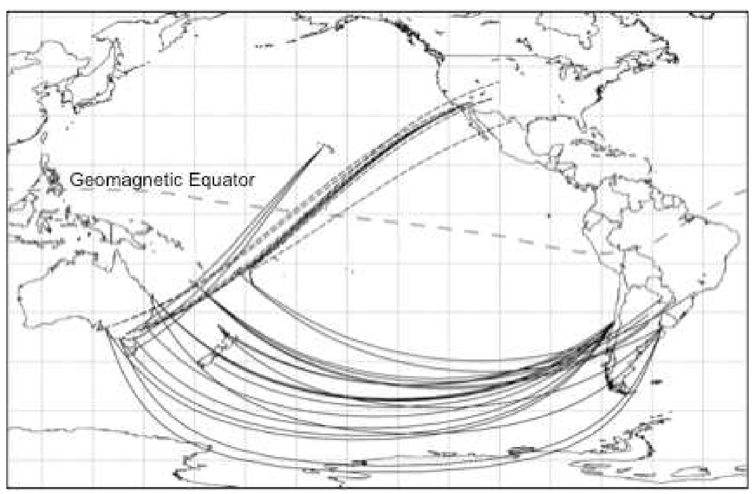


*Figure 3*: These 6m over-water paths ranged from 8,000 km to over 15,000 km in December 2017-February 2018. The east-west paths in the Southern Hemisphere mapped very well onto multihop Es. The North-South paths crossing the Equator are consistent with Es hops below and above the Geomagnetic Equator, with one F2 hop off the north-side EIA crest. *Data*: *DX Maps. Plots*: *G.Projector*

[1] Of course, short-term solar events can and do sometimes produce short-term impacts.

**East-West Characteristics**– The studies of the earlier Cycle 23 episodes found that those paths, which were entirely east-west oriented *without* crossing the Equator, were strikingly similar to those recently seen over the 2017 year-end. As in that previous solar-cycle, they were definitely *weak signal* contacts. By comparison, the recent events were more frequent, and some paths were somewhat longer. While this may have been due to the ionospheric conditions, it also appears to have been positively impacted by JT65 and FT8. *Very* few of the contacts were made by CW, and no SSB was noted at all.

As in the previous solar cycle, geographically, these paths consistently occurred in the mid-latitude Es zone, which has different seasonal and time-of-day patterns than Equatorial Es, Auroral Es, or Polar Es. All these paths mapped very well as ordinary, surface-sky-surface, multihop mid-latitude Es[2]. The path analysis process was quite straightforward. The range of a single E Region hop is nominally 1,700 - 2,200 km, with an average of about 2,000 km. Figure 4 shows how the various intermediate ranges expand, assuming simple, ordinary multihop paths. With this information, one can infer that the east-west end points are, at least, consistent with this table.

*Figure 4*
**Ground Footprints for Successive $nE_s$ Hops**

| Hop | Min (km) | Max (km) |
|---|---|---|
| 1 | 1,700 | 2,200 |
| 2 | 3,400 | 4,400 |
| 3 | 5,100 | 6,600 |
| 4 | 6,800 | 8,800 |
| 5 | 8,500 | 11,000 |
| 6 | 10,200 | 13,200 |
| 7 | 11,900 | 15,400 |

***East-West Ionospheric Situation*** – One important question on these long east-west directed paths is whether or not Es it is even possible over such distances. Put in other words, is there enough Es ionization, in enough of the right places, to make mid-latitude multihop Es propagation possible?

In the 8,000 km range and up, earlier studies of both similar and different paths have also shown that, very commonly, workable Es occurs when the west-end station is in its morning Es peak time and the east-end station is in its late afternoon-evening Es peak time, as Figure 5 illustrates [3].

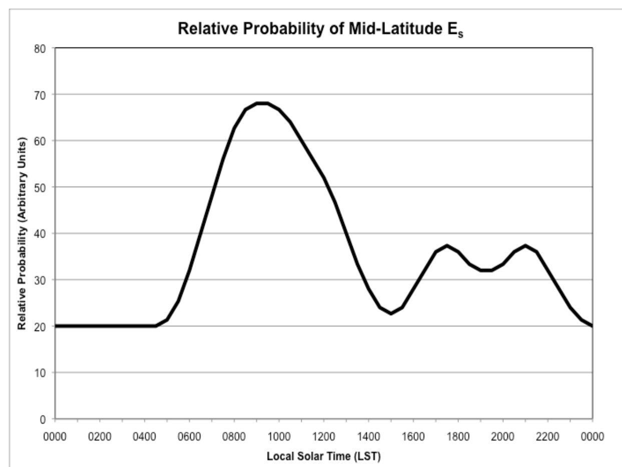

*Figure 5*: This stylized plot shows that the mid-latitude Es *probabilities* of high MUFs often occur in two broad *times* of day – one in the morning, about 0600-1300 local solar time, and a weaker one in the late afternoon-evening, about 1600-2200.

Clearly, this would be the ideal spacing for the two path *end points*. This gives the best opportunity for also finding available *mid-path* Es skip points, that, while they have a lower Es probability, they do occur under good conditions. This same pattern is also clearly seen in these more recent events.

**North-South Characteristics** – Both now and in the previous cycle, paths crossing the Equator were distinctly different from the east-west variety, in at least one important way. Figure 6, shows that it appears to *start* from VK as three midlatitude Es hops on the southern summer side of the Geomagnetic Equator. *Then*, it appears to make a single *F2 hop* off the northern branch of the Equatorial Ionospheric Anomaly (EIA). *Finally*, it goes on, either directly to ground stations in Hawai`i, or connecting over water to one more winter mid-latitude Es hop, and arriving at the west coast of North America. In some cases, the path goes still further, with a second northern overland Es hop to the east. This was referred to as Trans-Equatorial Es-F-Es or TEFE [4].

[2] One cannot eliminate the possibility of some intervening chordal hops, but that didn't seem to be the case.

During the previous cycle's low-solar-activity period, the hop across the equator was also studied in two different ways. First, the full ionospheric path mapping did not match well for Es. Then, computerized ionospheric models were used to visualize the conditions occurring along those paths. This clearly showed that this one hop was also *not* due to TEP, although, it was still very likely a north-side F2 hop.

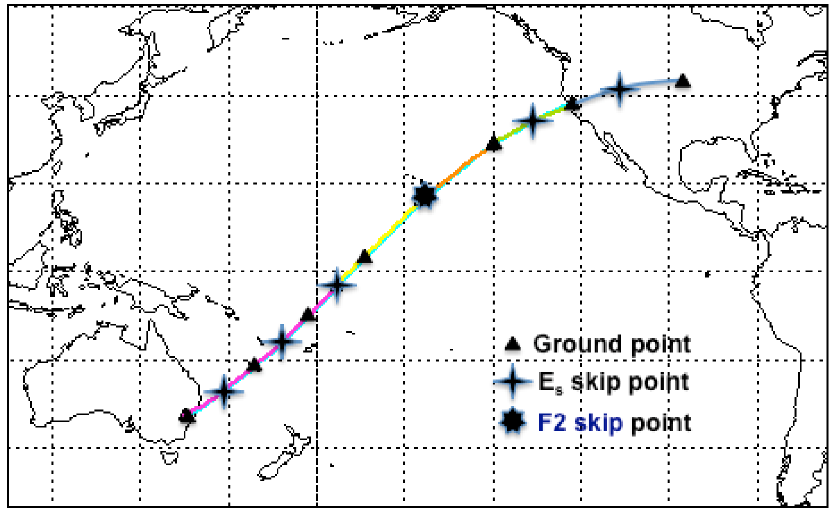

*Figure 6*: The path north from VK makes three summer Es hops, then links to one north-side F2-crest EIA hop south of KH6. In this case, it takes two more winter-Es hops into central W/K. *Data*: *DX Maps. Plots*: *G.Projector*

Note: TEP requires that there are two F2 skip points, one on each side of the geomagnetic equator, with each one about 15° from the geomagnetic equator itself. These ionization maxima are called "crests". First, they *must* be about equally ionized to produce a full 6m *chordal* hop across the geomagnetic equator. And, second, the two crests also *must* be properly *aligned* with the actual direct path between the two end-point stations.

*Neither* of these requirements is met at that time of year (i.e., near the solstices). At yearend, the northern side has a much higher MUF, while the southern side is much lower. In addition, due to the angle of the geomagnetic equator over the mid Pacific, the alignment of the two crests is at its very *worst* in December (and June) for a TEP path between VK/ZL and W/K.

On the other hand, the Es hops on either side of the geomagnetic equator map very convincingly align with the path direction, and the single northern F2 hop, and they are all consistent with the usual local times of day for optimum solar input.

***North-South Ionospheric Situation*** – The 2017-2018 events are remarkably similar to the previous cycle events. It certainly seems to be the very same phenomenon. Unfortunately, at this writing, the 2017-2018 ionospheric data are not yet available. There may be other explanations, but this approach seems reasonable.

**Southern Summer–Northern Winter 2018 - 2019?** – Based on the previous history, it may well be worth focusing on what might happen during the next couple of year-ends in the December-February time frame. Experience suggests that digital modes over the same Pacific paths discussed here may well open up again.

**Northern Summer 2018?** – Another opportunity might also be the Pacific Asia to North America paths, which also showed up quite a number of times in the same general period during the previous Cycle 23 solar minimum.

**Some Other Path Choices** – At the same time, in other parts of the world, (and despite the above comments about over water) one might also look for the trans-Eurasian paths that were seen about the same time in the Cycle 23 minimum.

Recalling that this discussion is primarily about extended Es, one area that might *not* be a good choice (though the author would be delighted to be proven wrong) would be looking for paths between North America and southern Africa. The path between VK/ZL and W/K, discussed further above, relies on the favorable alignment of both summer and winter Es timing and a F2 hop off one of the EIA crests.

Unfortunately, the over-water route between North America and southern Africa has significant issues in both cases. The Earth's magnetic field plays a key role in the production of all Es: The stronger the magnetic field, the better. Unfortunately, southern Africa suffers from the weakest effective magnetic field component on the planet. So, to begin with, 6m-class Es is rather rare there compared to other places. In addition, in either the southern local summer, or the southern local winter, the models show that the (north or south) EAI crests are either far out of alignment, or far too weak, to be effective [4].

**Is "Open Water" a Positive Factor?** – While it is true that fairly extended Es-like paths do materialize over large land masses, such as spanning Eurasia to about 9,000 km [5], it is still interesting to speculate about whether even longer extended paths benefit from the long stretches of open water. Water provides essentially unobstructed space, over a more or less flat, electrically conducting ocean surface. That *may* be a more ideal environment for unobstructed *intermediate surface contacts*. It is easy to imagine that other paths, which include a lot of different landforms, rough irregular surfaces, mountain ranges, and perhaps even the impact of intervening microclimates, might enhance scattering and phase canceling near the intervening ground points, and otherwise reduce the signal strength.

**Summary** – Based on the history to date, it appears that the extreme Es east-west paths (all on the same side of the equator) can show up during the local *summer* Es season in either hemisphere, at least during prolonged low solar activity. The north-south paths across the equator seem to be restricted to the year-end southern summer, at least so far.

Finally, it must also be said that, with the current state of Cycle 24, and with using digital encoding tools, there may be opportunities to expand our knowledge of these events, and perhaps even find some additional new pathways.

***Acknowledgements***

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***References***

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