Upper-Level Lows and 6-Meter Sporadic E

Using Amateur Radio to conduct real science in pursuit of a decades-old mystery.

Joe Dzekevich, K1YOW

*Ham Radio Science Citizen Investigation, HamSCI (***www.hamsci.org***), is a recently formed organization to connect professional ionospheric and atmospheric researchers with the worldwide Amateur Radio community. HamSCI was started by ham scientists who study upper atmospheric and space physics, and the group is dedicated to enabling amateurs' ability to make and contribute truly scientific observations through pursuit of the hobby we all enjoy. K1YOW's investigation, described in this article, is a great example of not only the power of curiosity, but also of the strength of merging science and Amateur Radio to help advance knowledge of Earth's ionosphere. I hope it encourages many others to be curious during their own operations, to connect with the scientific community, and to use their keen observation skills for the benefit of all.*
— Dr. Philip J. Erickson, W1PJE

I have always been interested in HF/VHF propagation, with a special interest in working 6-meter DX during the summer season, when the "magic band" opens on long-distance paths. In the spring of 2016, I noticed that almost every day, the 6-meter band was open via sporadic-E propagation for paths across Europe (see Figure 1), but the same was not true in North America. This situation was frustrating for me and for other North American hams trying to make contacts on 50 MHz. In the spirit of citizen science, I began to ask questions to explore what I was observing firsthand on the radio:

- What was different about average European 6-meter conditions compared to North America?
- Did this difference relate to sporadic-E layer behavior?
- What could I learn about the causes of sporadic E in the ionosphere?
- Could I draw conclusions, or even predictions, about 6-meter behavior?

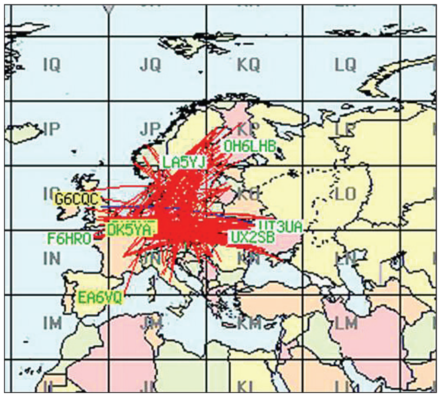

Figure 1 — Typical European sporadic E in August 2016. [**www.dxmaps.com**]

Sporadic-E Science

Any investigation often begins with a trip to the library (or, these days, to the internet) to read up on what is already known about a subject. A quick search uncovered an excellent E-layer study using satellite observations and based on a doctoral thesis by Dr. Christina Arras, who is now at a German research institute.[1] W1PJE also led me to a good and relatively recent tutorial summary of the chief mechanisms thought to be involved in the formation of sporadic E.[2] Another Italian paper explored statistical connections between thunderstorms in the lower atmosphere and sporadic-E layers over Rome.[3]

At this point, I assembled a brief list of what I had learned about the state-of-the-art ionospheric research findings on sporadic E:

- Sporadic-E layers are phenomena of the ionospheric E region, near 90 to 120 kilometers in altitude. (Remember

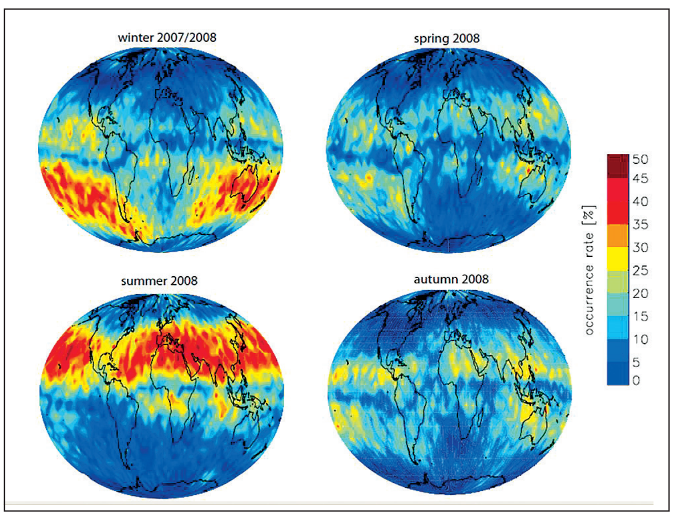

Figure 2 — Statistical maps of sporadic E show that North American longitudes are less active on average compared to European longitudes. Adapted from Arras et al., 2010.[1]

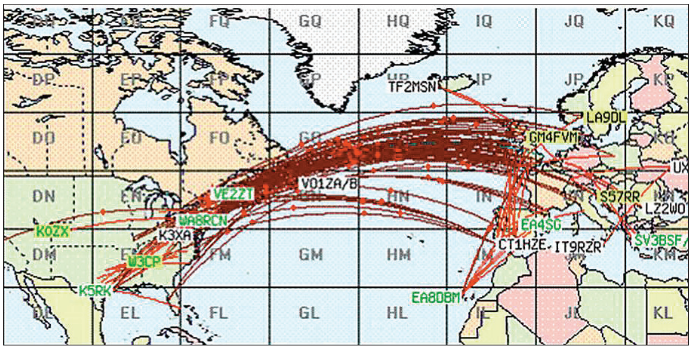

Figure 3 — June 13, 2016 transatlantic 50 MHz sporadic-E conditions. [**www.dxmaps.com**]

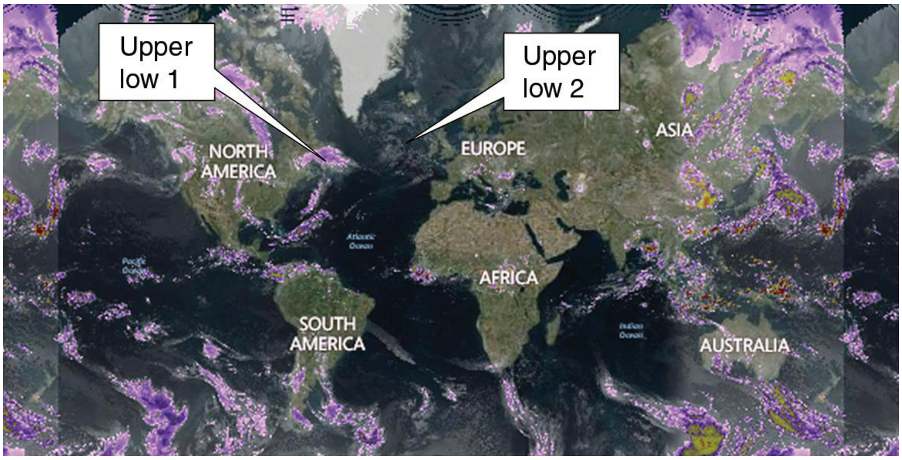

Figure 4 — June 13, 2016 lower atmosphere weather, showing well-positioned North Atlantic storms at the same location as active sporadic-E paths. [**earth.nullschool.net**]

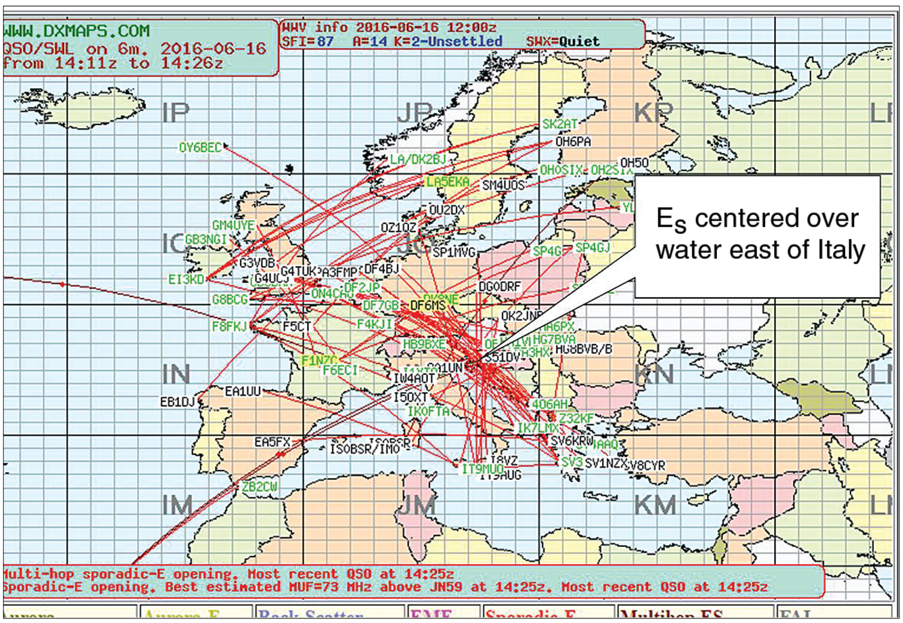

Figure 5 — June 16, 2016 conditions, showing a 6-meter sporadic-E opening with its center east of Italy. [**www.dxmaps.com**]

that the F region is much higher than this altitude.)

- Sporadic-E layers consist of enhanced electron density as compared to the background ionization created every day by the Sun's extreme ultraviolet rays.
- The sporadic-E layers appear mainly at daytime in mid-latitudes and mostly in the summer hemisphere.
- The layers have a vertical thickness of usually 0.5 – 5.0 kilometers, and a horizontal extent of 10 – 1,000 kilometers.

It quickly became clear that a prime cause of sporadic E is thought to be related to winds in the upper level neutral atmosphere:

- As seen by many rocket flights,[4] neutral winds around 100 kilometers in altitude can have strong *shears*, or changes in horizontal direction.
- Meteoric dust (mostly Fe+, Mg+, and K+), coming from tiny, milligram-sized or smaller micrometeoroids burning up near 100 kilometers in altitude, provides the raw material for sporadic-E layers.
- With their strong shears, E-region winds can pile up these meteoric dust ions into thin layers.
- Electrons follow the ions, causing thin sporadic-E layers and providing good skip opportunities at 50 MHz.
- Sporadic E is most often seen in summer, but it depends critically on neutral wind patterns, and these are quite variable.
- We would expect sporadic E to be variable as well, and indeed, we know it is from Amateur Radio's long experience.

I then realized that the Arras paper not only laid out the likely causes of sporadic E, but they saw in their study the same thing I observed: North America was in general not a sporadic-E hotspot, but Europe was. Figure 2 shows this very clearly, but more on this topic later. This didn't answer all my questions, though. If North America is not a sporadic-E hotspot, then why do hams occasionally encounter good sporadic-E propagation in the US? I then discovered that amateurs over the years have noticed that sporadic-E openings seem to happen near upper-level tropospheric (neutral atmosphere) disturbances, as well as the regular sporadic-E openings. Remembering the Italian paper, I thought that maybe this could be a factor.

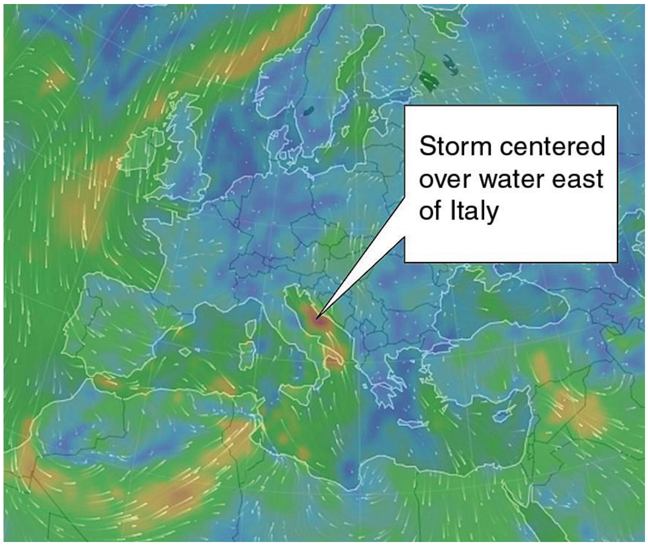

Figure 6 — June 16, 2017 lower atmosphere weather, showing a strong storm located under the 50 MHz sporadic-E cloud east of Italy. [**www.windy.com**]

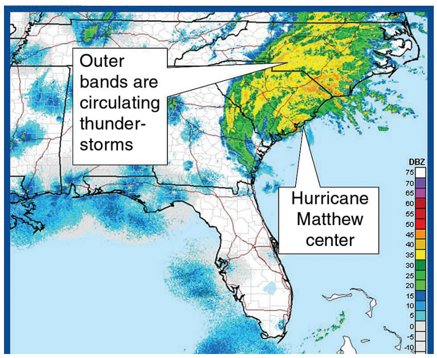

Figure 7 — A weather radar plot showing Hurricane Matthew's lower atmosphere effects on October 8, 2016. [**https://radar.weather.gov/**]

June 2016: Things Change

Returning to the radio, the general "North American quiet, European active" situation continued into the late spring and early summer of 2016, according to my personal observations and data gleaned from the DX Maps website (**www.dxmaps.com**). However, nature threw a curveball on June 12, and things became very different. Now, not only was North America seeing sporadic E on the 6-meter band, North American and European hams were working each other via transatlantic 6-meter communications, as shown in Figure 3. Something must have changed.

(Note that Amateur Radio operators get most of their spots from automatic reporting to the DX Cluster, but many also manually input spots to interfaces like DX Maps. This allows selection of specific weak-signal modes like JT65 and JT9 from the DX Maps web interfaces, and using the options menu, one can select all spots, or only spots from the DX Cluster. The information in this article used an "all spots" selection.)

The Mid-Latitude Hypothesis

Remembering the Arras study, I formed a predictive hypothesis: Besides the normal random sporadic E, mid-latitude sporadic-E openings might be enhanced by strong neutral atmospheric disturbances, like hurricanes and upper-level, low-pressure systems at mid-latitudes. Their cause could be lower-atmosphere, low-pressure systems that would disturb upper-level tidal winds, creating extra wind shears that would form the ionized layers and reflect amateur signals.

I knew from discussions with Dr. Philip Erickson, W1PJE, and other ionospheric researchers, that upper atmosphere wind shears are a very active research area in the professional community. I wondered if hams could help advance knowledge of this science using Amateur Radio.

Supporting Evidence

Because it had been reported that sporadic E was sometimes seen by ham radio operators during storms such as hurricanes, I decided to look at the weather models to see if there were any storms in the North Atlantic. Sure enough, there were two major storms in the North Atlantic on June 12, 2016 that were spaced within E-layer signal hops of each other and the North

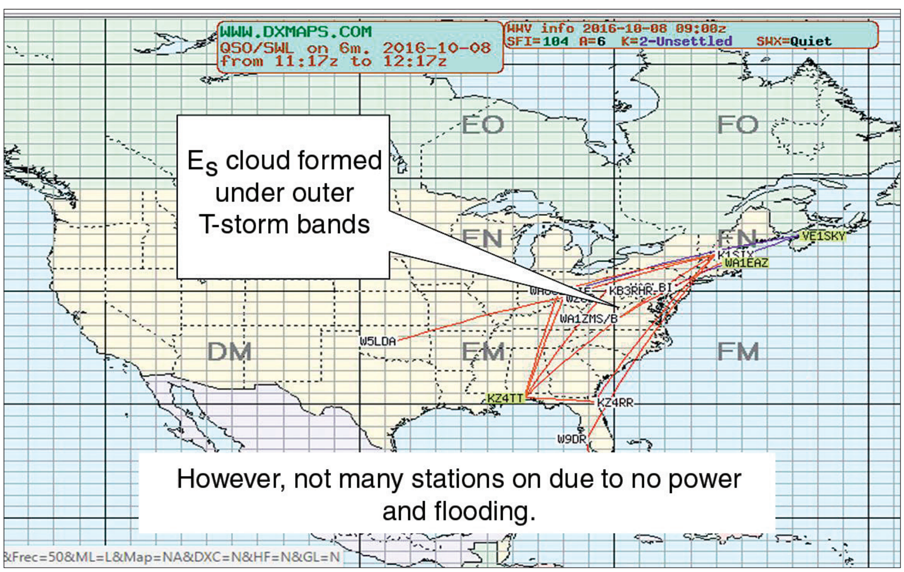

Figure 8 — October 8, 2016 sporadic-E radio paths at 50 MHz over thunderstorm belts associated with Hurricane Matthew.

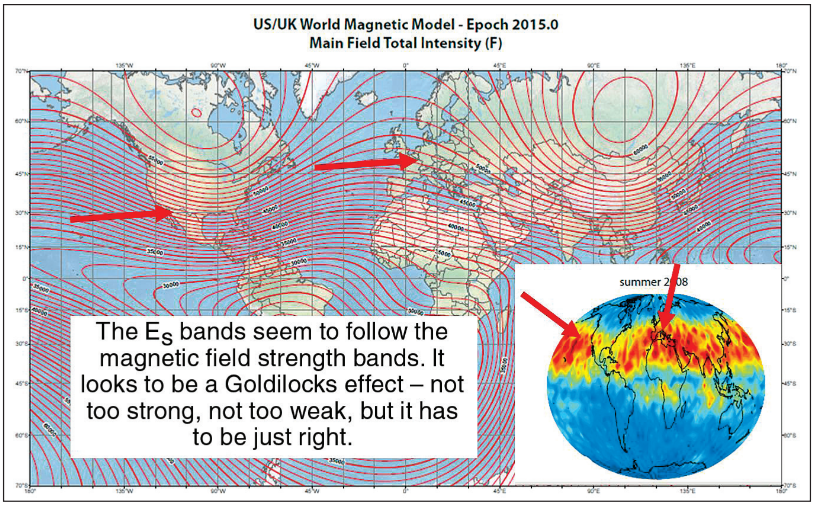

Figure 9 — Potential magnetic field strength effects on sporadic E: The 2015 epoch world magnetic field model shows that southern US and European magnetic fields have similar magnitude (**www.ngdc.noaa.gov/geomag/WMM/data/WMM2015/WMM2015_F_MERC.pdf**). Insert adapted from Arras et al., 2010.[1]

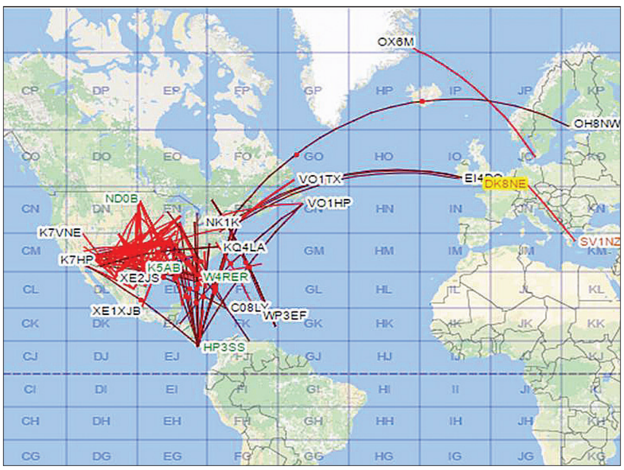

Figure 10 — May 20, 2017 conditions, showing multiple 50 MHz transatlantic paths. [**www.dxmaps.com**]

American and European coastlines, as shown in Figure 4. I was encouraged further by noting that on June 13, 2016, the upper-level low in the North Atlantic moved southeast and moved further apart from the Canadian Maritime upper-level low. This was quickly followed by an almost complete disappearance of North America-to-European double-hop sporadic-E paths unlike those we had on the 13th.

My own operating experiences on June 12 bore these thoughts out. During that spectacular opening, I worked transatlantic on 6 meters to EA7AH in grid square IM67, G4RRA in IO80, and EI4DQ in IO51, all on CW running a modest 100 W into an off-center-fed dipole antenna. One day earlier, during a VHF contest, things were even more extraordinary, as I worked 35 US stations in 2½ hours in the 1, 2, 3, 4, 5, 7, 8, 9, and 0 call districts on 6 meters from grid square FN42 without calling a single CQ.

Because it was looking like North Atlantic storms were connected to transatlantic 6-meter communications via two-hop sporadic E, I decided to go further and look at European sporadic E to see if some lower-atmosphere storms also existed in the same areas as the sporadic-E clouds.

Figure 5 shows the June 16 DX Map over Europe, and I noted a large sporadic-E opening centered over the water east of Italy. I was curious: was there a storm system in the same general area that was either causing or enhancing sporadic-E conditions up to 6-meter frequencies? Sure enough, there was. Figure 6 shows a lower atmospheric storm system in the exact same spot as the sporadic-E cloud.

Hurricanes

Now I could continue with the hypothesis that storms might be causing and/or enhancing sporadic E. What about major weather disruptions like Hurricane Matthew, affecting millions of people in the autumn of 2016? I knew that hurricanes spawn bands of thunderstorms containing lightning and high-altitude sprites (a fascinating subject), and the Italian study found that lightning can enhance sporadic E. Perhaps these conditions, along with the severe wind disruptions provided by such a huge storm, could enhance formation of sporadic-E layers as well. I was very curious as to whether or not Hurricane Matthew caused any sporadic E.

It's important though to pause and remind readers of a data selection effect: These observations depend on Amateur Radio operators being on the air. Hams won't be on the air in nearly as many numbers if they are being flooded or have no power (no backup batteries or generators), or if they sustain antenna damage from winds and fallen trees. Nevertheless, Figure 7 shows where Hurricane Matthew was on October 8, 2016. Sure enough, looking at Figure 8, there was a sporadic-E opening where the northwest thunderstorms were located.

Sporadic-E Continental Differences

All these findings made a strong case that storms are linked to the generation and/or enhancement of sporadic E. However, it was time to return to my initial question that started this effort. Significant meteorological storms did not occur daily in 2016. So why was Europe enjoying sporadic E almost every day, while North America was in a sporadic-E drought?

I returned to the scientific literature, and discovered that besides the sporadic E-linked processes of wind shears, meteoroid particles, ultraviolet heating from the Sun, and other factors, the Earth's magnetic field might play a major role, and this could have a longer-term effect.

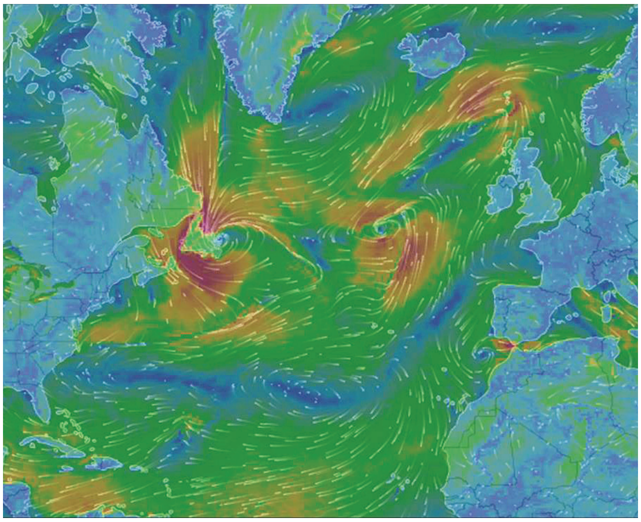

Figure 11 — May 20, 2017 lower atmosphere weather conditions. Note the strong storm activity located under observed 50 MHz sporadic-E transatlantic paths. [**www.windy.com**]

Examining this further, Figure 9 shows a worldwide map of the Earth's magnetic field and its variations. We see that the Earth's magnetic field strength in the southern US and Caribbean areas is at the same strengths seen in Europe, due to a dip in the Earth's magnetic equator. So, I hypothesized that the Earth's magnetic field's impact on sporadic-E formation might be a "Goldilocks Effect" — perhaps it should not be too weak or too strong, but must be in a range that is just right. Following this line of thought, Europe would see more sporadic E than North America, and by extension, Europe would also be like the very southern US and Caribbean, because of similar magnetic field strengths. These are the very beginnings of an idea that can be tested further with the ionospheric research community in the future, perhaps through HamSCI efforts.

2017 Sporadic-E Conditions

After the June 2016 openings, 6 meters in North America quieted down significantly. However, 2017 saw a return to great sporadic-E conditions. In May of 2017, 6-meter sporadic E really picked up, especially on transatlantic links.

Applying my earlier work to current conditions was telling. Figure 10 shows the DX Map for May 21, 2017 with a number of sporadic-E paths associated with lower-atmosphere activity: sporadic E over a central US vortex in the jet-stream trough; sporadic E over Georgia, formed on jet-stream trough shear lines for paths to the Caribbean, and three low-pressure systems in the Atlantic that allowed transatlantic paths from North America to extreme western Europe and from North America to Scandinavia. Figure 11 shows the positions of various storms and fronts, and it is obvious that a storm or front is under all the 6-meter sporadic-E paths. There are also some very long paths showing up in 2017 where hams in W4, W5, W7, and lower W6 land were working Japan and China, but these paths may be more related to the equatorial geomagnetic anomaly and F2 ducting (another deep set of RF propagation subjects).

All in all, 2017 was a much better year for North American sporadic E, and some of the predictive patterns from 2016 seem to be re-emerging. I have not seen North Atlantic 6-meter sporadic E unless there were storms also present.

But there are puzzles remaining. For example, when looking at 6-meter sporadic E along paths from northern South America to Africa, there are usually no storms present. Furthermore, sporadic E can be seen over land, with or without storms. There are also complicating factors due to geomagnetic storms and their effects. For instance, I have often noticed 6-meter sporadic E occurring after a geomagnetic storm, but usually not during a geomagnetic storm. And when it comes to weather, the further south we go, the less dependence there is on storms in my observations, so maybe sporadic E is more dependent on magnetic field strengths and alignment, coupled with other complex mechanisms not described here (i.e., equatorial ion fountains).

Summary

It should be clear that we do not yet completely understand the mechanisms behind sporadic E. The phenomenon is quite variable with a good number of "exceptions to the rule." For example, we hams make sporadic-E contacts in polar and equatorial regions, even though the literature tells us not to expect any sporadic-E layers there from wind shears. This is probably due to the polar regions being directly affected by solar wind inputs to the upper atmosphere.

Nevertheless, we can conclude a few things from my initial studies:

- Sporadic-E observations are fascinating, and act like one big experiment with many complex variables.
- We can use Amateur Radio as a tool to readily see and document sporadic-E occurrences.
- Upper-level low-pressure systems, with their strong possibilities to affect high-level tidal wind shears via coupling to thunderstorms, hurricanes,

strong fronts, and lightning, present a high degree of observational correlation to the appearance of mid-latitude sporadic-E layers.

- Low-pressure systems that generate intense disruptions, including lightning and sprites, could have extra potential to enhance the mid-latitude sporadic-E field up to 6-meter frequencies.
- Based on DX Maps, North America is perhaps not the best sporadic-E hotspot in the world on average.

However, in Europe, the magnetic field strength is the same as in southwestern North America, and thus there seem to be more sporadic-E openings in that region, like the appearance of more sporadic E in Europe. This may point to a magnetic Goldilocks Effect in some yet undetermined way, in that things must be not too strong nor too weak, but must be just right.

A working hypothesis, requiring more research, is that sporadic E may be mostly driven by solar tidal wind shear in the E-layer ionization field, along with some form of horizontal Lorentz forcing from Earth's magnetic field component.

More study is needed on all of these items, and ham radio can help.

A Bright Future for Ham Science Investigations

Modern citizen scientists benefit from having access to a wealth of research papers in ionospheric sporadic-E propagation, along with good websites that monitor global weather patterns and Earth's magnetic field. Also, we hams are good observers, and we now have organizations like HamSCI to help connect us to the latest scientific research.

We possess tools that allow citizen scientists to contribute observational knowledge and spatial coverage to the fields of radio propagation science. Thanks to digital modes such as FT8, JT65, JT9, and WSPR, we can easily establish unattended monitoring stations that report conditions around the clock. Websites such as DX Maps, PSKReporter, and the Reverse Beacon Network (RBN) allow us to see and measure propagation effects that we would have missed unless we were sitting at our rigs all day.

There are many opportunities for amateurs to observe and experiment, and to become active citizen scientists in the areas of radio and propagation research. It's an exciting time for discovery, with direct benefits to our ability to pursue this venerable and ever-changing hobby. I hope you will join me in seeing what more we can find out in the future.

Notes

[1]Arras, C. (2010), "A Global Survey of Sporadic E Layers Based on GPS Radio Occultations by CHAMP, GRACE and FORMOSAT–3 / COSMIC," *Scientific Technical Report* STR10/09, ISSN 1610-0956.

[2]Haldoupis, C. (2010), A Tutorial Review on Sporadic E Layers, in: *Aeronomy of the Earth's Atmosphere-Ionosphere*, chapter 29, pp. 381 – 394, IAGA Book Series Volume 2, Springer-Verlag.

[3]Barta, V., Scotto, C., Pietrella, M., Sgrigna, V., Conti, L., and Sátori, G. (2013), A Statistical Analysis on the Relationship Between Thunderstorms and the Sporadic E Layer over Rome, *Astronomische Nachrichten*, 334(9), 968-971.

[4]Larsen, M. F. (2002), "Winds and Shears in the Mesosphere and Lower Thermosphere: Results from Four Decades of Chemical Release Wind Measurements," J. Geophys. Res., 107(A8), doi:10.1029/2001JA000218.

Joe Dzekevich, K1YOW, was first licensed in 1962 and currently holds an Amateur Extra class license. He graduated from Northeastern University in 1977 with a Bachelor's of Science in Industrial Technology, and later earned a Master's of Business Administration from Clark University in 1985. Joe is currently a retired Reliability Engineering Fellow who has worked for Bell Labs, Digital Equipment Corporation, Chipcom/3Com, and Raytheon. Joe is also a senior member of the IEEE Reliability Society, where he held various offices in the local IEEE Boston Reliability Chapter, and developed and taught many of the chapter's courses. He is a member of NVARC (Nashoba Valley Amateur Radio Club), the ARRL, and HamSCI. He has always been interested in radio propagation, starting back in 1965, when he subscribed to the CRPL (Central Radio Propagation Lab) Ionospheric Predictions, where one used monthly CRPL prediction maps to chart predicted E-Layer and F-Layer radio paths. Joe can be contact at **k1yow@arrl.net**.

For updates to this article, see the *QST* Feedback page at www.arrl.org/feedback.