sporadic-E propagation at VHF
a review of progress and prospects
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Great strides in sporadic-E achievements and theory have been made since amateurs discovered this fascinating propagation mode in the 1930s. This review of progress and future Prospects provides a practical guide for effective use of VHF sporadic-E propagation.

Thousands of spectacular sporadic-E contacts made on the 50, 144, and 220-MHz bands during the past half dozen years have created considerable excitement in VHF circles. US and Canadian 6-meter operators have long awaited the opportunity to make 50-MHz E-skip contacts into Europe, and the first two-way transatlantic 50MHz sporadic-E contacts were made on July 11 1983, soon after British amateurs gained access to the band. Most of the British stations that made 5000km and longer contacts were running only a few watts! Since then many stations in Canada, on the East Coast and in the South and Mid West have been treated to European sporadic-E openings. Similar contacts between the East Coast and Hawaii (up to 8000km) and the West Coast to Japan (7600km and longer) are frequent enough to suggest even greater possibilities for 6-meter sporadic-E.

Numerous contacts in the 2200 - to 3200km range made recently on 144MHz prove that sporadic-E on the higher VHF bands is not limited to the 2200km distance maximum characteristic of "one -hop" E-layer propagation. Stations as widely separated as St Paul Island (in the Gulf of St Lawrence) and Florida have completed 2-meter contacts over 2200 km into the Midwest and Far West; during the June 1987 ARRL VHF QSO Party, several extraordinary contacts over paths 2900 km and longer were completed on 144MHz from Arizona and Nevada to Georgia and Florida via sporadic-E. Many other examples of contacts made over similar distances indicate that conditions capable of supporting such contacts may be more common than once thought. In spite of these accomplishments, the longest 144MHz sporadic-E contact was not made in North America, but rather is claimed by Gyula Nagy, HG0HO, and Salvatore Patruno, EA8XS, who united two continents over a 3865-km path on July 16, 1983.

Perhaps the most remarkable recent achievement came with a report of the first 220MHz sporadic-E contact. In an event long predicted and anticipated by amateur VHF enthusiasts, and preceded by several near-misses, Bill Duval, K5UGM, and John Moore, W5HUQ/4, finally broke through a 1500km path from Texas to Florida on June 14, 1987, during the ARRL VHF QSO Party. Undoubtedly, this feat will be repeated in the future as the popularity of the 220-MHz band grows.

What is Sporadic E?

Sporadic-E (also known as Es) propagation is probably familiar to many low-band operators as the summertime "short skip" on 10 meters. It is also responsible for most of the long-distance (600km and greater) contacts on the 6-meter band. Sporadic-E is a type of ionospheric E-layer reflection
caused by small patches of unusually dense ionization. These sporadic E-layer "clouds" appear unpredictably, but they are most common over the US and southern Canada during the daylight hours of late spring and summer. Sporadic-E events may last for just a few minutes to several hours; a given event usually affects only small areas of the country at any one time. During June and July, signals propagated by means of sporadic-E ionization may be heard on 50MHz for several hours a day on more than half the days. Sporadic-E is observed on 144 MHz less than a tenth as often as on 50MHz. Signals are often remarkably strong, allowing 50 and 144MHz stations running 10 watts, and often much less than that, to make contacts 1500 km and longer with relative ease.

**Phenomena related to Sporadic E**

![Fig 1: Classification of sporadic-E propagation phenomena by geographic region.](image)

Other closely related propagation modes are sometimes confused with temperate-zone sporadic-E. Long duration meteor scatter is often difficult to distinguish from true sporadic-E. When the MUF is just below 50MHz, for example, random meteors may elevate the MUF to a useful level for a few tens of seconds at a time. At times, such scatter simply evolves into solid sporadic-E propagation and may serve as an early warning of E-skip conditions. During especially intense sporadic-E sessions, back-scatter may be evident. Back-scatter signals are much weaker than normal E-skip signals; they may exhibit multipath flutter (a hollow, from-the-bottom-of-a-barrel sound) or have a slight echo. Back-scatter signal paths are usually well off expected great-circle bearings, but focus on known sporadic-E reflection centers. The expected communication range via back-scatter is short (in the 300 to 1100km range); thus, back-scatter may be useful for making contacts between the normal tropo distance and the shortest E-skip distances. Back-scatter contacts maybe especially useful in "filling n" grid-square multipliers on 50MHz during contests, for example. Back-scatter has been observed on 144 MHz when the MUF was in that range.

Field-aligned irregularities (FAI) is a newly discovered propagation mode that may exist simultaneously with sporadic-E and persists for an hour or more after all evidence of normal sporadic-E has disappeared. FAI signals are generally very weak and may easily be confused with back-scatter signals. Signals propagated by means of FAI have a rough, auroral quality; because of this SSB communication via FAI may be marginal at best. To make use of FAI, operators generally must point their antennas northward. More on 50MHz F2 prop. observations on Skew-path DX from FM18.
necessary with auroral propagation - toward an existing or former sporadic-E center. Distances up to 2000km have been reported for FAI work at 144 MHz. Intense auroral propagation that spontaneously evolves into sporadic-E in the northern latitudes of the US and Canada is known as auroral-E propagation. Sometimes this shift takes place over the course of a minute and may be evident during a single contact. A rough, raspy, auroral signal may be quickly transformed into a strong, crystal clear signal. When this happens, auroral-E has taken over. Another characteristic of auroral-E is that it sometimes supports communication over distances much greater than would be expected for other types of sporadic E (up to 3200km), because auroral-Es clouds are typically higher than temperate-zone clouds. Commonly observed auroral-E paths include Alaska, the Yukon and the Northwest Territories to the upper US Midwest and New England. Auroral-E is observed far less often than temperate-latitude sporadic E and primarily on the 50MHz band.

**Geographical, Seasonal and Daily Variations**

The appearance of sporadic-E is related not only to time of day and to season, but to geographical location. Researchers have identified five distinct geographic zones of sporadic-E occurrence based primarily on seasonal and hourly characteristics. These zones are shown in Fig 1. Within the northern temperate zone, sporadic-E may appear at any time, but long-term observations have shown that it occurs more often from mid-May to mid-August than any other months, followed by a less productive period from mid-December to mid-January. Mid-latitude sporadic-E also occurs most often from 0800 to 1200 and 1900 to 2300 local time, regardless of season, with a statistical peak at about the midpoint of each time period. The daily and seasonal probabilities of sporadic E over the US from May through August are shown graphically in Fig 2. There are also significant variations within the northern temperate zone. Sporadic-E ionization occurs most often in the western Pacific, China and South-east Asia, and least often over the north Atlantic and adjacent portions of the north-eastern North America! In the US, E-skip is nearly twice as common over the South-west as over the North-east. Peak times for sporadic-E in the rest of the world vary considerably. Like that of the northern temperate zone, the major sporadic-E season in the southern temperate zone occurs from late spring to early summer (mid-November to mid-February in the southern hemisphere). In the equatorial zone sporadic-E is nearly a constant phenomenon of the 8-hour period centred at noon regardless of season, but it is rare any other times. In the equatorial zones, sporadic-E is least likely to appear at noon, but it appears more than half the time in the 1800 to 2400 period with little variation throughout the year.

**E-Skip and Solar Activity**
The relationship between the formation of temperate-zone sporadic-E and solar geophysical conditions are still debated. Most researchers have held that there is no clear correlation between the sunspot cycle and sporadic-E formation that compares with close association between F-layer and solar conditions. Some recent work has suggested that this may not be the case, and that low solar activity, whether measured as solar flux (sunspot number) or short term geomagnetic conditions (planetary A and K indexes), are most favourable for temperate-zone sporadic-E formation.

One analysis of the relationship between the planetary K-index and sporadic-E, summarized in Fig 3, demonstrates that observed 50MHz E-skip conditions have occurred more often when the K index was low. When the index was high, as during the geomagnetic storm of June 15 to 22, 1965, observed minutes of sporadic-E activity fell off precipitously. The relationship between sporadic-E ionization and the 11 year solar cycle is less clear, but data from three long-term studies, presented in Fig 4, suggests that sporadic E may peak during solar minima.

**Causes of Sporadic E**
The cause or more likely the multiple causes of sporadic-E are still being pursued by researchers. Ten distinct types of sporadic-E, and at least nice different theories of causation, were listed in the review of what was known about sporadic-E in 1959. The classification of distinct types has been retained, but since the 1960s, the wind shear theory has gained more acceptance than any other in explaining temperate-zone sporadic-E formation. In its simplest form, the windshear theory holds that gaseous ions are accumulated and concentrated into small, thin, patchy sheets by the combined actions of high-altitude winds and the earth's magnetic field in the E region of the ionosphere. The resulting sheets, or sporadic E clouds, may attain the required ion density to serve as a reflecting medium for VHF radio waves. Recent work has emphasized the role of long lived ion and magnesium ions (thought to be the result of meteor evaporation) in the formation of sporadic E clouds. Sporadic E clouds observed by rocket-borne instruments and back-scatter experiments have been found to be 50 to 100km in diameter, 2 to 4 km thick and 95 to 115km in altitude. The results of one such rocket experiment are shown in Fig 5. Although most research has confirmed a close association between wind-shear and sporadic E, not all aspects of the sporadic-E phenomenon can be explained, including its diurnal and seasonal variations.

The Classical 'E' Skip Model

Fig 5: Electron density as a function of altitude across a sporadic-E cloud. Based on the results of an Aerobee rocket flight in May 1962.

The wind-shear theory is consistent with classical description of temperate-zone E skip derived from observations of amateur VHF communications and specially designed experiments. In the classical model, sporadic-E reflections are assumed to be specular (mirror-like) and associated with a single E cloud that lies midway along a given radio path at an altitude of about 105km. See Fig 6. At this altitude the maximum possible single-reflection (single hop) distance computes to about 2200 km. The highest frequency reflected back to the surface of the earth, the MUF, varies from 20 MHz to at least 220 MHz. At the MUF, the angle of reflection is greatest, the single-hop distance is longest and signal strengths are greatest. As the signal frequency decreases from the MUF, the angle of reflection decreases, the resulting signal path is shorter and signal strength is relatively less. At some critical frequency signals transmitted straight up will be reflected straight down (zero angle of reflection). The classical model also describes a relationship among MUF, signal frequency, angle of radiation and resulting path distance that can serve as a very useful tool for quick evaluation of sporadic-E conditions. These relationships are presented in Fig 7 and can be calculated more precisely if desired. The minimum MUF of a single sporadic-E reflector can be determined when the frequency and path distance of any observed contact are known.
Fig 6: Relationship between path distance and sporadic-E MUF. For a
E-cloud with a 144MHz MUF, the path distance at 144MHz will be a
maximum single hop distance of about 2200 km. As the frequency
is decreased from the MUF, the path shortens. At 50MHz, the
expected path length will be about 650 km. At the critical
frequency (0.188 x MUF) - 27MHz in this case, the path distance
decreases to zero (that is, a signal transmitted straight up will be
reflected straight down).

Consider a 50MHz contact between stations in Memphis and Indianapolis,
600 km apart, shown in Fig 8. What is the minimum possible MUF of the
cloud that is supporting that path? Refer to Fig 7 and read up from 600km
until you reach the dashed line corresponding to 50MHz. Then find the MUF
by interpolating between the solid curves for 144 and 200MHz. In this case,
the MUF is something over 144MHz - say, 160MHz. The process can be taken
one step further to estimate the likely distance that could be spanned on
144MHz using the same E cloud as a reflecting point. Follow the imaginary
160MHz MUF line up and to the right until it intersects the dashed line that
corresponds to a signal frequency of 144 MHz. This intersection corresponds
to 1800 km on the horizontal scale. Such an analysis strongly suggests that
a 144MHz path from Minneapolis to Tallahassee or any other 1800km path
with the same center point - should be possible. Fig 7 also reveals another
curious relationship: the MUF is about 5.3 times the critical frequency (zero
on the horizontal distance scale).

This classical analysis works well in many practical applications, and it has
enabled many alert operators to anticipate 144 and 220MHz sporadic-E. It
may also be helpful to keep in mind that the sporadic-E MUF often climbs
very rapidly, but reaches 144MHz only one-tenth as often as 50 MHz. The
sporadic-E MUF exceeds 200MHz on rare occasions. Because the VHF
amateur radio bands are widely spaced in the radio spectrum, monitoring
between the amateur bands such as TV Channels 2 to 13, FM broadcast or
aircraft navigation aids, may provide more precise indications of actual
conditions.

Multiple-Hop Paths and Other Complications

The classical model may help to explain single-hop paths, but what about sporadic-E contacts longer than
2200 km - the maximum single-hop distance (assuming an Es-layer altitude of 105km)? The classical
model requires that such paths be
completed by hops via at least two E clouds spaced at just the right distance to complete the path. Further, each cloud must exhibit the necessary MUF. Longer paths, such as those from the East Coast to Europe or even from the Midwest to Hawaii, require an even trickier cloud arrangement because at least three hops are necessary to complete them.

Numerous reports of 144MHz contacts in the 2200 to 3200 km range appear to challenge the classical explanation of long-path E-skip propagation. The primary difficulty lies with the distance between hops. Although such contacts exceed the normal 2200 km maximum for normal single-hop propagation, they are significantly shorter than 4000 km, the expected double-hop path supported by E clouds with MUFs just under 144 MHz.

A classical two-hop, 2500 km contact at 144 MHz would require that two Sporadic-E clouds with MUFs in the 200 MHz range exist simultaneously about 1250 km apart! This coincidence seems quite unlikely, as even one cloud exhibiting an MUF of 200 MHz is exceedingly rare.

**Fig 8: A 50MHz E-skip contact between Indianapolis and Memphis (600 km) suggests the existence of a sporadic-E reflection point over western Kentucky (at mid path).**

Some participants in 144 MHz contacts in the 2800 to 3200 km range have heard or worked stations at intermediate distances. This is evidence that multiple hops may be responsible in such situations. In other cases, there has been no evidence of intermediate hops. Lack of such evidence does not preclude the existence of intermediate hops, of course. In some cases, it has been argued that there were simply no stations active at intermediate distances.

There are other possible explanations for sporadic-E propagation beyond the one hop range. Sporadic-E clouds higher than 110 km could support contacts over longer distances (a cloud at an altitude of 150km would lengthen the single-hop range to 2500 km), but there is little evidence that sporadic-E clouds form at altitudes higher than 120km. E-skip paths may be lengthened by extended tropospheric enhancement or unusually high station elevation at one or both ends of the path, but it is unlikely that these factors explain
more than a few particular cases.

Tilted E clouds may provide a more promising solution. Rocket soundings of the E-layer have revealed that some clouds do not lie in parallel to the earth's surface, but are tilted a few degrees, and sometimes as much as 30 degrees, from the horizon. Such tilting could allow cloud-to-cloud reflections at frequencies greater than the normal MUF, creating paths in the 2200 to 3200 km range. Fig 9 shows this possibility for two clouds that exhibit the necessary orientation.

Prospects

Fig 9: Proposed explanation for observed 2200- to 3200 km sporadic-E contacts that behave as if propagate via a single reflection paths. Distances longer than normal single reflection paths might be possible by means of reflections between tilted E clouds. The MUF of the sporadic-E clouds along an earth-cloud-cloud-earth path need not be as great as that for the cloud in a single reflection, earth-cloud-earth path because the reflection angles required to bring signals back to the earth are less than for earth-cloud-cloud-earth model.

A 220MHz E-skip contact has been completed, and three and four hop 50MHz contacts are common enough to no longer be surprising. What is left to achieve? It is apparent that a transcontinental 144MHz contact is possible. The claimed 144MHz distance record of 3865km is greater than the distance from Los Angeles to Charleston, for example. On June 14, 1987, the North American continent was nearly spanned on 144 MHz when James Fry, NW7O/7, in Southern Nevada, hooked up with James Poore, KD4WF, Savannah, Georgia - a distance of 3165km. Undoubtedly, an actual trans-North American 144 MHz contact will be completed in the near future.

Transatlantic 144 MHz contacts are likely as well. Most of the 50MHz US-Europe contacts have been in the 5000km range, suggesting at least three hops, but a careful choice of location in North America can easily reduce the distance to the two-hop range. Newfoundland and Ireland are separated by little more than 3000km, and the distance even from Dublin to Prince Edward Island is less than 4200km - just within the 4400km limit of ordinary two-hop E-skip contacts.

After 50 years of experience with sporadic E, it seems reasonable to conclude that radio amateurs have experienced nearly everything possible for this propagation mode. Recent accomplishments prove that a great deal remains to be discovered about the unpredictable world of Sporadic-E.