Mid-Latitude Sporadic-E – A Review

Michael Hawk - Novemeber 12, 2001

INTRODUCTION

Purpose
Over the years, many observations, theories, and discussions have taken place surrounding the sporadic-E (E-skip) phenomenon. This article was originally written in response to a brief review of the basics of sporadic-E that I wrote for the April 1993 VUD. Unfortunately, other obligations prevented this article from being completed to my satisfaction until now. Although a large amount of material exists on the subject, I have not found one concise source of theories, correlations, and facts. And many of the subjects overview papers oversimplify or misrepresent some of these theories.

It is the purpose of this paper to provide a review of sporadic-E knowledge from a DX'ers perspective, while simultaneously bridging in observations from academia.

It is important to keep in mind that the ideas conveyed herein are theories, hypotheses, and observations. The fact remains that the catalyst for sporadic E is unknown and the behavior of mid-latitude sporadic E is unpredictable. When you start to believe that correlations and observations are fact, sporadic E will surprise you with an inexplicable result.

CONTENTS

1.0 BACKGROUND

1.1 Ionosphere Overview

The ionosphere is the region of the Earth's atmosphere containing free electrons and atoms, and associated ions produced by the sun's ultraviolet radiation (<100 nm wavelength).[1] The ionosphere is known to influence radio wave propagation of frequencies up to around 300 MHz, and is located in the lower portion of the thermosphere, beginning at about 80 km altitude.[2]

The ionosphere is known to consist of several distinct regions of ionization. Altitude, consistency, and ion type differentiate these regions. The first discovered subregion was named the E layer (E for Electric Layer). At later dates, additional layers were discovered at lower (D region) and higher (F region) altitudes.[3]

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[1] One nm = 10^{-9} meters
[2] One mile = one kilometer X .62
[3] The term layer is rarely used when describing the various parts of the ionosphere. "Region" is more commonly used, since the "regions" don't have a sudden terminating point that the word "layer" would imply. Instead, the various regions gradually merge together.

The D region is primarily known for its absorption of radiowaves at low frequencies. It quickly dissipates at night, allowing distant AM radio reception to occur.

The F region is the primary refractor/reflector of HF (shortwave) frequencies. Its “reflectivity” displays a direct relation to solar activity. During years of peak solar activity, the F region will have a much higher ionization density, allowing for higher frequencies and sharper angles of waves to be reflected. TV DX’ers and 6 Meter ham operators look forward to solar cycle peaks, as those years are when the F region can bring distant DX up to 50 or 60 MHz.

The E region of the ionosphere is located about 90 to 160 km in altitude. The height can vary a little, and, along with electron [ionization] density, depends on solar zenith angle and solar activity. During daylight hours, electron density (a measure of the ionization level) can reach 10^5 electrons/cm^3. At night, when the supply of x-rays from the sun is cut off, ionization levels drop to 10^3 e/cm^3. These ionization densities are expected under normal conditions, absent of sporadic-E.

1.2 Sporadic-E Definition

Within the E region, very thin regions of extremely dense ionization can form. These regions can apparently be caused by several mechanisms, and have a wide variety of characteristics. Because of this, one single definition cannot be completely accurate. According to the Space Environmental Services Center, “sporadic E (Es) is transient, localized patches of relatively high electron density in the E region of the ionosphere which significantly affect radio wave propagation. Sporadic E can occur during daytime or nighttime, and it varies markedly with latitude. Es can be associated with thunderstorms, meteor showers, solar activity, and geomagnetic activity.”

There are several problems with this definition, but it seems to be the best “official” definition available. This definition provides no insight into the diurnal characteristics of Es. The definition lends too much credence towards the thunderstorm and meteor shower correlations. The relationship with thunderstorms has been highly controversial in amateur circles, but most academia studies have ruled out such possibilities. The relation to meteor showers is still highly studies, as some indirect correlations have been observed. Both of these possible Es mechanisms are discussed in more depth later in this paper.

A much more precise definition of Es was found in a book titled “Worldwide Occurrence of Sporadic E”, written by Ernest K. Smith, PhD, 1957.[4] Sporadic E was defined as “a comparatively strong and protracted transmission (several minutes to several hours) “returned” from the E region of the ionosphere by some mechanism other than the normal reflection process from the daytime E layer.”

Through the use of careful and generic wording, this definition fits almost any type of Es currently known.

The careful wording of Dr. Smith’s definition is important, because there are a wide variety of sporadic-E types. In the temperate latitudes alone, through the use of ionosondes (data displayed in ionogram format), four have been identified.[5] See figure 1. An ionogram shows the altitude at which different frequency waves are reflected back to the originating point.

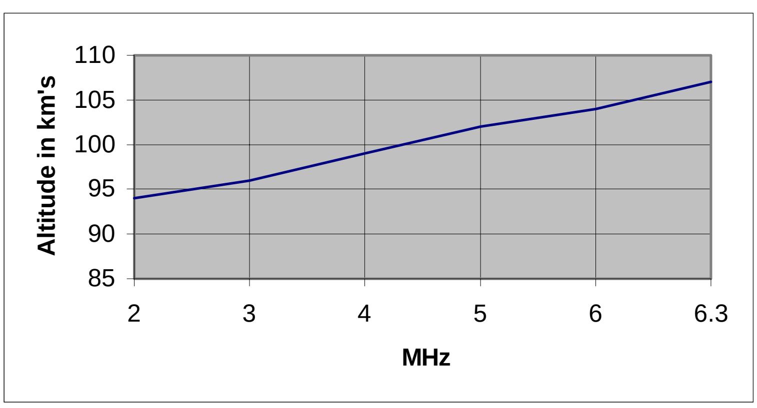

Figure 1 Sample Ionogram

2.0 Es CHARACTERISTICS

2.1 Ionization

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[4] National Bureau of Standards Publication. A few copies are available through rare bookstores for $20-$80. May 2001 check of Amazon.com revealed 2 copies available through independent dealers.

[5] An ionogram is a plot of the group path height of reflection of ionospherically returned (echoed) radio waves as a function of frequency. Figure 1 is an example. Vertically incident measure the date for this graph.

An ion is an atom or group of atoms having an electric charge. This results when a neutral atom of group of atoms loses or gains one or more electrons. For this reason, either ion density, or more commonly electron density, can be used for ionospheric "strength" calculations. The most common E region ions are O^{2+}, O^{+}, and NO^{+}, as well as some metallic ions.

The reason an atom or group of atoms may lose an electron is primarily through the well-documented impact of solar radiation. Throughout the day, the level of production of ions exceeds the level at which the ions recombine with electrons. At night, the production of ions ceases with the setting of the sun, and the slow process of recombination gradually lowers the electron density. Additionally, recombination rates are inverse to altitude. This can be demonstrated by the fact that the D region diminishes quickly at sunset, minimizing absorption of low frequencies (< 8 MHz). If it weren't for this fact, long range propagation on the AM broadcast band wouldn't occur until well after sunset. At the "higher" regions, enough electrons continue to persist throughout the night, allowing refraction in the E and F regions to continue all night.

As previously mentioned, normal ionization levels in the E region during the day are around 10^5 e/cm^3. Note that Es can have ionization levels twice the normal amount. This high density accounts for the high maximum useable (refractable) frequencies (MUF) that occur with Es. There are several formulas which, through the use of electron density, approximate the critical frequencies[6] (f_oEs), MUF's, and other parameters. Many are highly inaccurate extrapolations from other propagation types.

Although ionization levels are quite high when Es occurs, the highest levels are generally confined to very small patches, commonly referred to as clouds. The shape of the clouds is likely ragged, and not true circles or ellipses. Additionally, clouds have been shown to have concave undersides in many instances, with tilts up to 10°. For simplified calculations, however, they are often thought of as pure circles or ellipses, with axis parallel to the horizontal plane. In cases such as these, the diameter of the cloud could be to several hundred km. The vertical thickness of these clouds is usually quite small – no more than a few km thick. The thickness of clouds has been measured by rocket flights through ionized areas.

During large/intense Es outbreaks, elevated ionization can be very widespread. In these conditions, the concepts of Es "clouds" is tough to identify at lower frequencies. Embedded in this "sheet" of elevated ionization density are small patches of very high ionization. At higher frequencies, these very dense areas can be identified, and the "cloud" concept holds.

2.2 Distances Propagated and MUF

Through the use of simple geometry, it can be figured that the theoretical maximum distance for a transmitted signal to be propagated after only one encounter with the Es region ("single hop" propagation) is 2100 km. This appears to be very accurate for the HF bands (< 30 MHz), but many transmissions exceeding 2350 km have been observed in the VHF bands. This is likely due to much improved "groundwave" and tropospheric characteristics, which add distance to the theoretical maximum on both sides of the typical model.[7] Figure 2 shows average distances received on FM broadcast and TV broadcast frequencies. The average FM distance is likely longer because of the simple relationship between electron density and critical angle of propagation. In other words, it is "easier" for the atmosphere to produce shorter distance propagation in the lower frequency low-band VHF range.

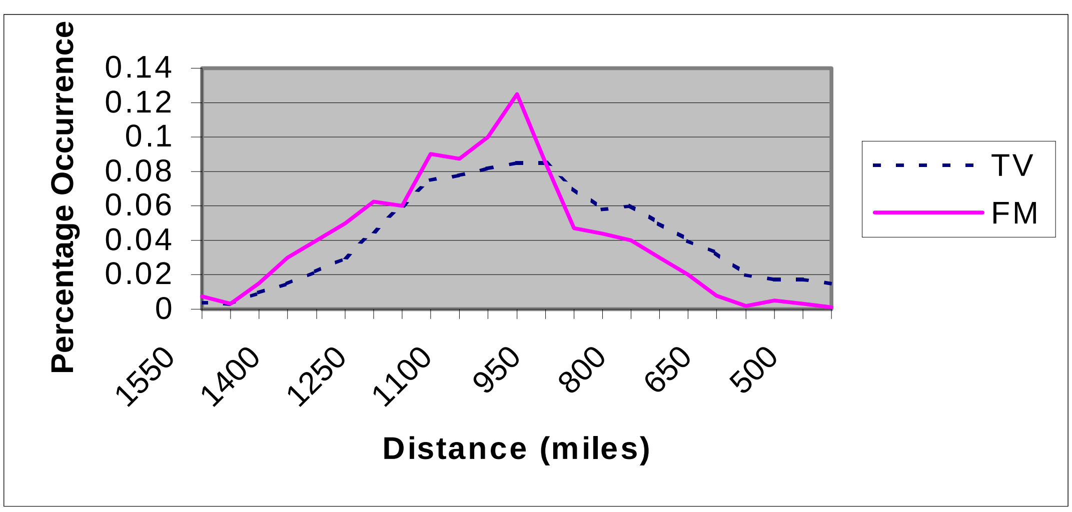

Figure 2 Distance propagated at FM and low band VHF TV frequencies, collected from VUD reports

[6] Critical Frequency (f_o) is the highest frequency that reflects/echoes a vertically transmitted radio wave back to the transmission point. A relatively low critical frequency can result in a "high" MUF, given that the waves related to the MUF are encountering the ionization at a high angle (no perpendicular as is required for critical frequency measurements).

[7] Many believe a gradual bending of the wave occurs, as the density of the media changes, rather than mirror-like reflection. Although this is not pure refraction either, refraction is the generally accepted term.

Remember that simple geometry will not take into account the gradual “bending” of a wave (the property similar to refraction discussed previously). For the ease of calculations, you can assume “reflection” occurs instead by taking into account the “virtual height” of the refraction. Many formulas revolve around the virtual height, which is an altitude higher than where the actual refraction is taking place. See figure 3.

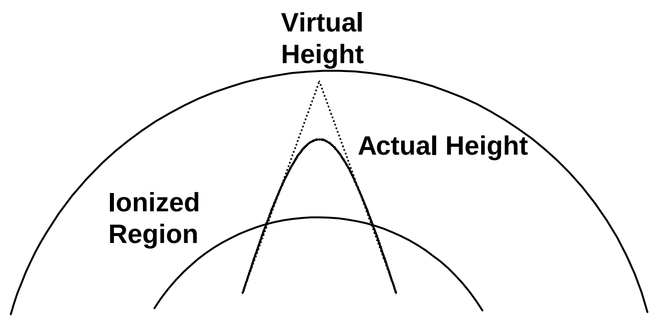

Figure 3 Refraction of a radio wave with Virtual Height

It has been observed frequently that if one patch of ionization forms, others of varying strength likely exist or will form shortly. If this is the case, and two patches exist within the horizon of a midpoint, the theoretical distance propagated by Es can nearly be doubled, so long as the clouds are in line with both the transmitter and receiver. This “double hop” propagation is fairly common during widespread occurrences of Es, especially below 70 MHz. Similarly, three or more clouds could potentially line up, providing even further distances propagated. Of course, the likelihood that each of the cloud are adequate strength and geometrically lined up is pretty slim, especially if you’re interest is in higher frequencies.

One other factor as to the maximum distance propagated by Es is the height of the Es cloud. According to ionosonde (devices used to measure reflectivity of the ionosphere) data, Es usually occurs around 90-100 km altitude. This data also reveals that multiple layers of “clouds” have formed on occasion, usually spaced by about 6 km. Varying heights might allow for longer or shorter distances propagated, but remember that we are constrained to an altitude close to 100 km, so the variances will be small. On a side note, as mentioned earlier, the E region exists between 90 and 160 km. Since Es consistently occurs around 100 km, many scientists refer to a distinct “Es Layer”.

As electron density of the cloud increases, its critical angle also increases. In other words, at a given frequency, a cloud may have a critical angle of 40°. In an hour, the electron density may have increased enough to raise the critical angle to 45°. This would result in a shorter minimum path length. Refer to figure 4.

Figure 4 critcal angle (ϕ) and frequency relation

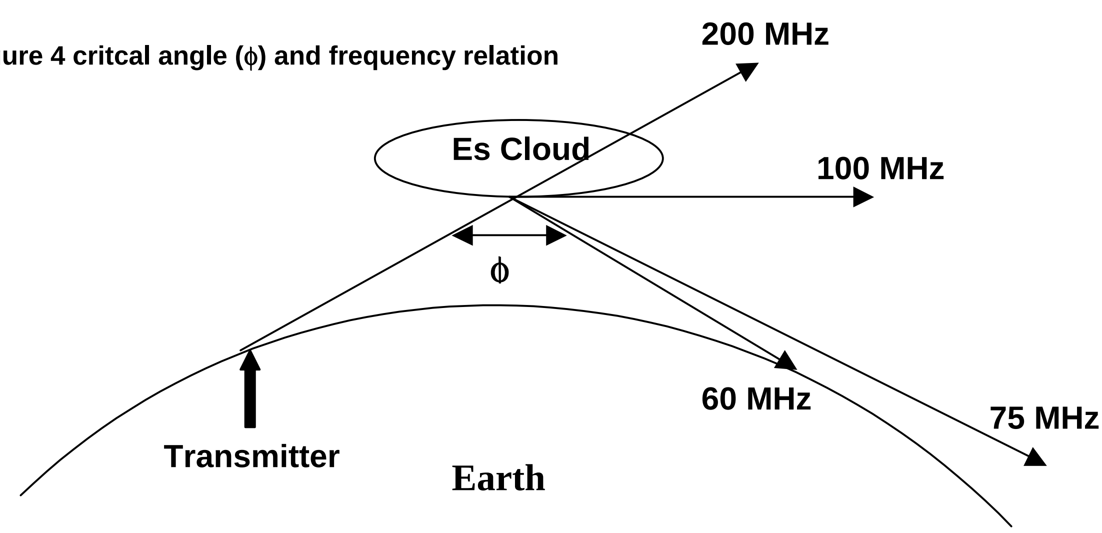

Figure 4 is meant to demonstrate that a region of ionization will “refract” signals of varying frequencies differently. A higher frequency may be unaffected, while lower frequencies are more and more impacted. In the example, the 60 MHz frequency is the highest frequency (MUF) that is getting refracted back to the Earth. The critical angle for a 60 MHz signal is represented by ϕ. A lower frequency, say, 30 MHz, would be refracted at an even smaller angle, resulting in a smaller critical angle than the 60 MHz signal.

At even lower frequencies, the critical angle might be 90°, meaning a signal sent straight up is reflected back down. The highest frequency at which a vertically incident wave is reflected back to the transmission point is known as the critical frequency (f_o). Formally defined, critical frequency is the frequency capable of penetration just to the layer of maximum ionization with a vertically incident wave. Radio waves of lower frequencies are refracted back to the ground, and those at higher frequencies pass through.

Since both critical frequency and critical angle are functions of ionization density, relations can be modeled mathematically. If you know what the MUF is, you can calculate what the critical angle or critical frequency is. Similarly, if you know either the critical angle or critical frequency, you can calculate the MUF.

It is important to note that the models for calculating MUF and critical frequency are more reliable for other types of propagation than Es. Generally, the "secant law" is used to make these calculations, but under some conditions can underestimate or overestimate MUF for Es.

For a moment, if we assume that the model holds true, we can plot the relation between critical frequency and MUF. This is demonstrated in Figure 5.

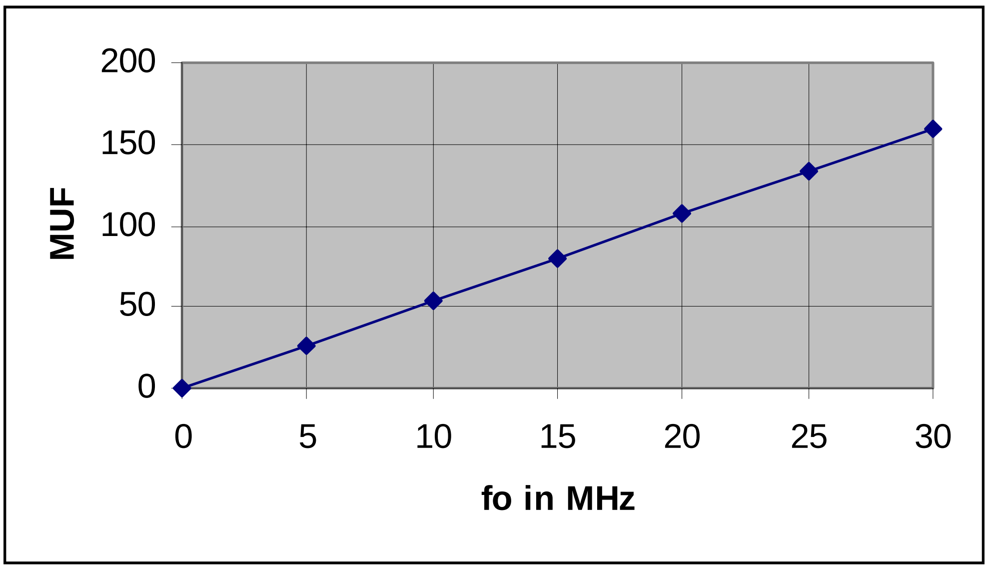

Figure 5 Critical Frequency and MUF

Figure 5 shows a linear relation between MUF and f_o. This is derived from two common formulas:

$$MUF = 48\sqrt{N}$$

$$f_o = 9\sqrt{N}$$

N represents the electron density in e/m^3. Observations have shown that Es does NOT have a totally linear relation as the above formulas would indicate. Despite this, this discussion is important to understand the principles involved.

Why is any of this useful, anyway? Critical frequency measurements are recorded by ionosondes – devices that transmit a spectrum of waves straight up, and determine the height and strength of the reflection, and determine the critical frequency. Many observatories and research centers continuously monitor the ionosphere, and some even post the results near real-time on the internet.

2.3 Cloud Movement

Within the ionosphere at the E region and below, strong currents exist. After the formation of an ionized cloud, these currents move the cloud, usually to the west or northwest. Just as weather patterns generally move in one direction (west to east) localized events can and do cause weather to occasionally stagnate or even move in the opposite direction. Similarly, sporadic-E clouds can move in any direction on occasion – especially north and south (and less likely to the east).

The velocity of these clouds has been measured in a variety of ways. These include the use of Doppler shifts and VHF oblique propagation. The result varies between 20-130 m/s (110+ mph). Higher velocities are also thought to exist.

Calculation of the velocity of clouds through the use of VHF oblique propagation is slightly less scientific, but a process that anyone observing an Es opening can use. The process revolves around plotting the location of the cloud by identifying the transmitting and receiving locations. A line is drawn between the two points, and the midpoint identified. The midpoint is the approximate location of the ionized area. Several data points are necessary, and a long period of time required to make this approximation. Possible caveats to this method include irregular shaped clouds and the existence of multiple clouds of ionization confusing the location.

Measuring Doppler shifts requires the use of highly technical (and expensive) equipment. In spite of this, errors in this method exist as well. The part of the cloud reflecting the wave may have a different velocity than the cloud as a whole. A strong analogy is that of a balloon. A balloon may be moving in one direction, but the molecules inside are moving in random directions.

2.4 Daily Variation
It has long been known that Es doesn't simply occur "during the day". It is known that ionization levels throughout the ionosphere tend to have two peaks, centered on either side of noon. Es occurrence seems to follow a similar trend.

Figure 6 is a graph of the occurrence of Es during summer months. As can be seen, the summer peak is in the morning (0700-1200) and a secondary peak occurs 2000-2200. This graph comes from White Sands, NM over a 7 year period.   It is important to note that the White Sands data seemed more "skewed" towards the morning peak than similar measurements taken in other mid-latitude locations. However, *all* indicated a slightly stronger likelihood of Es in the morning than in the afternoon/evening.

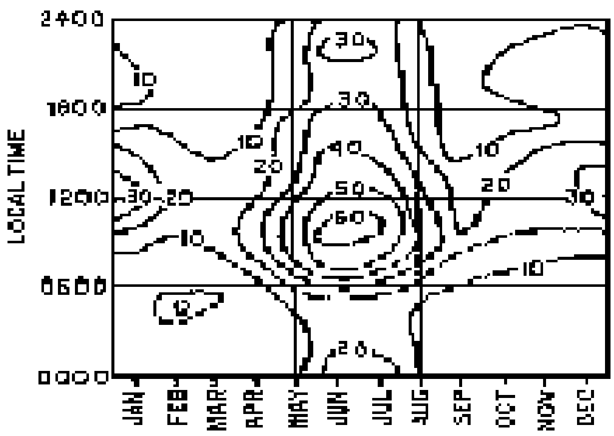

Figure 6 Percentage of time Es exceeds FoEs of 5 MHz, from White Sands, NM 1948-1954

Figure 6 was obtained from *A survey of the present knowledge of sporadic-E ionization*, JA Thomas and EK Smith, Journal of Atmospheric and Terrestrial Physics Vol 13.

Remember that despite the apparent greater likelihood of Es in the morning hours, this data was collected over a period of years. This diurnal characteristic is much less noticeable in the day to day casual observation of DX'ers. And don't turn the radio off after dark! Many still remember an opening that occurred after midnight on June 19, 1992, resulting in MUF's of 144 MHz+.

Additionally, during the winter peak (discussed in the next section), Es is most common *just after sunset.*

2.5 Monthly Variation
In observing Es on a larger time scale, it is well documented that Es occurs most often in the summer, with a secondary peak in the winter. These peaks are centered very close to the solstices. The summer peak can be characterized by probability of occurrence being 5 to 8 times that of winter. The use of the descriptors "summer" and "winter" is intentional, as the peak in the Southern Hemisphere is in it's summer months, which is the Northern Hemisphere's winter.

Similar to the diurnal characteristics discussed in the previous sections, year to year observations will not always demonstrate the "normal" behavior. Some years have occurrences common in "off peak" months, such as October and February. Other years peak early or late.

2.6 Annual Comparison
Patrick Dyer, WA5IYX and Emil Pocock, W3EP, have shown that there seems to be a pattern to the quantity of Es observed each year.[8] These observations come from use of his records over the 11 year period in which Dyer consistently monitored the FM band. He noted a potential 4 to 6 years cycle.

Ken Neubeck, WB2AMU, proposed that this potential sub-cycle of Es is related to the latitudinal location of sunspots on the sun.[9] During the approximately 11 year solar cycle, not only do the quantity of sunspots change, but the location of sunspot groupings also changes. Beginning at the solar minimum, sunspots are primarily located at about 30° latitude on both sides of the solar equator. As the cycle progresses, the locations of the spots slowly converge to the solar equator. At the end of the cycle, a transitional period occurs where spot groupings may exist at both 5° and 30°.

[8] See P.J. Dyer and E. Pocock, "Eleven Years of Sporadic E", QST, March 1992, pp 23-28
[9] See K. Neubeck, "Sporadic-E and Auroral Propagation", World Radio, March 1993 pp 19-28

Neubeck believes that during these transition periods, Es peaks will be diminished, and there will be more occurrences of Es during abnormal months. The end result being less Es than normal for the year.

I would hesitate to start to draw conclusions based on an 11 year study – which would only constitute 2 Es cycles, if in fact they exist. Neubeck's theory has been largely discarded as a "casual observation" rather than something to pursue in the scientific community, due to lack of long-term data, a concrete scientific explanation of how sunspot location would impact Es, and lack of scientific data or loose correlation of sunspot latitude to any cycles of ionization on Earth.

2.7 Sunspot Cycle

By overlaying a graph of the 2800 MHz solar flux (a measure of solar radiation intensity), Dyer's graph showed no correlation to the solar flux. This is opposite of normal F region propagation, where the quantity and intensity of propagation at higher frequencies is directly related to the amount of sunspots.

Sunspots appear as dark spots on the sun's surface, and are relatively cool in temperature. They can range from 750 km in diameter to tens of thousands. The important aspect of a sunspot with regards to propagation is the area that surrounds the spot. These areas have much increased radiation. If many spots exist on the sun, the total radiation emitted increases substantially, leading to higher ionization levels on earth, which improves F region and normal E region propagation. However, it does not appear that this impacts Es directly.

2.8 Worldwide Occurrence

As already mentioned, the Es season is reversed in the southern hemisphere. Also, the amount of time Es occurs is not constant through common latitudes. Generally, Es is more common in the temperate latitudes closer to the tropics. Many amateurs in the USA have made the common observation that Florida and Mexico seem to be the most common "pests" in Es DX'ing. However, even "southern latitude" generalization is not 100% accurate. Long-term studies have indicated a large increase in occurrence near Japan.[10]

3.0 POSSIBLE Es MECHANISMS

3.1 Introduction

For decades, professionals and amateurs alike have been baffled by the cause of Es. Even the intense study during the IGY[11], the advent of rocket exploration of the ionosphere, ionosonde deployment, and other technological advances have only brought up more questions than they have answered. Because of the extreme difficulty encountered by scientists in isolating the mechanism which causes Es, it is fairly apparent that it must be a complicated series of events, requiring the right "ingredients" for the final product of Es to result.

Some of the following possible mechanisms have been touched on already. Of course, ionization by the sun's ionization is likely a base "ingredient" as well.

3.2 Ionospheric Wind Shear

The wind shear theory of sporadic-E formation is generally credited to J.D. Whitehead of the University of Queensland, Australia. The basic theory is based on the east-west winds in the E region. These winds are caused by gravity waves, and can result in vertical movement. Vertical shears can compress ions into a thin layer, resulting in high density ionization. This effect seems to particularly apply to the metallic ions of Fe^+ (Iron) and Mg^+ (Magnesium). This is because the recombination rate of these ions is greater than other molecular ions, allowing them to remain charged (ionized) long enough to be pooled together into highly dense thin sheets.

The theory identifies a relation between the horizontal component of the Earth's magnetic field as impacting the probability as to whether Es will form under shearing conditions.

The shearing effects in the E region are well documents. Additionally, many experiments on horizontal winds and electron density have given support to this theory with respect to mid-latitude Es.

The theory does not explain other types of Es as well as it does mid-latitude Es. However, this is not of much concern to DX'ers, as we primarily observe the "true" Es type that occurs in the mid-latitudes.

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[10] EK Smith, "Temperate Zone Sporadic E Maps (foEs > 7 MHz)," Radio Science, Vol 13 (1978), pp 571-575

[11] The IGY was the International Geophysical Year. Solar Cycle 19, peaking in the late 1950's, was the largest cycle on record. Scientists, in anticipation of a high intensity peak, declared the peak year the IGY. This was done to raise awareness within the scientific community, and led to intense study of solar-terrestrial relations. No other time period has brought such significant advances in the study of radio wave propagation.

The windshear theory, when combined with tidal winds, is widely regarded as an accurate and plausible explanation of Es. A 1998 review of the theory by JD Mathews (Journal of Atmospheric and Terrestrial Physics, Vol 60, pp 413-435) has once again reaffirmed the theory.

3.3 Thunderstorms and Associated Phenomena

The possible correlation of Es to thunderstorms is a theory that refuses to die. This theory can be traced as far back as the 1920's. In 1933, Naismith and Appleton had some success in finding a correlation. These scientists are well known for their ground breaking ionospheric study and documentation, so the possible correlation was not taken lightly. However, in 1938 they concluded that the results from 1933 might have been inaccurate. The theory was rejuvenated in the 1950's when a study in India showed a possible correlation to squall-line thunderstorms (but not super-cells).

No studies intending to link thunderstorms to sporadic-E have resulted in conclusive data. For years, the scientific community doubted any possible relation, given the simple fact that thunderstorms occur in the troposphere (0-14 km altitude), and Es occurs at 100 km. In between the troposphere and the ionosphere's E region exist invisible barriers where the medium of the atmosphere radically changes. These transition zones, named the tropopause and stratopause, prevent certain interactions between layers from occurring due to the change atomic content, wind, temperature, and other attributes.

Additionally, thunderstorms are generally localized events. On the other hand, Es "outbreaks" frequently occur, in which Es clouds are reported over large portions of the planet. As much as1/6 of the Earth may be within line of site of an Es cloud capable of f_oEs > 6 MHz during these outbreaks. Similarly, long term observations of data collected from ionosondes also don't indicate a correlation between thunderstorm frequency and Es frequency.

The thunderstorm correlation theory primarily hangs on in amateur circles. Ionospheric researchers quickly point to the fact that the diurnal, monthly, and yearly characteristics of thunderstorms do not match sporadic-E closely at all. Similarly, the worldwide distribution of Es does not match that of thunderstorms.

But, as with most areas of sporadic-E, the analysis is not that simple. In recent years, it has been discovered that a higher level of interaction does occur between lower and upper layers of the earth's atmosphere. In fact, one aspect has been reported and well documented in mainstream media – sprites and blue jets (sometimes referred to as upward lightning).

Red sprites are optical phenomenon that occurs directly above a thunderstorm, associated with it's lightning. They can extend to about 90-95 km altitude – right to the E region, but not into the E region. The duration of a sprite is only 3-10 milliseconds, as measured by high-speed photometers. Sprites are rarely visible to the human eye. It is estimated that sprites occur in conjunction with less than 1% of lightning strokes in a thunderstorm. The true mechanism of a sprite is not known.

Blue Jets are similarly related to thunderstorms, and are only visible with special television systems. Blue Jets only reach altitudes of 45-50 km, and emanate from the tops of "thunderheads" in a cone shape.

The discovery of sprites and blue jets in the early 1990's shows that there may be many more undiscovered interactions between activities in the troposphere and stratosphere (and the ionosphere).

Supporting these possibilities was the discovery of Elves and TIPPs – Trans-Ionospheric Pulse Pairs. Elves (Emission of Light and Very Low Frequency perturbations due to EMP Sources) appear like a halo in the lower ionosphere, and propagate downwards. They seem to precede sprites.

It appears that TIPP's source is a positive bipolar breakdown – an event associated with thunderstorms. The impact of TIPPs on the ionosphere's ionization density and ability to propagate radio waves is not clear.

All of these newly discovered interactions have renewed focus on the effects of weather in the ionosphere. To date, no direct or indirect correlation between these events and Es has been identified.

3.4 Other Weather

J.D. Whitehead's research concluded that according to the wind shear theory, gravity waves associated with tropospheric weather might have some influence on Es. The late Mel Wilson, W2BOC, believed that weather could play an important role in the development of Es.[12] He stated that "birthplaces" of Es clouds were often associated with fronts or low pressure systems, and could produce a series of clouds. His study primarily focuses on the theory that whatever the catalyst at the birthplace is, it creates a series of clouds that generally move to the northwest. Not much evidence of weather being the catalyst is provided in his study.

[12] Midlatitude Intense Sporadic-E Propagation, QST, December 1970

3.5 Meteor and Cometary Origin

Theory suggests that meteors should play some role in the formation of Es, though likely very indirect. Many of the ions found by rocket investigation of the E region, and Es formations, have meteoric origin. As mentioned before, metallic ions appear to be a necessary component, due to their slower recombination rates. Meteors are a major source of these metallic ions.

Studies have investigated the occurrence of random meteors and total meteors for correlations to Es. Random meteors, which occur in great numbers every day of the year, have a marked increase in the June-August period. Investigation of this in closer details reveals the peak is several weeks after the Es peak in the Northern hemisphere. Additionally, there is no secondary peak of meteors in the northern hemisphere winter months, as there is with Es. This simple analysis quickly discounts a meteor-related Es catalyst or mechanism.

In relatively recent studies, a proposal of a cometary origin of Es has come to light.[13] Dr. G. Neil Spokes, amateur radio operator and amateur astronomer, built this theory around data collected in other studies. The 11-year study of Es at 88 MHz by Pat Dyer and Emil Pocock (referenced earlier in this article) showed that some dates seemed more favorable for Es. The logical conclusion that Dr. Spokes suggested for a phenomenon that strictly follows the calendar was an astronomical one.

Dr. Spokes proposes that gases or tiny particles associated with comet paths were the cause. This was not such a large leap in thought, as it is already known that comets leave debris in their paths around the sun. When the earth encounters this debris, meteor showers result.

Unfortunately, the data from the Dyer/Pocock study does not easily identify periods of time when auroral activity[14] may have prevented Es observation, or provide for an offset for our periodic calendar adjustments. This could account for small changes in the data, lessening (or increasing) the appearance of year-to-year daily correlations.

As it stands, mathematical studies using random number generators skewed towards a late June peak provide similar results as the data collected. This isn't to say that there is absolutely no chance that there is an astronomical relation – it just shows that "only" 11 years of data is tough to use as a basis for building an astronomically-based theory.

3.6 Geomagnetic Activity

Correlation between auroral activity and auroral zone Es has been *proven* to exist, but no correlation has been shown for temperate zone (mid-latitude) Es. Many of these studies make use of the planetary A and K indices (24 and 3 hour measures of auroral activity). As previously mentioned, the A index is difficult to accurately use, since it is a measure of activity over the last 24 hours, and thus, significant activity that occurred several hours ago and "inflate" the result of the A index. The A index is often not reflective of current conditions.

And unfortunately, the studies which utilized the K index as comparative data over-simplified the data by either concluding that an index of "2" or greater constituted disturbed conditions (4 would have been more accurate), or by using only 2 or 3 K index data points from a given 24 hour period.[15]

The area of geomagnetic activity and its effect on mid-latitude Es (whether as a catalyst or inhibitor) is an area in need of a long term conclusive study.

Again, a correlation has been shown to exist for high-latitude Es and auroral activity. During very intense geomagnetic storms, not only can auroral propagation/scatter occur, but Es-like propagation can occur within the auroral zone. This type of Es is discussed in more detail in the Section 4.

4.0 SPORADIC-E CLASSIFICATIONS

4.1 Introduction

As was touched on earlier, there have been slight variations in Es characteristics that have lead to multiple classifications of Es. These characteristics primarily include the latitude they occur at, height of ionization, and other observed relations.

During the IGY, a standard was developed to further describe these types of Es. Each type of Es has a lower-case letter designator. These designators are rarely seen in today's studies, as the bulk of them deal with just the mid-latitude/temperate zone Es. For this reason, the primary intent of this section is to demonstrate that not even all Es is the same, further complicating the study of Es.

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[13] Technical Correspondence, QST, April 1993

[14] The Dyer/Pocock study reveals no correlation between Es and the A index, a 24 hour measure of auroral activity. This does not mean that auroral activity does not inhibit mid-latitude Es, as the A index is, by its nature, a lagging indicator and often not reflective of real-time conditions.

[15] See Neubeck, World Radio March 1993

These classifications and their characteristics are described in great detail in E.K. Smith's book, referenced earlier in this text.

4.2 Temperate (Mid-Latitude)
Temperate zone Es is the type that we in the United States, Europe, and other temperate zone latitudes are most familiar with. This is the type of Es that this paper primarily deals with.

Four types of Es exist in the temperate zones. They are Type h (high), c (cusp), l (low) and f (flat). Type h and c are often grouped together into a category called "sequential" Es. It originates at higher E region altitudes (140+km) and as it intensifies, works its way downward to 100 km.

Type f is a classification for nighttime Es, as a requirement is that no "regular" E region can be present. Height of the ionization stay the same with increased ionosonde frequency, producing an ionogram with a flat-line.

Type l is a daytime-only classification.

4.3 Equatorial Es
The equatorial region is defined as the area of the earth within 10 degrees of the *geomagnetic* equator (not the geographic one). Type s (slant) and q (equatorial, or fringe) occur within this region.

Type q is the most common, as has a high correlation with the equatorial electrojet. The correlation is so high that it really isn't even a "sporadic" phenomenon.

Type s can occur at both the auroral and equatorial latitudes.

4.4 Auroral
Type classifications a (auroral), f (flat), r (retardation) and s (slant) occur in this zone.

Type a is commonly called "auroral-E" or "AE" in amateur radio circles. This type of Es has a direct relation with geomagnetic disturbances, and often occurs in conjunction with auroral scatter. The birthplace of type a Es is always within the auroral curtain. Since the auroral curtain can extend well into the mid-latitudes during severe geomagnetic storms, this type of Es can occur within the mid-latitudes. However, MUF's rarely exceed 88 MHz from this Es.

Type f in the auroral latitudes varies very little from type a. Type r's differentiating characteristic is a thicker ionization area.

4.5 Type n Es
For completeness, we must discuss type n Es. Type n was set aside in the IGY system as a catch-all for any Es that didn't fit the above categories.

4.6 Backscatter
Es backscatter is not well understood, and little scientific study of the phenomenon as it applies to us as DX'ers has been done. Backscatter generally propagates signals from 300-1100 km with a characteristic multipath flutter. In some cases, an antenna bearing for reception is offset from the great-circle bearing to the transmitter.

Unfortunately, backscatter sounds similar to tropospheric scatter, and has been reported to last for 30 seconds to a few minutes, just like tropospheric scatter. Amateurs have reported that backscatter generally only impacts a very small range of frequencies, where tropospheric scatter will often affect a larger range, such as the entire FM band (88-108 MHz). I personally have never heard a backscatter signal that I am aware of, so cannot speak from experience on the subject.

5.0 CLOUD FORMATIONS

5.1 Two Cloud Formations
Many times, Es openings provide higher MUF's than what we'd expect through theoretical calculations. Sometimes, actual MUF's are as much as twice the value theory would indicate. This could perhaps be attributed to a two-cloud formation (not to be confused with double hop). Figure 7 demonstrates a possible scenario.

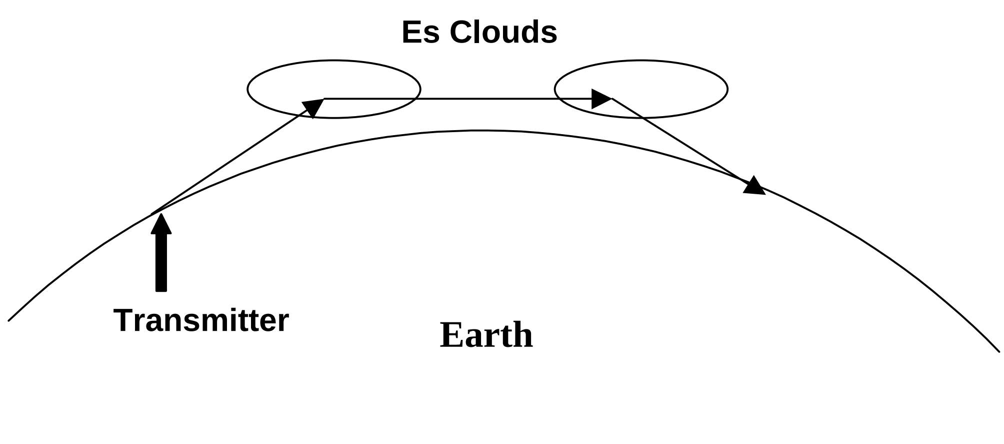

Figure 7 The Proposed Two-Cloud Es Formation

A two-cloud formation for Es would be somewhat analogous to what can happen with trans-equatorial F region propagation. The closer cloud begins the refraction process, and the second cloud finishes the process by refracting the signal back to earth.

It has been proposed that this scenario may exist much more often than thought. As mentioned earlier, it would not take as dense of ionization to propagated higher frequencies. Thus, many receptions in the 1000-1400 mile range could be by the process. Additionally, it could be responsible for those occasional long receptions of 1450 miles or greater.

During intense sporadic-E openings, it is well documented that a widespread elevation of ionization occurs, and a greater number of strong to intense clouds also exist. This leads some credence to the thought.

5.2 Cloud Shapes and Tilts

Es ionization may not necessarily form in a thin sheet parallel to the ground. Some studies have indicated the Es ionization is sometimes tilted, as much as 10°, with respect to the ground. Additionally, J.D. Whitehead’s work of 1978 on the shape of Es ionization indicates that odd shapes even form – frequently concave on the underside.

The implication of this is that again, errors can be injected into some of the theoretical modeling of Es, and identification of midpoints. Additionally, ionosonde data can be misleading. Since ionosondes rely on reflection of vertically incident waves, tilted clouds could result in a signal not being reflected, despite ionization being more than adequate.

6.0 CONCLUSIONS

In some respects, many advances have been made over the last 30 years in the study of sporadic-E. We have a better understanding of the composition of the ionosphere and Es ionization itself. Interactions between the ionosphere and weather are beginning to be discovered and understood. The wind-shear theory has withstood years of validation and tests.

However, in most ways practical to DX'ers, little has been accomplished since the characteristics of Es were first documented in the late 1950's.

And one question still stands: Would DX'ers lose more than they gain by being able to predict Es?

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