New methods for predicting the start and other features of the UK (Northern Hemisphere) Sporadic E (Es) radio propagation season,

by Dr Chris Barnes, GW4BZD, Bangor Scientific and Educational Consultants, Bangor, Gwynedd,LL572TW.

e-mail doctor.barnes@yahoo.co.uk

Abstract

The sporadic E mode of propagation is briefly described and reviewed. The question is posed could we ever predict the start and duration of the main propagation season. A new hypothesis is proposed based on the modulation of planetary weather and wave circulations and their effect on the Es layer dependent on the phase and direction of the equatorial zonal winds, so called QBO (Quasi-biennial Oscillation). Experimental work is presented which leads to a testable model, which strongly supports the hypothesis. We learn here that through a combination of atmospheric science and lateral thinking it has been possible to remove some of the mystery from the enigmatic phenomenon of sporadic E. It has, perhaps become a bit less sporadic and a bit more predictable! Having such a method at our disposal will have time saving implications for ardent radio amateurs who are Es hunters of the future and it may well be useful for climate and space weather researchers to boot. Additionally, the question is posed could a similar or additional methodology be used to predict specific days on which openings will occur once the season is underway and further additionally can the same or an additional theory predict the likelihood or otherwise of the sometimes present but lesser late autumn and mid –winter 'blips' in Es activity.

Keywords: Sporadic E, Radio propagation, Planetary Weather, Planetary Wave, QBO, Quasi-biennial oscillation, Ionosphere, Sunspot cycle, Sunspot maximum, Space weather, Electron density, Meteor debris, Thunderstorm, Gravity Wave, AGW, VHF. Zonal wind, Jet stream, Mesoscale, Auroral-E,

1. Introduction

Sporadic E or Es is as the name suggests a highly variable and sporadic form of radio propagation dependent on lesser known characteristics of the Earth's ionosphere. A good and readable review of Es and related propagation suitable for radio amateurs is to be found at http://www.df5ai.net/Material/articles.html **[1].**

Some of us wait patiently in springtime for the start of this apparently random season, which seems to vary from the last days of April to even as late as early June. ***The question arises then, could we ever predict such a start with any more certainty. This article will attempt to show just that and explain the scientific reasoning behind it.*** We are all familiar with HF sky wave propagation wherein the diurnal and solar cyclic ionization properties of the so called F region in the ionosphere bends or more correctly put scatter refracts radio signals back toward the Earth's surface. The F layer is a continuous region whereas with sporadic E radio signals bounce off much smaller clouds or volume patches of unusually ionized atmospheric gas in the lower E region (altitude range approximately 90 to 160 km). Sporadic

E occasionally allows for long-distance communication at VHF frequencies usually only suited to line of site or tropospheric propagation.

Communication distances of 800–2200 km can occur as a result of a single Es cloud. This variability in distance depends on a number of factors, including cloud height and density. The maximum useable frequency (MUF) also varies widely, but most commonly falls in the 27–110 MHz range, which includes the amateur radio 10- and 6-meter bands. Propagation at 2 metres and even higher frequencies may occur in very strong Es events.

As a random and abnormal event and not the usual condition Es can occur at almost any time; it does, however, display seasonal patterns. Because of this, Sporadic E activity peaks predictably in the summertime in both hemispheres. In Europe and North America, the peak is most noticeable in mid-to-late June, trailing off through July and into August. Sometimes subsequent smaller peaks are seen in late autumn and around the winter solstice.

Until recently many countries in Europe transmitted low band analog TV which with an appropriate 'dual standard' receiver could be used as an ideal indicator of the presence of Es propagation. These days few, if any, such signals remain with the advent of UHF DVB. Still a reasonable indicator of the probability of finding 6m Es propagation is the presence of short of very short skip on 10m. For example, a good start is to search for local 10m beacons such as for example, but not limited to, the German CW beacon on 28.205.

Signals received via Sporadic E can be extremely strong and may range from barely perceptible in strength to overloading over very short periods. Although polarisation shift can occur, single-hop Sporadic E signals tend to remain in the original transmitted polarisation. Long single-hop (900–1,500 miles or 1,400–2,400 kilometres). Shorter-skip (400–800 miles or 640–1,290 kilometres) signals tend to be reflected from more than one part of the Sporadic E layer, resulting in flutter and even phase distortion.

Sporadic E usually affects 6M most regularly, 4M somewhat less and there can be as few as two or three good 2M openings in a season. The typical expected distances are about 600 to 1,400 miles (970 to 2,250 km). However, under exceptional circumstances, a highly ionized Es cloud can propagate 6M signals down to approximately 350 miles (560 km). When short-skip Es reception occurs, i.e., under 500 miles (800 km)on 6M, there is a greater possibility that the ionized Es cloud will be capable of reflecting a signal at a much higher frequency – i.e., at 2 metres – since a sharp reflection angle (short skip) favours low frequencies, a shallower reflection angle from the same ionized cloud will favour a higher frequency **[2].**

At polar latitudes, Sporadic E can sometimes accompany auroras and is then associated with disturbed magnetic conditions called Auroral-E **[3].**

2. Mechanism of Sporadic E

We are learning more about Sporadic E year on year but no one single mechanism fully explains all its attributes. Attempts to connect the incidence of Sporadic E with the eleven-year Sunspot cycle have, however, provided tentative correlations. There seems to be a positive correlation between sunspot maximum and Es activity in Europe. Conversely, there seems to be a negative correlation between maximum sunspot activity and Es activity in Australasia.

Thunderstorms are also known to affect Sporadic E, see Davies and Johnson (2005) **[4].** This and the link with solar behaviour suggests that that the behaviour of Es clouds must be capable of modulation from both above and below. Whitehead (1989)**[5]** has summarised a considerable amount of both theoretical and experimental work on Es. His findings imply that mid-latitude sporadic-E is most likely due to a vertical shear in the horizontal east-west wind and that this theory accounts for the detailed observations of the wind and electron density profiles. Preferred heights of sporadic-E are separated by about 6km and descending layers are often seen moving down with velocities in the range 0.6–4 ms−. Sometimes sporadic-E layers are very flat and uniform, and at other times form clouds of electrons 2–100km in size moving horizontally at 20–130 ms^{-1}. Surprisingly Whitehead also finds that

Sporadic-E is probably not correlated with meteor showers even though a source of the ions involved might be meteor debris. This is because metal ions are stable in the E-layer for long periods.

Further, according to Whitehead, the major problem with purely a windshear theory of Sporadic E is in accounting for the dramatic seasonal variation and, to a lesser extent, for the geographical and diurnal distributions.

Sporadic E clouds are ideally shaped for radio reflection and are known to have a concave underside with an extremely high internal electron density making them difficult to track with H.F. radar, see From and Whitehead (1978) **[6].**

Davies and Johnson (2006) **[7]** have shown that during a thunderstorm multiple mechanisms enhance the Es layer, especially gravity waves and EMPS above Elves (upwardly propagating lightning). Sporadic E propagation from a fixed location is known to exhibit a wax and wane effect over an approximate 40 minute or so interval. The present author believes a paper by Lu et al (1984) **[8]** may explain this elegantly. In making VHF Doppler Radar Observations of Buoyancy Waves Associated with Thunderstorms they have observed large quasi-sinusoidal wave trains with periods of about 40 min. Power spectra of the vertical velocity time series showed enhancements at all frequencies during thunderstorm activity, but for periods longer than 30 min the enhancements were larger, particularly for the mid-tropospheric range gates from 5.7 to 12.9 km. The present author believes such wave trains would periodically enhance the E –layer according as upwardly propagating gravity waves. Furthermore when no thunderstorm activity was present, the vertical velocity fluctuations were small and erratic.

Some have suggested that sporadic E propagation cannot take place in the absence of thunderstorms but others have shown an association with jet streams. The latter is not so unreasonable, considering the work of Fritts and Nastrom (1992) **[9]** who consider Sources of Mesoscale Variability of Gravity Waves due to Frontal, Convective, and Jet Stream

Excitation they conclude a major role for localized sources in energizing the mesoscale motion spectrum at horizontal scales < ~100 km, and correspondingly greater influences for such motions at greater heights. Such heights are exactly those where the E's clouds are found.

Other earth and atmospheric scientists concur with the opinion that the ionosphere, e.g. F-region is inevitably driven from both above and below, see for example Rishbeth (2006) **[10].** They conclude that ''Ionospheric weather", as a part of space weather, (i.e., hour-to-hour and day-to-day variability of the ionospheric parameters) awaits explanation and prediction within the framework of the climatological, seasonal, and solar-cycle variations. Further they give the reason for the extreme variability of the thermosphere–ionosphere system as its rapid response to external forcing from various sources, i.e., the solar ionizing flux, energetic charged particles and electric fields imposed via the interaction between the solar wind, magnetosphere and ionosphere, as well as coupling from below ("meteorological influences") by the upward propagating, broad spectrum, internal atmospheric waves (planetary waves, tides, gravity waves) generated in the stratosphere and troposphere. They also state that Thunderstorms, typhoons, hurricanes, tornadoes and even seismological events may also have observable consequences in the ionosphere. Even the release of trace gases due to human activity have the potential to cause changes in the lower and the upper atmosphere. They summarise experimental results that have confirmed that the ionosphere is subject to meteorological control (especially for geomagnetic quiet conditions and for middle latitudes).D-region aeronomy, the winter anomaly of radiowave absorption, wave-like travelling ionospheric disturbances, the non-zonality and regional peculiarities of the lower thermospheric winds, ***sporadic-E occurrence and structure,*** spread-F events, the variability of ionospheric electron density profiles and Total Electron Content, the variability of foF2, etc., and feel that these all should be considered in connection with tropospheric and stratospheric processes.

3. Predicting the start of the Sporadic E season (6 metre)

Following the above, reference to weather maps, thunderstorm detectors and Jetstream mapping ought, as others have already suggested, and to some extent experientially proved

, to be useful in predicting the possibility of individual sporadic E events but could we ever predict when the season might commence and how long it might last?

Riggin (1986) **[11]** has studied study the plasma instabilities associated with night-time sporadic E layers, using the Cornell University Portable Radar Interferometer (CUPRI), a 50-MHz Doppler radar system. The CUPRI beam was directed over Arecibo, Puerto Rico, and concurrent electron density profiles within the CUPRI scattering volume were measured by the Arecibo Observatory's 430-MHz radar. During the strongest Es event, radar echoes were received from several altitudes up to 130 km. Large mean Doppler velocities (at times exceeding 250 m/s) were observed during this event and the power spectra closely resembled those obtained at the magnetic equator. This led to the conclusion that the mid-latitude large-scale waves are generated by the same gradient drift instability mechanism responsible for equatorial large-scale waves and that the similar type waves can be generated at mid-latitudes with drift velocities well below the sound speed because of the very sharp plasma density gradients associated with metallic ion sporadic E layers.

Following from this the present author has applied a little lateral thought to the problem of prediction. The buffer sitting between the ionosphere and the troposphere is the stratosphere. The winds above the equator in the upper stratosphere exhibit a peculiar pseudo cyclic variation in direction, phase and amplitude the so called QBO or Quasi-biennial oscillation. The history and development of theories of the QBO have been summarised by Lindzen (1987) **[12].** The direction of the QBO has merely been linked with Atlantic Storminess in the past and more recently discussed by the Met Office Centre for Ecology and Hydrology **[13].** The present author wondered if the QBO could be used for far more detailed medium term weather trend prediction and after examining retrospective data has filed a series of patents accordingly **[14,15**]. This disclosure does not compromise the detail. Since the weather and sporadic E are clearly linked and since according to Riggin **[11**] equatorial and mid latitude processes with regard to sporadic E may be linked it was natural for the author to extend this hypothesis to examine if there was any link between the QBO and the start of the E's season. The QBO is commonly recorded by meteorologists as the so called zonal wind index. The two most common QBO zonal wind indices refer to equivalent pressure heights of 50mb and 30mb and data for these is available from N.O.A.A**. [16, 17].** The sign of the index indicates the direction of the zonal wind and the numeric value assigned indicates the descent rate.

So is there any firmer evidence that the QBO and Sporadic E could be linked? There are several references in the Scientific Literature to the appearance of so called time series wave behaviour in Sporadic E, ranging from the 40 minute wax and wane effect, through the diurnal tide effect (there are even some references to a tri-urnal (8h) effect) to longer Planetary wave periods of 2,5,10 and 16 days as, for example, reported by Haldoupis et al (2004) **[18]** and one paper, Pancheva et al (2003) **[19]** observes a seven day period and another a five day period, see Tsunoda et al (1998) **[20].** The Pancheva paper is important for it establishes a 7-day periodicity in foEs directly with concurrent variations over a large distance in the mesospheric neutral wind measured with atmospheric radars in Saskatoon, Canada, and in Sheffield, United Kingdom and provides a new physical explanation for the observed relation between sporadic E layers and planetary waves.

The QBO direction and descent rate is also known to affect the entire global circulation at 50 mb, see Holton and Tan (1980) **[21],** both Southern and Northern Polar Vortices, Baldwin et al (2012) and Calvo et al (2009) **[22,23**], Jet stream and storm tracks, see Tinsley (1988**)** **[24],** and to modulate the length of certain Planetary wave periods, see for example Sato et al (1994) [**25],** Mitchell et al (1999**)** **[26],** Sridharan et al (2003)[**27],** Kodera (1993) **[28],** Hibbins **[29]** and finally Cheng and Huang (1999) **[30]** whose study provides illustrative support for the mechanism of the QBO modulation of planetary wave propagation and the associated effects in the residual meridional circulation.

Hence, considering the above, we now have a Scientific Basis for the hypothesis presented by this present work.

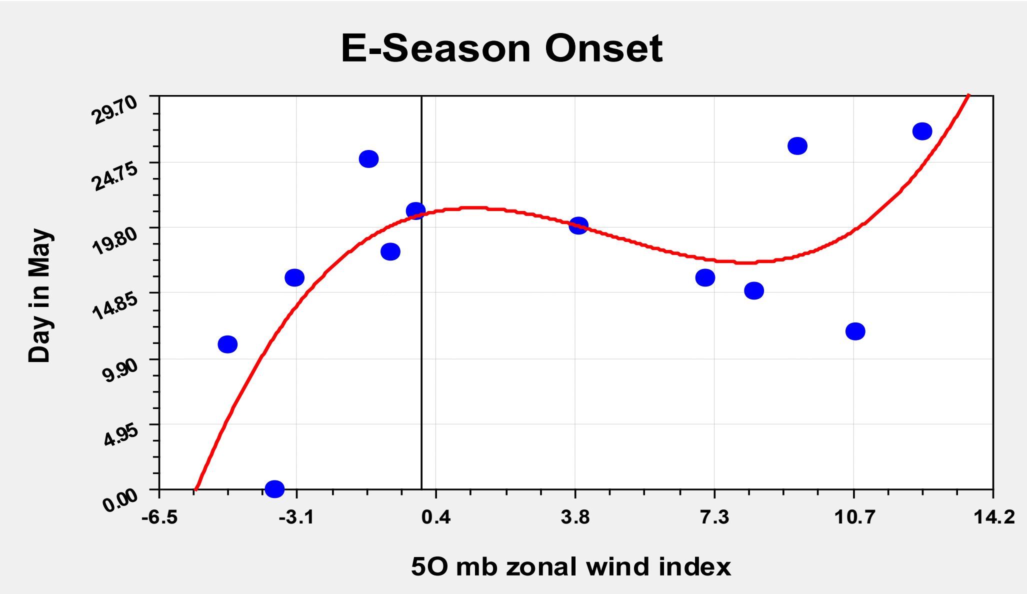
4. Experimental Method

The initial data given is for North Wales in the UK. The experimental date data simply comprises retrospective date entries in the author's amateur radio log dating back to 1992 i.e. approximately 2 solar cycles. Since that date the author has been a keen 6 meter operator and has, in the past, often checked the bands on a methodical basis to try and establish the presence of E's. One can assume that, retrospectively, he may often, but not necessarily have always caught the very start date of the Es season because until this present study that was not his specific intention. One cannot guarantee that one will always be in the operating shack 24/7, thus any such data can be subject to error. Nevertheless, it was decided to use these past first observed Es dates from previous years as a first attempt at 'start' date data. The zonal wind data was obtained from www.cpc.ncep.noaa.gov/data/indices/qbo.u50.index **[16],** and were the values of the zonal wind index in the month of March preceding each year's Es season.

An attempt was made to correlate the onset of the E'S season each year with the value of the 50mb zonal wind index in April of each same year. Initially a linear correlation was attempted but the correlation factor was poor. The best fit is obtained using a cubic equation. Data plotted only represents the E's seasons in which the author was active between 1992 and 2013. The former and the latter dates are inclusive. 2014 data has not been included in the model.

5. **Initial Results**

The initial results are shown below:



.

5.1 Testing the model

The value of the 50mb zonal wind index for April 2014 was given on the NOAA website as 9.72. When this value is plugged into the curvefit model using the above cubic fit a start date of May 14.85 is returned. Significant variation can be seen between some of the data points and the curve predicted. It is suggested here that particularly for the points in error lying above the data plot, these may have been generated with higher values on occasions the author was simply not in the shack at about the right time in order to catch the earliest Es opening of the season. Clearly with the model in this state it is not sufficient to prove the hypothesis but does offer a tantalising taste of what might be possible. The best fit points seem to predict the start of the season to within a day but the worst fit ones can be out by up to plus/minus several days.

5.2 Refining the model.

The main question is can this sort of model be refined to be worthwhile? It would be ideal if, for example, the prediction could be made with more notice. Due to the way in which the zonal winds descend this is not a problem. Data from zonal winds higher in the atmosphere, the so called 30mb QBO offers predictably of Es April or May onset dates from as early as

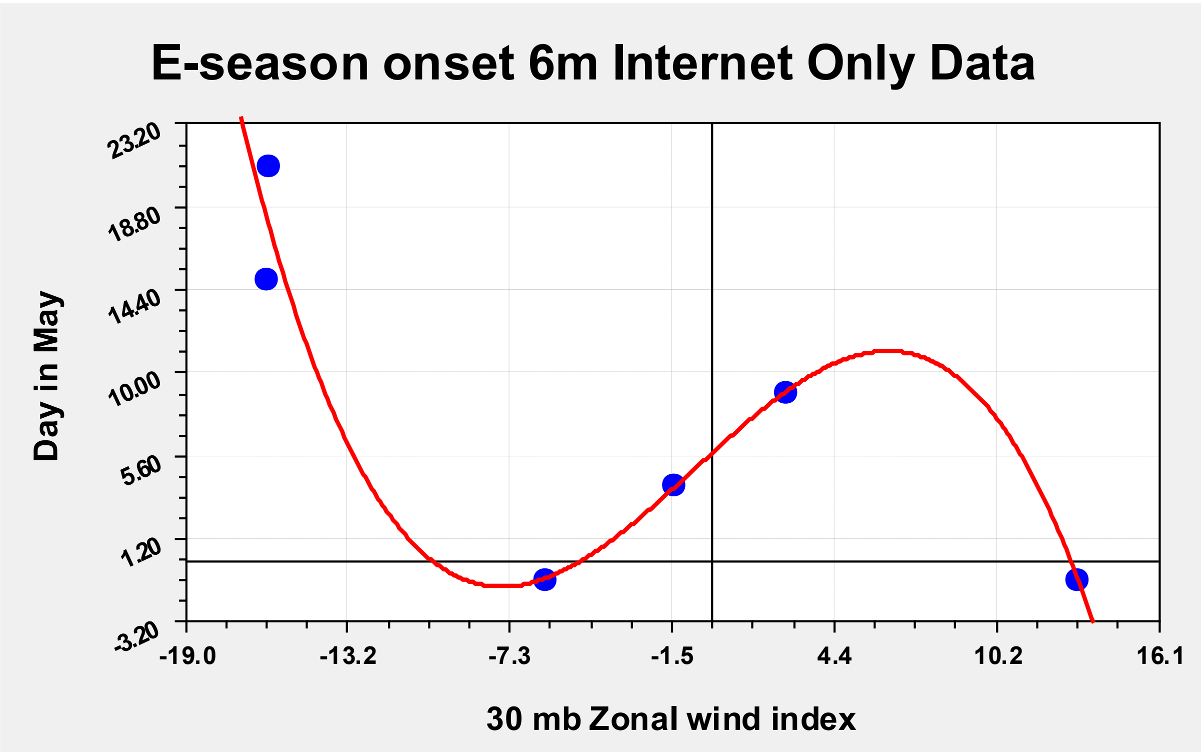
January. Due to phase variations in the descent rate, the shape of the new plot will not be expected to mirror the above plot but it may also be cubic in general form**.**

A first subsequent question is can the data input be refined to make it more reliable? The notion of using retrospective start date data acquired from Internet sources seems reasonable in that a large number of amateur radio operators will have contributed thereby increasing the chances of coming up with a correct start date for the Es season in any given year.

A second subsequent question is can an algorithm generated by date data from the Internet by refined by making a compilation of data from the present author's log?

5.3 Refined results

The refined result using January 30mb zonal wind data and Internet only Es start dates is shown below.



This time the data is a near perfect fit to the cubic model, with a near perfect regression order =0.974. The phase is shifted with respect to the in initial result above for the 50mb zonal wind.

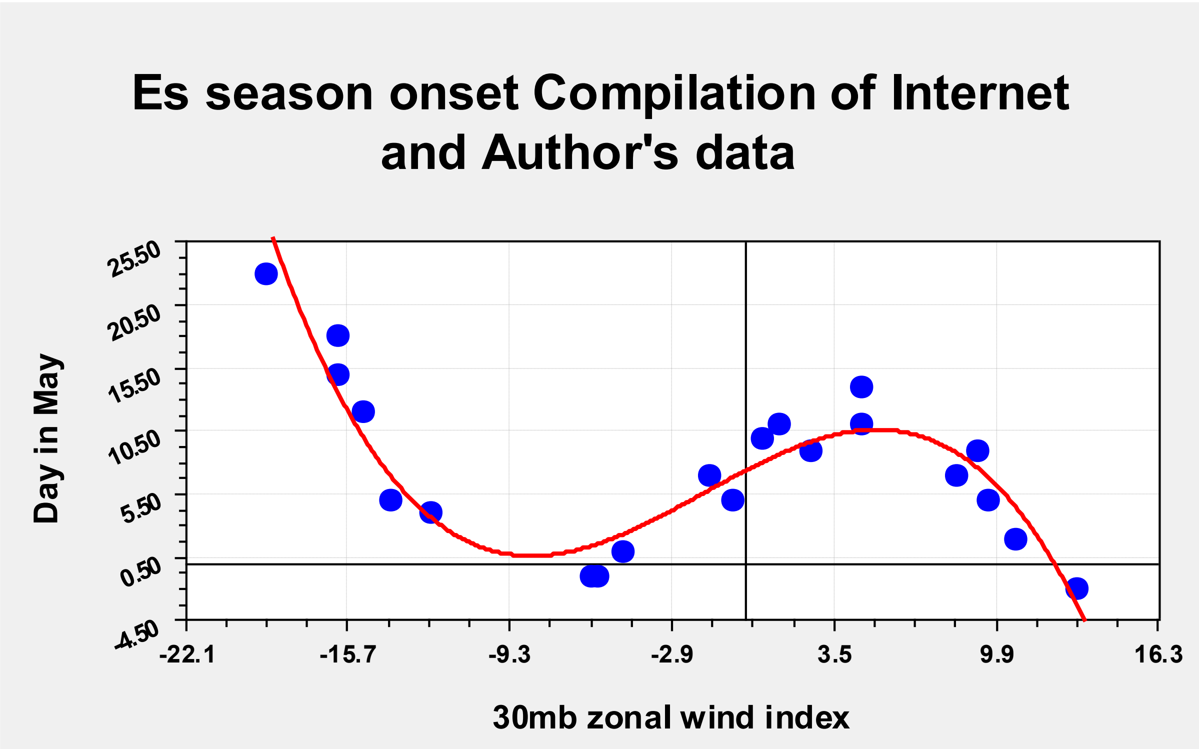
The validity of the model was tested by fitting years not available in the internet data and comparing them to the author's data. In cases where the author's observed start data was equal to or less than the predicted date this too was then adopted into the model. Author's data with start dates beyond those predicted by the model were rejected on the basis that he had simply not been in the operating shack at the right time to catch the appropriate start date.

The compilation data file and its best cubic fit are shown in Table 1 below.

Index	Day Number	Year
-13.99	5	1992
9.62	5	1993
8.37	7	1995
-5.8	-1	1996
0.74	10	1998
1.4	11	1999
4.62	11	2000
-15.02	12	2001
4.63	14	2002
-4.84	1	2004
-1.4	7	2004
-0.46	5	2005

-18.9	23	2006
2.6	9	2007
-12.43	4	2008
10.71	2	2009
-16.02	18	2010
9.18	9	2011
-16.09	15	2012
-6.07	-1	2013
13.13	-2	2014

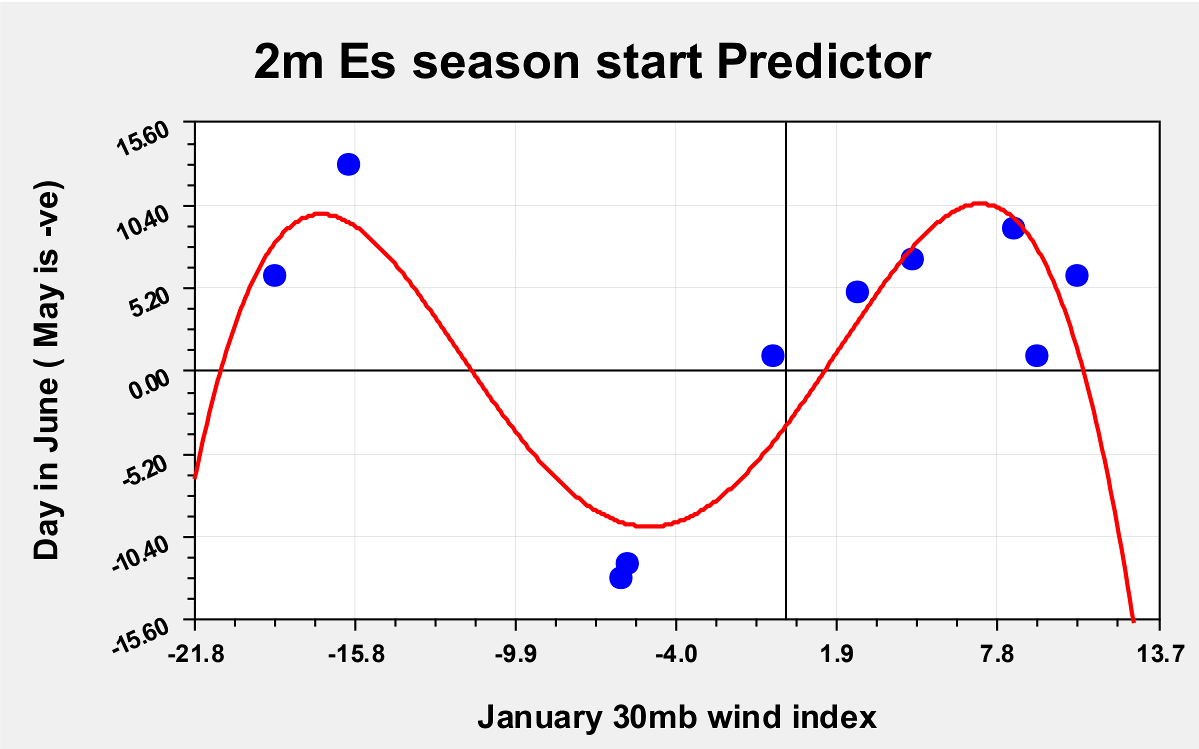
Table 1



The correlation coefficient for this data set is .93 and the worst case predictability for any year's sporadic E season start date is within 2.5 days. Given the sensitivity to geographic position in the UK which the author has noted when using similar modelling for weather trend prediction this is quite impressive.

5.4 2 metres

As the Es season progresses the openings become more intense and there may be propagation as high as 144 MHz (2m). Most 2 m openings occur in June, although some occur earlier. The same approach has been taken to model available 2m data. The author has a poor 2m location and simple antenna and rarely experiences 2m sporadic E so in this case reliance has been placed on UK Internet data from a variety of sources. Since some openings start in May, days in April are represented by negative values on the ordinate axis.



The regression factor of .88 is somewhat lower than that for the 6m predictor giving a potential margin of uncertainty of about 5 days. As such the predictor is less useable than the 6m predictor but given the number of separate geographic sources taken to compile the data and the very local geographic sensitivity of Es propagation in general then this is perhaps not surprising.

6. Discussion

We have learned here that through a combination of atmospheric science and lateral thinking it has been possible to remove some of the mystery from the enigmatic phenomenon of sporadic E. It has, perhaps become a bit less sporadic and a bit more predictable!

Having such a method at our disposal will have time saving implications for ardent Es hunters of the future and may well be useful for climate and space weather researchers to boot.

7.1 Part 2 Predicting Sporadic E: Main Season Length

In the UK and Europe, it is generally accepted that the main Sporadic E or Es season starts in April or May, peaks in June or July and is all but over by late August. Reed (1997) **[31]** has offered an explanation for different shaped activity distributions in Sporadic E openings in terms of x-ray solar flux.

Occasionally we see an additional peak or peaks in Sporadic E activity in late autumn and again around the mid-winter period which might coincide with the main southern hemisphere peak?

Following the method developed for predicting the start of season (Part 1), the author decided to explore if the state of the QBO (equatorial zonal wind) could also be used to predict the length of the main season.

7.2 Experimental

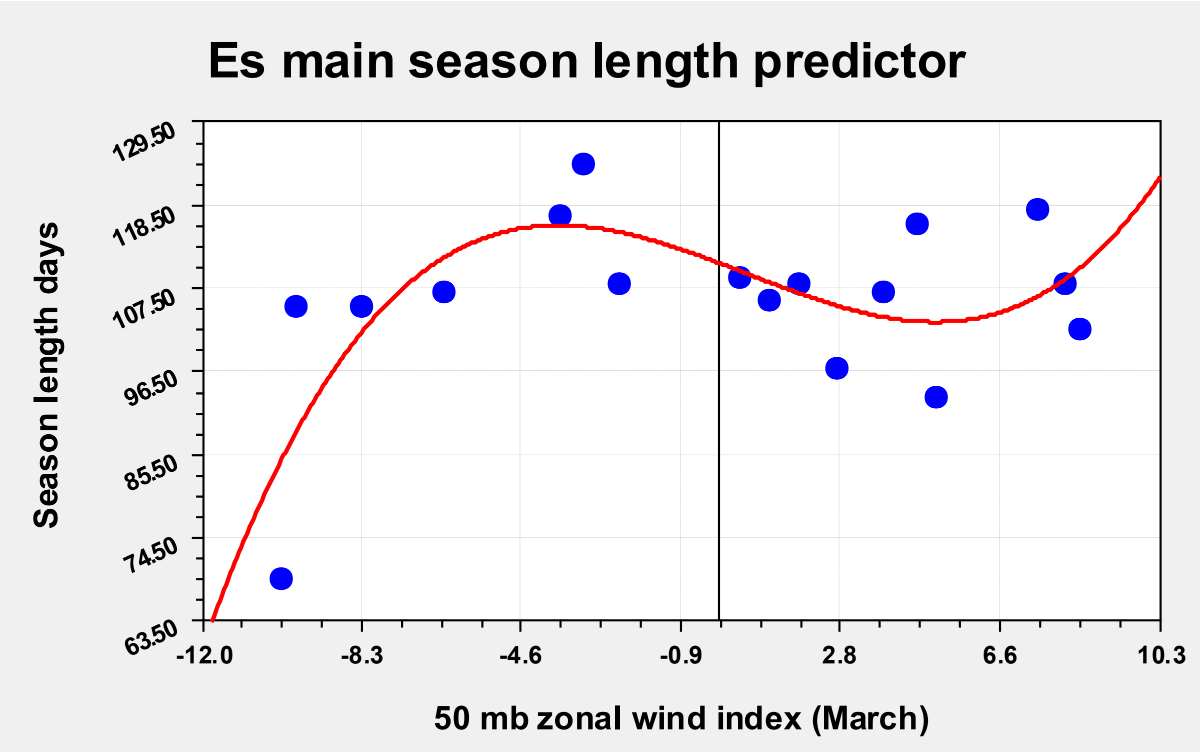
This time data was much harder to come by. Reed's data **[31]** for 6m suggested that, at least at his QTH, 1996 activity in August was significantly lower than that for 1994 and 1995. The author's own log certainly concurs that 1996 was an early ending season.

Since Internet data appears scarce in defining the end of the ‘main’ season the author has relied entirely on data from his own log which covers some but not all of the 6m seasons from 1992 to 2013. The author has defined the ‘main’ season length in days from when sporadic E was first worked in April or May through to the last contact found in the log but excluding any contacts in late October, November or December on the basis that according to the data of Reed **[31],** these are distinctly separate peaks.

7.3 Results

The season lengths were plotted against the corresponding year’s March 50mb zonal wind indices. The results which correlate best according to a cubic function and are shown below:

This time the regression factor is only of the order of .7, so not brilliant, and nowhere near as good as for using this type of method to predict the onset of the Es season and meaning that any estimate could be out by up to +/- 13 days. However, given that the whole season can vary from about 70-130 days in length any improved estimate on this is welcome. The result is shown below:



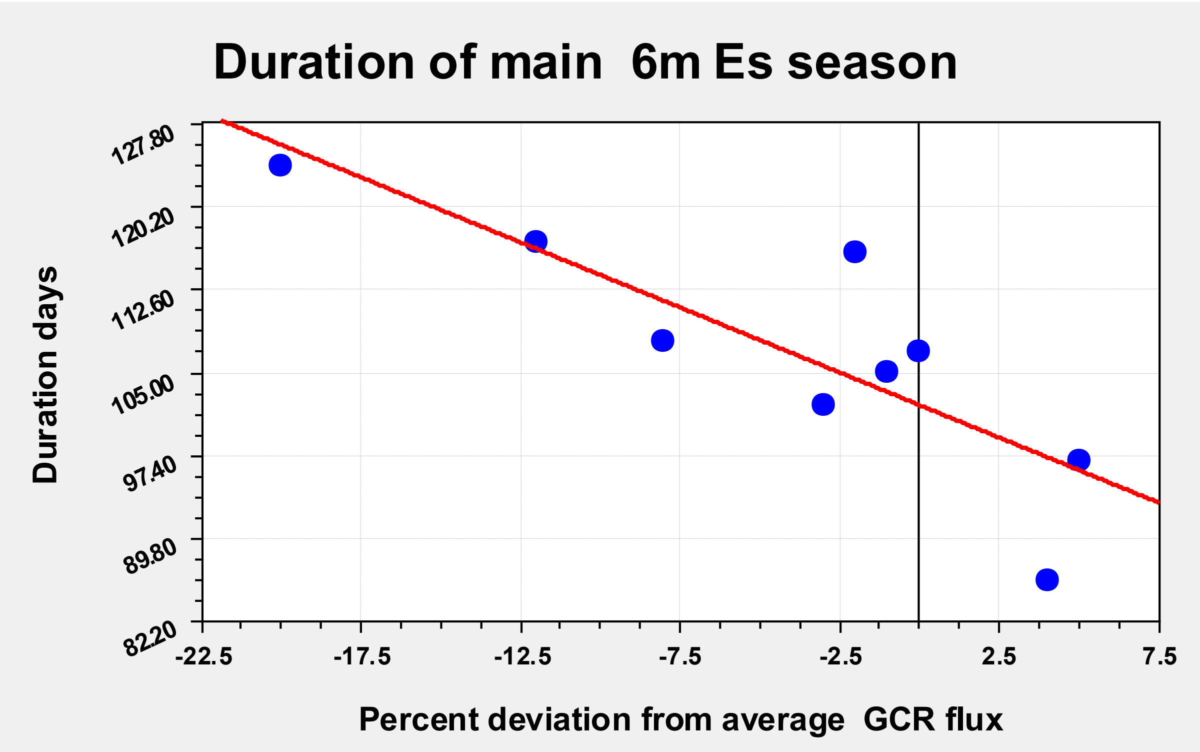
7.4 Discussion

On the basis of his 1990's data, Reed **[31]** has suggested changes in solar X-ray flux as being an important factor in determining the shape of the Es season intensity-duration distribution function. The present author has no data between 2008 -2012 but the data for 2007 which had low sunspot numbers has a reasonably low season length of 97 days but not the shortest. Clearly there are other factors at work. This is because Es and the atmosphere in general depends on driving from both above and below.

Most certainly the solar cycle influences the QBO, see Liu et al (2010) **[32]** and Nastrom and Belmont (1976) **[33]** and the QBO and storm tracks, see Tinsely (1988) **[34]** . Possibly other planets perturb the Earth –Sun magnetic field as well, see Dudok de Wit and Watermann (2009) **[35].**

However, Solar Influence on our atmosphere is only half the story. We must also consider Cosmic Rays as well, see Tinsley et al (2012) **[36].** High energy Galactic Cosmic Rays can not only have an influence on the ionosphere direct but also possibly on cloud nucleation in the Troposphere, see Pierce (2011)**[37]** and Tinsely and Deen (1991) **[38].** Both could thus be relevant to the behaviour of Sporadic E.

It is thus very instructive to plot the duration of the main 6m Es season against a percentage deviation form an 'average ' GCR (Galactic Cosmic Ray) input to the planet, see below :



The GCR data are courtesy of the Oulu Cosmic Ray Station in Finland http://cosmicrays.oulu.fi/. The linear regression factor is .83 and an even higher correlation coefficient can be obtained by switching to a quadratic fit. In any event the duration of the Es season can be predicted well by this method.

Although the GCR flux varies hourly and on a day by day basis it also varies more dramatically over longer timescales of years and so might probably be able to be used predictively for Es seasons as an adjunct to or possibly prove more effective than the zonal wind method.

Thunderstorms are of course very relevant to Sporadic E and Schlegel et al (2001) **[39]** have found that lightning frequency is anti-correlated with cosmic ray flux. Thus accordingly the present hypothesis would suggest, the more cosmic ray flux, the less lightning and hence the less sporadic E. Since this effect seems to determine the duration of the season it is more than likely countered by the effect of both meteor injection and any high speed solar wind streams at the start of the season which can enhance thunderstorms for up to 40 days, see Scott 2014 **[40].**

8. PART 3; Once we know the season start date can we predict specific opening dates?

There have been several publications in recent years linking sporadic E openings to thunderstorms. So if we know where the thunderstorms are we might be able to predict the likely path of an opening. But could we ever predict more precisely on which days to listen for Es once the season has started or after any subsequent opening, at least know the days with highest probability of finding an opening.

In the past people have suggested that the aftermath of certain meteor showers may increase the probability of Es openings on specific dates. However, the metal ions which meteors inject tend to be very long lived in the ionosphere so perhaps we need an alternative hypothesis. Planetary waves were first proposed as relevant to metal ion Es layers as early as 1997, see Clemesha et al (1997) **[41].**

In Part 2 we saw how a strong solar wind stream could enhance Es for up to 40 days. We might ask the question, if this is the case why is there not just one continual Es opening for the entire season. Indeed the facts are there are probably almost continual openings somewhere in the Northern Hemisphere sometime in the summer months. It is the much localised nature of Es clouds in time and space that limits us. Then because of this we need to know just what puts Es clouds in a particular place at a particular time. The best hypothesis we have is the planetary wave hypothesis. This tends to suggest that there should be repetitions in Es openings at intervals of two or three times a day, see Fytterer et al (2013) **[42]** and according to the normal Rosby wave interludes of 2,5,7,10 and 16 days , see Haldoupis, C., Pancheva, D. and Mitchell, N. J., 2004 **[43].** Because there can be non-linear interactions between planetary tides and planetary waves, see for example but not exclusively Kamalabadi et al (1997) **[44],** we might also potentially expect Es openings with these Rosby wave periodicities +/- 1 day and +/- 1.5 days. There are two ways of checking this.

Firstly, we can check the scientific literature and examine what has been discovered and published. Secondly, we can examine archive data of real openings and QSO'S. The author has examined his own log for 6m data and has examined multiple internet sources for 2m data.

8.1 Experimental

The number of instances of a particular number of days gap (between 1-20 days) between openings from the UK has been examined for both 6m and 2m and converted into a statistic.

At the height of the sporadic E season across some 20 years of data the results are very informative. The **minimum** probability of finding a 2 metre opening is 11-12 days after a first opening or after subsequent openings.

For 6 metres the **minimum** probability is also at day 12 but **also in the period days 17-20.**

So at least we now know when not to expect an Es opening.

The maximum probabilities for openings for the two bands are shown tabulated.

Table 2 shows the results for 2m sporadic E.

2 Metres		
Rank	Day (s)	Probability
1	1	0.14
2	4	0.11
3	7	0.11
4	10	0.11
5	2,3,8	0.07
6	9,13,18	0.05
7	5,14,17,19,20	0.036
8	6,15	0.018
9	11,12,16	0

Table 2

While table 3 shows the results for 6M sporadic E.

6 Metres		
Rank	Day (s)	Probability
1	5	0.16
2	2	0.14
3	1	0.127
4	3	0.11
5	9,10	0.08
6	6	0.064
7	4,7,16	0.05
8	8	0.032
9	11,14,15	0.016
10	12,17-20	0

Table 3.

Discussion

The day ranking orders are different for each band. **For 2m the highest probability of finding another opening is a day after the first.** Presumably this is because the much higher ionisation levels required are able to persist better the first 24 hours. The Rosby wave periods of 7 and 10 days also feature quite strongly and overall there are combined odds of about 7/10 of finding another opening sometime within the first week but at first sight and from this statistic alone it would seem we could never say this with any more certainty.

It is instructive to look at the 6m results. Here, the common Rosby wave periods feature more strongly. **There is better than a 6/10 chance of having another opening in the first 5 days and almost an 8/10 chance of finding another opening within the first week after a first or subsequent opening during the season.**

Voiculescu et al (1999) **[45]** have examined a large database of mid-latitude E region coherent backscatter, obtained with a 50 MHz Doppler system and used it to investigate the long-term variability in echo occurrence. They found the backscatter to be dominated by pronounced quasi-periodic variations with periods in the range from about 2 to 9 days that persisted for time intervals from about 10 to maybe more than 20 days and which have no relation to geomagnetic activity. The most commonly observed periods appeared in two preferred bands, namely a 2 to 3 day and the 4 to 6 day band. Using concurrent ionosonde data they found that variations in backscatter were exactly in-phase with similar periodicities in the occurrence of relatively strong sporadic E layers. Their findings support the possibility the present hypothesis that planetary waves are responsible for longer term periodicities in Es. They also concluded there is a close relation between planetary waves and the well- known, but not well understood, seasonal Es dependence which of course the present author expanded upon in Part 1 of this article. From the results above it is evident that 4-6 day band is relevant to both 6m and 2 m openings but that both bands are relevant to 6m openings.

The work in the present article strongly supports the notion that sporadic E may in many ways be more predictable than we ever thought. We now know when a season might start, how long its main part is likely to be and the days with highest probability to listen for openings on various bands. Nevertheless on those days we should still look for evidence of triggers particularly thunderstorms towards one or other end of the intended propagation path and **the author has also noted that small patches of Jetstream flowing roughly orthogonal to the proposed path are also a good pointer.** An excellent Jetstream online mapping facility to use for this purpose is the one at the California Weather Server **[46].**

In the final part of the article we will ask the question can we predict years in which a late autumn blip in Es activity will occur and is there such a thing as mid-winter Es in the UK or is what we hear really F2 propagation?.

9. Part 4

Can we predict the late Autumn October/November blip in Sporadic E and is European mid-winter 6M propagation Es or F2?

In order to try and understand autumn and possible winter Es propagation, we need to revisit the mechanism of sporadic E.

No one single hypothesis completely explains the behaviour of sporadic E. This does not mean to say that existing hypotheses are incorrect it is more likely that we need to combine various facets of each to get nearer to the true picture.

Although meteors are probably not relevant to individual sporadic E openings they are a very important source of metal ions at E- layer height. Wind shear is equally important. Haldoupis et al (2012) **[47]** have shown that mid-latitude sporadic E layers form when metallic ions of meteoric origin in the lower thermosphere are converged vertically in a wind shear. Further they found that the occurrence and strength of sporadic E follow a pronounced seasonal dependence marked by a conspicuous summer maximum. Something known of course by radio amateurs for some five or six decades, and also known since the early years of ionosonde studies, the cause of this summer peak has remained a mystery as it cannot be accounted for by the windshear theory of E s formation alone. Further Haldoupis et al **[47]** showed that the marked seasonal dependence of sporadic E correlated well with the annual variation of sporadic meteor deposition in the upper atmosphere.

Perhaps the key paper on meteor rates is that of Singer et al (2004) **[48]** which studied meteor rates per se at the Arctic Circle without specific reference to sporadic E. However, when one looks at the distribution curves for 2002-2004 the number of meteors per hour across a year more or less mirrors but somewhat precedes the likelihood of UK /European/

Northern Hemisphere Es with a pronounced summer peak . For meteors this is between day 165 and 190, possibly 30-40 days earlier than the Es peak. It is interesting to note that meteoric material in the ionopshere has a long lifetime of this order before falling to the troposphere where it can act as cloud nucleating centres, , see for example Bowen (1955) **[49],** given this there is possibly no wonder Haldoupis et al **[47]** were able to reach their conclusion. There would appear to be two smaller sub-peaks in meteor rate some 30 days before the late autumn and mid-winter period.

We are all familiar with the fact that meteor showers are very regular in nature so why then are autumn and winter Es openings not so consistently regular. In fact close inspection of the data for 2002-2004 does show slight year on year variation. Whether it is possible to use this variation in known meteor showers to account for the large observed year on year absence or presence of October/November Es openings remains to be seen. Kopp (1997) **[50]** has certainly shown that metal ions are very abundant at Sporadic E layer height with mean total column density of the ionized metals is within 4.4 ± 1.2 × 10^9 cm^−2 in even in periods without special meteor shower activity. They also showed the column density to increase by 1 order of magnitude during the Perseid meteor shower of August 12, 1976. Since the Perseids precede the late autumn Es 'blip' by about 80 days and meteoric deposit's lifetime in the upper atmosphere is about half of this period, the present author feels it may be unlikely that they are causative in this respect.

Wright (1967) **[51]** was perhaps one of the first to propose an understanding of Es similar to that we have today. He made standard measurements of sporadic *E* blanketing frequencies (f_bE_s, assumed to indicate peak ion densities) during November 1965 from three temperate latitude stations. His understanding predicts two important properties of sporadic *E:* (*a*) that major events consist predominantly of slowly-recombining monatomic ions, probably of meteoric origin, and (*b*) that these ions converge and accumulate in thin layers through combined effects of the geomagnetic field and the profile of horizontal winds. His data seemed to prove both facets of Es were prerequisite. Again the hypothesis of a meteoric origin for the ions suggested that major events of f_bE_s might correlate with the increased meteoric mass arriving during large showers. Wright **[50]** presented some evidence of this correlation for the November 1965 Leonid meteor shower. The Leonid shower is regarded as both bright and fast **[52].** The present author feels that given the lifetime of meteoric material it is possible this shower may be sufficient to account for mid-winter E's openings although these tend to be more a North American than a European feature.

One question remains, how does Es break up from thin continuous layers to become more like apparently sporadic or randomly moving lens shaped patches. Moreover, could this mechanism be crucial in understanding why we sometimes have late autumn and winter Es and other times do not. We only need to look at a smooth pond or calm sea to perceive an answer. The surface of which can become very perturbed as a result of wind and waves. The atmosphere is literally full of tides and waves on all sorts of timescales from seconds to many days. Some waves for instance such as the AGW's (acoustic gravity waves) above thunderstorms have very dramatic effects and propagate up to E layer height, this has been both observed by both atmospheric scientists, see Kazimirovski **[53]** and also as proposed by radio amateurs, see for example Grassmann et al **[54]**. So maybe thunderstorms provide sufficient wind shear energy to break the Es layers into patches and their repetition is linked with planetary waves, see Parts 1-3 above. There is additional evidence that Es are influenced by other types of gravity waves. For instance, SM7GVF has found a link between E's and Volcanic Activity **[55].** Volcanoes generate strong upwardly moving infrasound of, in some cases, up to 10 million watts acoustic power, see for example, but not exclusively, Johnson (2013) **[56].** Es is enhanced during solar eclipses and the proposed mechanism is the effect of temperature gradient on wind shear, see Chen et al (2010) **[57].**

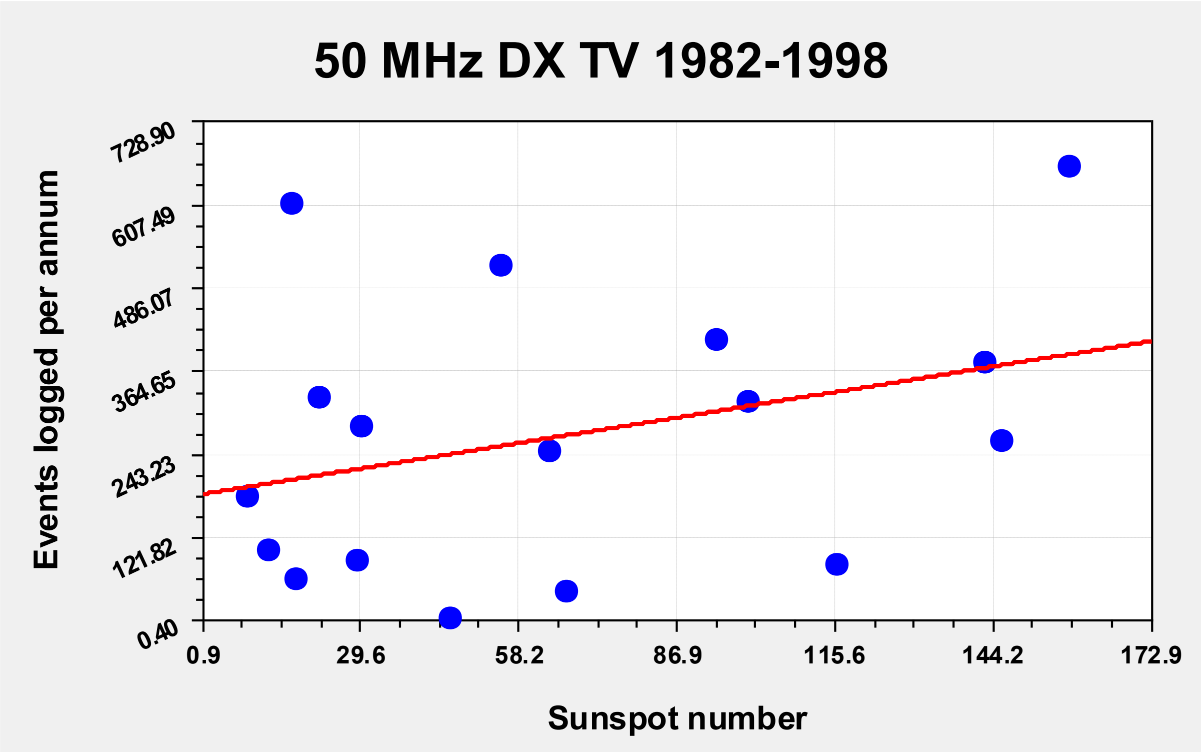
Given the above, we can now formulate additional hypotheses about what might influence the presence of otherwise of late season Es openings. Although these lesser mechanisms such as volcanoes and eclipses are academically interesting, thunderstorms remain the single most common and documented feature to do with Es. Let us ask ourselves if there is anything that could control the seasonal occurrence of thunderstorms, because if so this would also control Es and our chances of seeing late season openings.

9.1 Data and Experimental

When one searches on line for amateur radio references to E's openings outside the usual May-August season, references are **indeed very scarce.**

Before we can fully formulate a hypothesis we must try and acquire sufficient data to examine which years have exhibited good late season Es. One such useful reference is the '6 and 10 report' **[58],** which concluded that Es was the **controlling factor for DX on 6m in October 1998** whereas F2 was the controlling factor for 10m. Additionally, M6PCZ refers to some very short skip on 10M in October 2010 but concludes it was backscatter rather than E's. He does not mention whether this is tropospheric or ionospheric propagation but another possibility is that it was tropospheric ducting, see http://www.radio-electronics.com/info/propagation/tropospheric/tropospheric-propagation.php **[59].** The present author's data suggests that late autumn Es were prevalent in the following years: 2003, 2004 and 2007.

A huge amount of data for propagation in the 40-70 MHz band has been gathered by DX TV enthusiast William Kitching, G4FBZ during the years 1992-1998 inclusive **[60].** The data, re-evaluated by the present author below, is whole year data so it has not been possible to separate out the late season Es peak. However, it is instructional in that it only shows a weak correlation with solar cycle, suggesting that only a small fraction of what was received was F2 propagation.



The months/years with autumn openings that Kitching **[60]** specifically refers to as being possibly Es or a mix of Es and F propagation are November 1988 and October/ November 1989. ***Interestingly 1988 features in the 6/10 report above also and the two years 1988 and 1989 have the lowest ever cosmic ray counts in the last 50 years or so.***

9.2 Hypothesis

From the behaviour observed above it is possible to formulate a simple hypothesis, namely that; in years with increased cosmic ray activity there is certainly an early end to the main Es season, see part 2 above.

Thus the hypothesis being presently proposed is that low cosmic ray counts together with an appropriate bright, fast meteor shower some thirty days earlier favour late autumn sporadic E openings. . The cosmic ray connection being because cosmic rays and thunderstorms are actually anti-correlated, see U. V. Shamansky and Vladimir A. Kovalenko (2003) [61] and Kozlov et al (2007) [62]

The anti-correlation is perhaps somewhat surprising given that Svensmark and Friss-Christensen 1997 **[63]** published in the journal Atmospheric, Solar and Terrestrial Physics an indication that cloud cover varies in cycle with cosmic ray intensities suggesting a close cause-and-effect-relationship. Because cosmic rays are anti-correlated with the 11-year sunspot cycle, this predicts that cloud cover is modulated by solar activity in a non-direct way. The two are not at odds because of the way in which cosmic rays influence the global electric field and atmospheric conductivity however. The present author has also another suggestion. Increased cloud cover will tend to cause global cooling which ought to reduce storm intensity generally and vice versa.

9.3 **Results**

The results shown, **table 4,** are a compilation of the author's own data and those from the references above and appear to be in support of the hypothesis.

Year	**Cosmic Ray Count percent from average**	**Months**	**Es.**
1988	**-15%**	**oct/nov**	**Yes**
1989	**-15%**	**oct/nov**	**Yes**
1992	**-5%**	**sep**	**Yes**
1997	**7%**		**None**
2002	**-5%**	**sep**	**Yes**
2003	**-6%**	**nov**	**Yes**
2004	**-12%**	**nov**	**Yes**
2007	**5%**	**oct**	**Yes**
2009	**10%**		**None**
2010	**7%**		**None**

Table 4

It can be clearly seen that there are no late season openings observed in years when the cosmic ray flux is above 7% over average.

9.4 Mid –winter E's is there such a thing in the UK?

Again data is very scarce and hard to come by. The author's only experiences of mid- winter propagation were in 2000 and 2001 respectively have been to the USA and Canada at times of very high solar activity and he has always assumed this was, therefore, F2 propagation. However, these years represent years when the cosmic ray flux was -3% and -5% below average respectively and thus since there would appear to be an element of discrepancy he would welcome hearing from anyone who has logged shorter, European contacts at this time of year which did not occur during tropospheric lift conditions. It is also interesting to note that activity from the Leonid meteor shower (November) peaks approximately every 33 years, see Chandra et al (2001), **[64]** and that the year 2000 was only 1 year after such a peak.

10. OVERALL CONCLUSIONS

This short series of articles has shown us that sporadic E as a useful DX mode for VHF radio amateur operators is perhaps a little less 'sporadic' and a little more predictable than any of us would have ever thought. Moreover, it has given us a clearer picture of mechanism sporadic E and has established links between the various and previously 'competing' theories of Es.

1. We can see Es clouds as:

- Localised offshoots of Es layers containing highly conductive metal ion interiors and radio reflective concavely curved lower surfaces
- Meteors as a long lived 30-40 day metal ion source
- Patchy Es clouds arising because of coalescence and propulsion by wind shear which is modulated at multiple levels in time and space by AGW from thunderstorms, and planetary waves and tides

2. We can see the start of the 6M Es season as:

- Predictable to within a few days in more than a month
- Predictable by using an algorithm connected to the behaviour of the QBO (Zonal equatorial winds)
- This being the link between energy inputs from 'above' and 'below' and modulator of many atmospheric features world-wide

3. We can see the start of the 2M Es season as similarly predictable.

4. We can see that once the season has started or that once a strong opening has occurred that there are higher probabilities of finding openings on some days than others according to planetary wave hypothesis advance here but not withstanding the presence of strong thunderstorms along possible propagation paths. Probability of a re-occurrence is greatest on the first day after a 2m opening and on the 5^{th} day after a 6 metre opening. The 6m behaviour is most closely in line with the observation of Tsunoda et al **[20].** Probability of re-occurrence is second greatest on the 4^{th}, 7^{th} and 10^{th} days after 2m openings and on the 2^{nd},1^{st} and 3^{rd} days after 6m openings in rank order, all these, lengthwise, are either Rosby wave periods or Planetary wave periods modulated by Planetary tides and would therefore appear to confirm the new hypothesis proposed here. Finite probability of Es repeat openings on the second, fourth and tenth days after the start of a season or any subsequent opening is consistent with the observations of Karami et al (2012) **[65]** using a digital ionosonde for Es over Tehran in July 2007 but interestingly no 16 day periodicity is found here which is contrary to the observations of Karami.

5. We can predict the end of the main Es season either by means of a QBO algorithm or by means of a GCR algorithm again to within a relatively small number of days.

6. We can use the Oulu GCR monitor to predict the likelihood of late Autumn Es which only seem to occur for a cosmic ray count of less than 5% above average but may, conceivably, be influenced by the quality of meteor showers some 30 days earlier.

7. We only remain somewhat uncertain about mid- winter Es which, at the height of the solar cycle could conceivably be hard to distinguish from F2 propagation. An appeal for more data from other operators might resolve this situation.

11. Further Possibilities

Increased predictability of Es propagation may conceivably have advantages for other uses of the radio spectrum such as for example military and emergency international communications. Because of the intimate connection of Es with both troposphere and ionosphere there may even be implications for climate and weather forecasting. Troposphere and ionosphere are also thought to be linked to the lithosphere via the global electric circuit and via the earth's magnetic field. Thus there may even, remote as it may seem, be implications for volcanism and earthquake forecasting.

References

1. Collection of articles on sporadicE: http://www.df5ai.net/Material/articles.html
2. http://en.wikipedia.org/wiki/Sporadic_E_propagation
3. http://www.dtic.mil/dtic/tr/fulltext/u2/a265059.pdf
4. Lightning-induced intensification of the ionospheric sporadic E layer, C. J. Davis & C. G. Johnson, Nature 435, 799-801 (9 June 2005) | doi:10.1038/nature03638, Abstract at http://www.nature.com/nature/journal/v435/n7043/abs/nature03638.html
5. Recent work on mid-latitude and equatorial sporadic-E, Journal of Atmospheric and Terrestrial Physics, Volume 51, Issue 5, May 1989, Pages 401–424 Abstract at: http://www.sciencedirect.com/science/article/pii/0021916989901220

6. On the peculiar shape of sporadic-Eclouds Journal of Atmospheric and Terrestrial Physics Volume 40, Issue 9, September 1978, Pages 1025–1028 Abstract at: http://www.sciencedirect.com/science/article/pii/0021916978900065

7. The location of lightning affecting the ionospheric sporadic-E layer as evidence for multiple enhancement mechanisms, C.J. Davies and C.G. Johnson (2006) Geophysical Research Letters > Vol 33 Issue 7 Abstract at : http://onlinelibrary.wiley.com/doi/10.1029/2005GL025294/abstract

8. VHF Doppler Radar Observations of Buoyancy Waves Associated with Thunderstorms, Daren Lu, T. E. VanZandt and W. L. Clark, J. Atmos. Sci., 41, 272–282. Abstract at: http://journals.ametsoc.org/doi/abs/10.1175/1520-0469(1984)041%3C0272%3AVDROOB%3E2.0.CO%3B2

9. Sources of Mesoscale Variability of Gravity Waves. Part II: Frontal, Convective, and Jet Stream Excitation. Fritts, David C., Gregory D. Nastrom, 1992: J. Atmos. Sci., 49, 111–127.

   doi: http://dx.doi.org/10.1175/1520-0469(1992)049<0111:SOMVOG>2.0.CO;2 Abstract at: http://journals.ametsoc.org/doi/abs/10.1175/1520-0469(1992)049%3C0111:SOMVOG%3E2.0.CO%3B2

10. F-region links with the lower atmosphere? H Rishbeth - Journal of atmospheric and solar-terrestrial physics, 2006 – Elsevier. Abstract at http://www.sciencedirect.com/science/article/pii/S1364682605002567

11. Radar studies of long-wavelength waves associated with mid-latitude sporadic E layers, D. RigginW. E. SwartzJ. ProvidakesD. T. Farley, Journal of Geophysical Research: Space Physics (1978–2012) > Vol 91 Issue A7. Abstract at: http://onlinelibrary.wiley.com/doi/10.1029/JA091iA07p08011/abstract?deniedAccessCustomisedMessage=&userIsAuthenticated=false

12. A Theory of the Quasi-Biennial Oscillation, Lindzen, Richard S., James R. Holton, 1968, J. Atmos. Sci., 25, 1095–1107.

    doi: http://dx.doi.org/10.1175/1520-0469(1968)025<1095:ATOTQB>2.0.CO;2.

13. Report of the CEH, UK Met Office 2014, http://www.metoffice.gov.uk/media/pdf/1/2/Recent_Storms_Briefing_Final_SLR_20140211.pdf

14. UK Patent application number GB1403127.2

15. UK Patent application number GB1404039.8

16. http://www.cpc.ncep.noaa.gov/data/indices/qbo.u50.index

17. http://www.cpc.ncep.noaa.gov/data/indices/qbo.u30.index

18. A study of tidal and planetary wave periodicities present in mid-latitude sporadic E layers, Christos Haldoupis1, Dora Pancheva and N. J. Mitchell, Journal of Geophysical Research: Space Physics , Volume 109, Issue A2, February 2004. Abstract at: http://onlinelibrary.wiley.com/doi/10.1029/2003JA010253/abstract

19. Evidence of a role for modulated atmospheric tides in the dependence of sporadic E layers on planetary waves, , Journal of Geophysical Research: Space Physics 2003. Abstract at http://onlinelibrary.wiley.com/doi/10.1029/2002JA009788/abstract

20. Quasi-periodic radar echoes from midlatitude sporadic E and role of the 5-day planetary wave, Geophysical Research Letters, Roland T. Tsunoda, Mamoru Yamamoto, Kiyoshi Igarashi, Klemens Hocke and Shoichiro Fukao, Volume 25, Issue 7, pages, 951–954, 1 April 1998. Abstract at: http://onlinelibrary.wiley.com/doi/10.1029/98GL00663/full

21. The Influence of the Equatorial Quasi-Biennial Oscillation on the Global Circulation at 50 mb, James R. Holton and Hsiu-Chi Tan, J. Atmos. Sci., 37, 2200–2208. Abstract at: http://journals.ametsoc.org/doi/abs/10.1175/1520-0469(1980)037%3C2200:TIOTEQ%3E2.0.CO;2

22. Quasi-biennial modulation of the southern hemisphere stratospheric polar vortex, Mark P. Baldwin and Timothy J. Dunkerton, Geophysical Research Letters, Volume 25, Issue 17, pages 3343–3346, 1 September 1998. Abstract at: http://onlinelibrary.wiley.com/doi/10.1029/98GL02445/full

23. Nonlinearity of the combined warm ENSO and QBO effects on the Northern Hemisphere polar vortex in MAECHAM5 simulations, Natalia Calvo, Marco A.

Giorgetta, Ricardo Garcia-Herrera and Elisa Manzini, Journal of Geophysical Research: Atmospheres, Volume 114, Issue D13, 16 , July 2009. Abstract at: http://onlinelibrary.wiley.com/doi/10.1029/2008JD011445/abstract

24. The solar cycle and the QBO influences on the latitude of storm tracks in the North Atlantic, Brian A. Tinsley, Geophysical Research Letters, Volume 15, Issue 5, pages 409–412, May 1988. Abstract at : http://onlinelibrary.wiley.com/doi/10.1029/GL015i005p00409/abstract?deniedAccessCustomisedMessage=&userIsAuthenticated=false

25. 'Short Period Disturbances in the Equatorial lower Stratosphere, K Sato, F Hasegawa, I Hirota - J. Meteorol. Soc. Jpn, 1994 - www-aos.eps.su-tokyo.ac.jp Full paper at : http://www-aos.eps.s.u-tokyo.ac.jp/~kaoru/CV/PDFs/SatoHasegawaHirotaJMSJ1994.pdf

26. The 16- day planetary wave in the Mesosphere, by NJ Mitchel, DOI: 10.1007/s00585-999-1447-9; Print ISSN: 0992-7689; Online ISSN: 1432-0576; Publisher: Springer-Verlag; Additional Links ... 1. Department of Physics, The University of Wales, Aberystwyth, Ceredigion, SY23 3BZ, UK; 2. Find at: http://link.springer.com/article/10.1007/s00585-999-1447-9#page-1

27. QBO influences on the variability of planetary waves in the equatorial mesopause region, S. Sridharan1, S. Gurubaran1, and R. Rajaram1, Earth Planets Space, 55, 687–696, 2003, Full version at http://www.terrapub.co.jp/journals/EPS/pdf/2003/5511/55110687.pdf?origin=publication_detail

28. Quasi-decadal modulation of the influence of the equatorial quasi-biennial oscillation on the north polar stratospheric temperatures, Journal of Geophysical Research: Atmospheres, Volume 98, Issue D4, pages 7245–7250, 20 April 1993. Abstract at : http://onlinelibrary.wiley.com/doi/10.1029/92JD02930/abstract?deniedAccessCustomisedMessage=&userIsAuthenticated=false

29. Quasi-biennial oscillation influence on long-period planetary waves in the Antarctic upper mesosphere, R. E. Hibbins, M. J. Jarvis and E. A. K. Ford, Journal of Geophysical Research: Atmospheres , Volume 114, Issue D9, 16 May , 2009. Full paper at: http://onlinelibrary.wiley.com/doi/10.1029/2008JD011174/full

30. Modulation of Planetary Wave Propagation by the Tropical QBO, Chen and Whang, 1999. Full paper at: http://cmsr.iap.ac.cn/upload/File/cw/1999-1-QBO-CAP.pdf

31. A Review of 50 MHz Sporadic E in 1996, Issue 53 Six News, May 1997, by Steve Reed, G0AEV, http://www.uksmg.org/content/es96.htm

32. THE INFLUENCE OF THE 11-YEAR SUNSPOT CYCLE ON THE ATMOSPHERIC CIRCULATION DURING WINTER, LIU Yi, LU Chun-Hui, CHINESE JOURNAL OF GEOPHYSICS Vol.53, No.3, 2010, pp: 354~364. Full paper at: http://www.agu.org/wps/ChineseJGeo/53/03/ly.pdf

33. Nastrom, G.D. and Belmont, A.D. (1976). The influence of long - period dynamo region winds on the surface geomagnetic field elements. Journal of Geophysical Research 81. doi: 10.1029/JA081i025p04800. issn: 0148-0227. Abstract at : http://earthref.org/ERR/25806/

34. The solar cycle and the QBO influences on the latitude of storm tracks in the North Atlantic, Brian A. Tinsley, Geophysical Research Letters, Volume 15, Issue 5, pages 409–412, May 1988. Abstract at: http://onlinelibrary.wiley.com/doi/10.1029/GL015i005p00409/abstract

35. Solar forcing of the terrestrial atmosphere , Thierry Dudok de Wit, Jürgen Watermann, C. R. Geoscience xxx (2009) xxx–xxx, External geophysics, climate and environment (Climate). Abstract at: http://lpc2e.cnrs-orleans.fr/~ddwit/soleil/DdW_solar_forcing_CRGeo2009.pdf

36. Solar Variability Influences on Weather and Climate' Possible Connections Through Cosmic Ray Fluxes and Storm Intensification BRIAN A. TINSLEY Center for Space Sciences, University of Texas at Dallas, Richardson, Texas, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 94, NO. D12, PAGES 14,783-14,792, OCTOBER 20, 1989. Full paper at: http://gacc.nifc.gov/sacc/predictive/SOLAR_WEATHER-CLIMATE_STUDIES/GCR%20GEC-Solar%20Variability%20influences%20on%20Weather%20and%20Climate%20GCR%20Tinsley%201989Oct.pdf

37. Cosmic rays and clouds: Potential mechanisms, Jeffrey Pierce, Filed under: Climate modelling Climate Science Sun-earth connections— group @ 26 September 2011 - See more at: http://www.realclimate.org/index.php/archives/2011/09/cosmic-rays-and-clouds-potential-mechanisms/#ITEM-8796-0http://www.realclimate.org/index.php/archives/2011/09/cosmic-rays-and-clouds-potential-mechanisms/#ITEM-8796-0

38. Apparent Tropospheric Response to MeV-GeV Particle Flux Variations' A Connection Via Electrofreezing of Supercooled Water in High-Level Clouds? Brain A Tinsley and Glenn W Deen, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. D12, PAGES 22,283-22,296, DECEMBER 20, 1991. Full paper at: http://gacc.nifc.gov/sacc/predictive/SOLAR_WEATHER-CLIMATE_STUDIES/GEC-Tropospheric%20Response%20to%20MeV-GeV%20Flux%20Variations%20on%20Electrofreezing%20of%20supercooled%20water%20Tinsley%201991.pdf

39. Journal of Atmospheric and Solar-Terrestrial Physics Volume 63, Issue 16, November 2001, Pages 1705–1713 Thunderstorms, lightning and solar activity—Middle Europe http://www.sciencedirect.com/science/article/pii/S1364682601000530

40. Evidence for solar wind modulation of lightning, C J Scott et al 2014 Environ. Res. Lett. 9 055004 doi:10.1088/1748-9326/9/5/055004. Full paper at : http://iopscience.iop.org/1748-9326/9/5/055004/article

41. Wave-associated sporadic neutral layers in the upper atmosphere, B. R. Clemesha, P. P. Batista & D. M. Simonich, Rev. Bras. Geof. vol.15 no.3 São Paulo Nov. 1997. Full paper at : http://www.scielo.br/scielo.php?pid=S0102-261X1997000300003&script=sci_arttext

42. T. Fytterer, C. Arras, and C. Jacobi, Mitteil. Inst. f. Meteorol. Univ. Leipzig. Full paper at: http://www.uni-leipzig.de/~jacobi/docs/Fytterer_2013_LIM_8h-Es.pdf

43. A study of tidal and planetary wave periodicities present in mid-latitude sporadic E layers. Journal of Geophysical Research, 109 (A2). Haldoupis, C., Pancheva, D. and Mitchell, N. J., 2004. Full paper at: http://onlinelibrary.wiley.com/doi/10.1029/2003JA010253/full

44. Evidence for nonlinear coupling of planetary waves and tides in the Antarctic mesopause F. Kamalabadi J. M. Forbes N.M. Makarov and Yu. I. Portnyagin, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 102, NO. D4, PAGES 4437-4446, FEBRUARY 27, 1997. Full paper at : http://onlinelibrary.wiley.com/doi/10.1029/96JD01996/pdf

45. Evidence for planetary wave effects on midlatitude backscatter and sporadic E layer occurrence, Mirela Voiculescu, Christos Haldoupis, Kristian Schlegel, Geophysical Research Letters - GEOPHYS RES LETT 01/1999; 26:1105-1108. DOI:10.1029/1999GL900172. Abstract at : http://www.researchgate.net/publication/252960685_Evidence_for_planetary_wave_effects_on_midlatitude_backscatter_and_sporadic_E_layer_occurrence

46. California weather server, 300mb Jet stream mapping, http://squall.sfsu.edu/crws/jetstream.html

47. An explanation for the seasonal dependence of midlatitude sporadic E layers C. Haldoupis, D. Pancheva, W. Singer, C. Meek, and J. MacDougall, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 112, A06315, doi:10.1029/2007JA012322, 2007. Full paper at : http://onlinelibrary.wiley.com/doi/10.1029/2007JA012322/pdf

48. Diurnal and annual variations of meteor rates at the arctic circle , W. Singer, U. von Zahn, and J. Weiß, Atmos. Chem. Phys., 4, 1355–1363, 200 www.atmos-chem-phys.org/acp/4/1355/SRef-ID: 1680-7324/acp/2004-4-1355, http://www.atmos-chem-phys.net/4/1355/2004/acp-4-1355-2004.pdf

49. E. G. Bowen (1955), 'The Relation between rainfall and meteor showers' Commonwealth Scientific and Industrial Research Organization, Journal of Meteorology, **13,** 142-148. Full paper at : http://www.atmos.washington.edu/~dennis/BowenRainMeteors_1956.pdf

50. On the abundance of metal ions in the lower ionosphere , Ernest Kopp, Journal of Geophysical Research: Space Physics , Volume 102, Issue A5 Pages 9497–9842. Abstract at : http://onlinelibrary.wiley.com/doi/10.1002/jgra.v102.A5/issuetoc

51. Sporadic E as an indicator of wind structure in the lower ionosphere and the influx of meteors, J.W. Wright, Journal of Geophysical Research, Volume 72, Issue 19, pages

4821–4829, 1 October 1967 Abstract at : http://onlinelibrary.wiley.com/doi/10.1029/JZ072i019p04821/abstract;jsessionid=D4705BC17EADE8C8B181407A0788F9F2.f02t04?,deniedAccessCustomisedMessage=&userIsAuthenticated=false

52. Wikipedia List of Meteor Showers: http://en.wikipedia.org/wiki/List_of_meteor_showers

53. Coupling from below as a source of ionospheric variability: a review, E. S. Kazimirovsky, Annals of Geophysics, Vol 45, No 1 (2002), Abstract at: http://www.annalsofgeophysics.eu/index.php/annals/article/viewArticle/3482

54. Thunderstorm effects on sporadic E propagation in 144 MHz by Volker Grassmann (DF5AI), Sabine Cremer (DL1DBC), Udo Langenohl (DK5YA), Allard Munters (PE1NWL), Gabriel Sampol (EA6VQ), Joachim Kraft (DL8HCZ) http://df5ai.net/ArticlesDL/Thunderstorm/ThunderstormEffectsDUBUS.pdf

55. http://sm7gvf.dyndns.org/sm7gvf/sm4gvf/Openings.html

56. Comparison of some volcano infrasounds, Jeffrey Johnson Volcano Acoustics Workshop IAVCEI Kagoshima 2013. Article at: https://vhub.org/resources/2801/download/Johnson_volcano_infrasound_comparisons.pdf

57. Gravity waves and spread Es observed during the solar eclipse of 22 July 2009, Gang Chen, Zhengyu Zhao, Yuannong Zhang, Guobin Yang, Chen Zhou, Shuo Huang, Ting Li, Ning Li andHengqing Sun, Journal of Geophysical Research: Space Physics, Volume 116, Issue A9. Full paper at : http://onlinelibrary.wiley.com/doi/10.1029/2011JA016720/full

58. Sporadic E (Es) as the control for 50 MHz Dx, The Six Ten Report October 1998: http://homepages.force9.net/explore/6and10/articles/50eslink.htm

59. Definition of tropospheric ducting at : http://www.radio-electronics.com/info/propagation/tropospheric/tropospheric-propagation.php

60. DX TV at the height of Sunspot Cycle 22, William F. Kitching at: http://www.g4fbz.net/dxtv/sunspot22/dxtv.htm

61. Influence of cosmic rays on atmospheric-electrical characteristics bottom layers of an atmosphere, U. V. Shamansky and Vladimir A. Kovalenko, SPIE Proceedings | Volume 5027 | Atmospheric Physics (2003). Abstract at : http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=757432

62. Relationship between variations in thunderstorm very-low-frequency radio noise and variations in the solar wind density (1979–1994),V I. Kozlov, R. R. Karimov, V. A. Mullayarov, Find out how to access preview-only content Bulletin of the Russian Academy of Sciences: Physics, July 2007, Volume 71, Issue 7, pp 997-999. Abstract at : http://link.springer.com/article/10.3103%2FS1062873807070313#page-1

63. Variation of cosmic ray flux and global cloud coverage, Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 59, No. 11, pp. 122&1232, 1997. Full paper at : http://kbar.sitecore.dtu.dk/upload/institutter/space/forskning/05_afdelinger/sun-climate/full_text_publications/svensmark_96_variations%20of.pdf

64. Sporadic-E associated with the Leonid meteor shower event of November 1998 over low and equatorial latitudes, H. Chandra, S. Sharma, C. V. Devasia, K. S. V. Subbarao, R. Sridharan, J. H. Sastri, and J. V. S. V. Rao, Annales Geophysicae (2001) 19: 59–69 . Full paper at: http://hal.archives-ouvertes.fr/docs/00/31/67/45/PDF/angeo-19-59-2001.pdf

65. Karami, K., S. Ghader, A. A. Bidokhti, M. Joghataei, A. Neyestani, and A. Mohammadabadi (2012), Planetary and tidal wave-type oscillations in the ionospheric sporadic E layers over Tehran region, J. Geophys. Res., 117, A04313, doi:10.1029/2011JA017466. Full article at : http://onlinelibrary.wiley.com/doi/10.1029/2011JA017466/full