Putting the Meteors back in Meteorology *by Dr Chris Barnes, Bangor Scientific and Educational Consultants, Bangor Wales LL57 2TW E-mail doctor.barnes@yahoo.co.uk*

Author Website http://drchrisbarnes.co.uk

Abstract

The effects of three extra-terrestrial drivers on UK weather and short-term climate are considered namely, meteor showers, solar flux and GCR on the interdecadal climate in the UK. At least in the study period, these are seen to be in control with no evidence of warming. The UK temperature anomaly can be accounted for by a simple algorithm. In the UK in the inter-decadal period 2005-2011 annual rainfall is most strongly correlated with cosmic ray flux. The much higher correlation coefficient for Cosmic Rays is supportive of the notion of a stronger, real physical effect and is also supportive of the work of Svensmark. Alternatively, and/or additionally meteoric debris does provide the nucleation material for rainfall, but cosmic rays provide the correct atmospheric electricity conditions. Annual temperatures over the period can be correlated with a simple linear algorithm (SFCM) involving cosmic ray flux (C), solar flux (SF) and radio meteor flux (M) according to the equation

Delta Temp = -.707 + 2.916* SFCM

Where SFCM = {(SF-C) +M} P<.023 so statistically significant

Having opposite signs in the equation, Cosmic ray flux has a counter effect to solar flux

Key words: Climate, climate change, weather, interdecadal, warming, global warming, cooling, global cooling, temperature, UK temperature, sunshine, rainfall, weather, meteors, cosmic rays, solar flux, sunspot number, radio meteor flux, nucleation, atmospheric electricity, mesosphere, Polar Mesospheric Cloud, Noctilucent Cloud, meteoric debris, meteoric smoke, comet, orbit, lunar, moon, sun, solar, PMC, NLC, stratosphere, atmosphere, troposphere, meteor shower, meteor storm, NO2, NOX, ozone, cloud, clouds, feedback.

1. Introduction and question posed.

In ancient history, the term meteorology literally meant the study of anything that fell from the sky. Meteors from outer space were called "fire meteors". Rain was called "hydrometeors", and frozen precipitation, such as hail and snow was referred to as "ice meteors". The Question posed here is quite simply; do space meteors and other extra-terrestrial sources have significant influence on our weather and climate and if so by how much? There is also recent and substantially growing interest in Space Weather influence on Earth's weather and climate as either a dominant alternative or an emerging and modulating adjunct to anthropogenic climate change.

1.1 Related work

As early as 1956, Bowen **[1]** discussed the relation between meteors and rainfall and he found, at least for the month of January that there was a tendency for more rain to fall on certain calendar dates than on others. There was also a close correspondence between the dates of the rainfall maxima in both hemispheres, and he concluded this was very hard to explain on a climatological basis, but that the effect could have an extra-terrestrial influence. Bowen observed that the rainfall peaks occurred about 30 days after major meteor showers and suggested that this was because of the nucleating effect of meteoritic dust descending into cloud systems in the lower atmosphere, the time difference being accounted for by the material's rate of fall. His hypothesis was tested for a specific meteor shower, namely the Bielids, known to have a 6.5-year period. The rainfall 30 days after this meteor shower was found to have a similar period and the phase of the rainfall periodicity was almost identical to that of the meteor shower.

Whipple and Hawkins (1956) **[2]** further commented on the correlations of both heavy rainfall and of noctilucent clouds with meteor streams. The latter being caused by suspensions of meteoric debris in the upper atmosphere. They further proposed a means for removal depending on the timing of disintegration of micrometeorites under the influence of corpuscular radiation from the sun.

As an alternative to visual meteor observing which does not detect daytime showers or micrometeorites, radio and radar methods of meteor detection are available, Manning (1948)**[3].** Signals are scattered both forward and backwards by meteors, but forward scatter of continuous wave (CW) signals is the preferred method of detection. Radio amateurs have featured heavily in the development of this technology and the same type of system used by Andy Smith G7IZU was also adopted for use at Jodrell Bank Radio telescope http://www.jb.man.ac.uk/meteor/. Unfortunately, VHF TV which was the main source of radio carrier for this type of meteor detection has almost exclusively ceased to operate in Europe since 2011 and so the hunt is on for new sources of suitable radio emission. It is hoped that this paper will be the catalyst for someone somewhere to develop more dedicated sources and detectors. It is known that both meteor rates measured by both scintillation and radio methods show height and number variations according to the solar cycle, see Bumba (1949) [**4**] , Hughes (1974)**[5]** , Lindblad (1976)**[6],** Ellyett (1977)**[7],** Simek and Pecina (2000)**[8],** Lindblad (2003)**[9]** and Dubietis and Arlt (2007)[**10].**

The appearance of summer Northern Hemisphere noctilucent clouds affects meteor decay times, see Singer et al (2008) [**11**]. This is most likely because ablation of meteors at mesospheric E-layer heights 88-110km results in the formation of this phenomenon because of the effect of ice particles on the mesospheric potassium layer, see Raizada et al (2006) [**12**]. Gumbel and Megner (2009)**[13]** have shown that meteoric smoke needs to be electrically charged in order to bring about sufficient mesospheric ice nucleation.

Lifetimes of meteoric material in the mesosphere are not unlimited. It takes about a week for meteoric smoke to interact with stratospheric sulphuric acid at heights as low as 40 km (see Saunders et al 2012)**[14].** Proof that meteoric dust is partly responsible for rain cloud nucleation is found by studying radioactive Beryllium delivery to terrestrial soils; see Graly et al (2011)**[15].**

1.2 Hypothesis

a) It may be expected therefore and a potential hypothesis to be investigated here is that meteors will indeed affect weather and climate either as a barometer of the solar cycle or more directly by albedo and/or atmospheric chemistry effects at mesospheric, stratospheric and tropospheric heights.

b) Since Northern Hemisphere meteor rates are not constant, there ought to be seasonal effects evident as a potential test of aspects of this hypothesis.

Solar association with weather and climate is universally accepted, although at least for some there has been pre-occupation with the effects of anthropogenic drivers.

c)The only other extra-terrestrial and extra-solar system potential driver is Galactic Cosmic Rays or GCR. Svensmark and Christensen (1997)**[16]** have investigated the global cloud cover observed by satellites. They found that the observed variation of 3–4% of the global cloud cover during the recent solar cycle was strongly correlated with the cosmic ray flux. This, in turn, is inversely correlated with the solar activity. The effect is larger at higher latitudes in agreement with the shielding effect of the Earth's magnetic field on high-energy charged particles. The observed systematic variation in cloud cover was proposed to have a significant effect on the incoming solar radiation and may, therefore, provide a possible explanation of the tropospheric and stratospheric 10–12-year oscillations. They stated that the relation between cosmic ray flux and cloud cover ought to also be of importance in an explanation of the correlation between solar cycle length and global temperature.

The work of Svensmark is both controversial and topical as it has since led to the Cosmoclimatology theory of climate change in 2007. Following much criticism from the CO2 climate warming lobby, Svensmark, Pepke and Pedersen published again in 2013 in Physics Letters A **[17]** and showed, that there is in fact a correlation between cosmic rays and the formation of aerosols and clouds. According to the study, solar activity is responsible for circa 50 percent of temperature variation. Had Svensmark been endeared with the knowledge of Magnetic Pole movement and EEP change, highlighted by the present author, see Barnes (2025) **[18,19]** possible his theories would have been more successful and universally accepted.

1.3 Rationale for making study

Thus, the present study presented below is topical, timely and novel as it examines in detail correlation both annual and seasonal variation of weather and climate anomaly in the UK in terms of simple and complex functionality against all three above possible drivers. The present author has recently showed magnetic pole shift to be the predominant climate driver since 1958 **[19]** and possibly much earlier **[18]** and the same publications show CO2 to be a very minimal driver right now. Pole shifts of course alters the way in which energetic particles such as those caused by solar events and comic rays interact with the upper atmosphere and hence impinge on weather and climate **[18,19]**.

1.4 Rationale for date range of study.

The date range encompasses an inter-cycle period, solar cycle 23/24. The date range is after the 1990's when Pole shift was only just starting to accelerate.

2. Experimental

2.1 Data Sets

The data sets used have been obtained as follows:

1. UK weather data sets; temperature, rainfall and sunshine anomaly have been obtained from the UK Met Office website at http://www.metoffice.gov.uk/climate/uk/anomalygraphs/
2. Cosmic Ray data has been obtained from the University of Oulu at http://cosmicrays.oulu.fi/
3. The radio meteor data was taken from the Colorgramme at http://www.tvcomm.co.uk/radio/ The data from sets 1 and 2 were used without further processing. The data from source 3 was processed according to a colour/area to number estimation algorithm wherein black=0, blue =2, green =4, yellow =6, orange =8 and red =10, unfortunately, the site has changed, and the old data is no longer available.

2.2 Experimental Part 1: Annual Correlations

Data set 1 provides monthly anomaly data compared with three possible long term average data sets (LTAS). Data set 3 only provides data for the years 2005-2011 inclusive so this limits the study. The monthly data for each of these years for rainfall, temperature and sunshine has been totalised and averaged by the present author. Correlations are sought with weather feature each potential climate driver in turn. Where applicable more complex correlation algorithms have also been sought employing more than one driver.

2.3 Testing the theory that meteor rates are influenced by the solar cycle.

The radio meteor data treated accordingly as described above was plotted against sunspot number for the years 2005-2011. A near sinusoidal relationship is seen as plotted in Figure 1 below. The date range had to end at 2011 because this is the date European VHF TV, formerly used by amateur astronomers and meteorologists for detecting meteor pings (radio echoes caused by ionised meteor trails), was switched off. At the time of writing this present draft of this paper in 2025, the author has now discovered another source of VHF emissions which can be used for radio meteor studies, this is to be found on a frequency of 143.048500 MHz VHF and is the GRAVES Radar located in France. For any parties interested in trying to reproduce this type of work there is a lot of information at https://www.rmob.org/.

In the first part of present study, the theory that meteor rates are influenced by the solar cycle was tested by plotting the value of the annual meteor flux, y -axis against smoothed annual sunspot number for each year of the study. Figure 1 shows the plot as a sinusoidal fit.

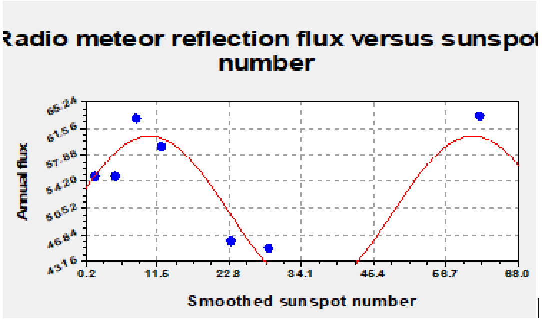


Figure 1.

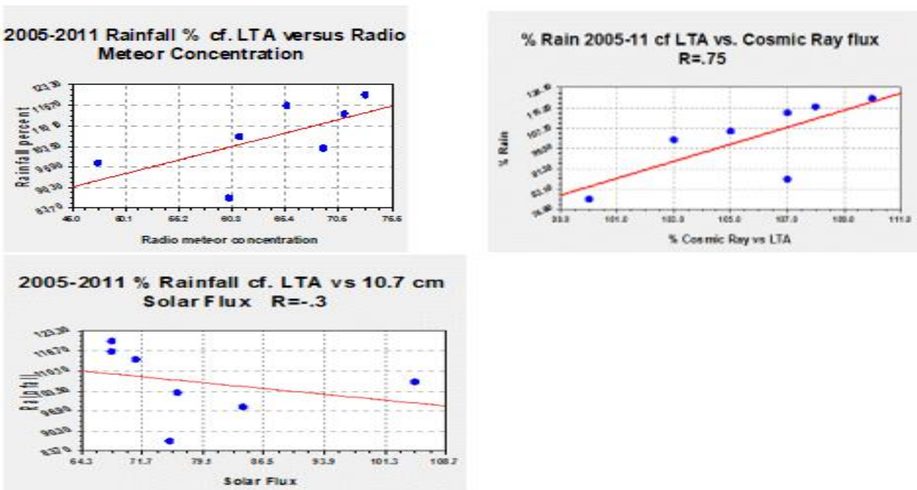
Figure 1: Annual meteor flux, y -axis against smoothed annual sunspot number x-axis for each year of the study.

3. Results and Discussion

The results for annual rainfall correlations are shown and discussed initially.

3.1 Annual Rainfall Correlations

Annual rainfall has been correlated singly and separately with the three known possible extra-terrestrial drivers, see figure 2 below.



R= .64

Figure 2

At least in the UK in the period including the years 2005-2011 inclusive, annual rainfall would appear to most strongly correlate with Cosmic Ray Flux, although clearly there is some effect of meteors and to an even lesser extent the solar cycle. One data point appears to be anomalous in that it is by far and above the largest residual in all three linear correlations. That is the point associated with the year 2010, which had only an aggregate 87 % of LTA rainfall. Interestingly March to October 2010 saw several eruptions of the Icelandic volcano Eyjafjallajökull. Other volcanic eruptions for example that of Mount Pinatubo are known to have had a dramatic effect on the immediate hydrological cycle in both time and space, see for example, Trenberth and Dai (2007) [20]. Fischer et al 2007 [21] have studied tropical volcanic eruptions over the last half millennium, and even these are shown to produce somewhat drier conditions over Europe for up to 2 years after each eruption. It is logical to suppose therefore that 2010 in the UK may be an anomalous dry year because of Eyjafjallajökull particularly as it was predominantly under a South Easterly Jetstream, see Gudmundsson et al (2010) [22]. and given it was an explosive-mixed eruption of unusually long duration, see Gudmundsson et al (2011)[23].

Following the above if one removes 2010 from the data set and re-examines the correlations, significant changes occur, see Figure 3 below.

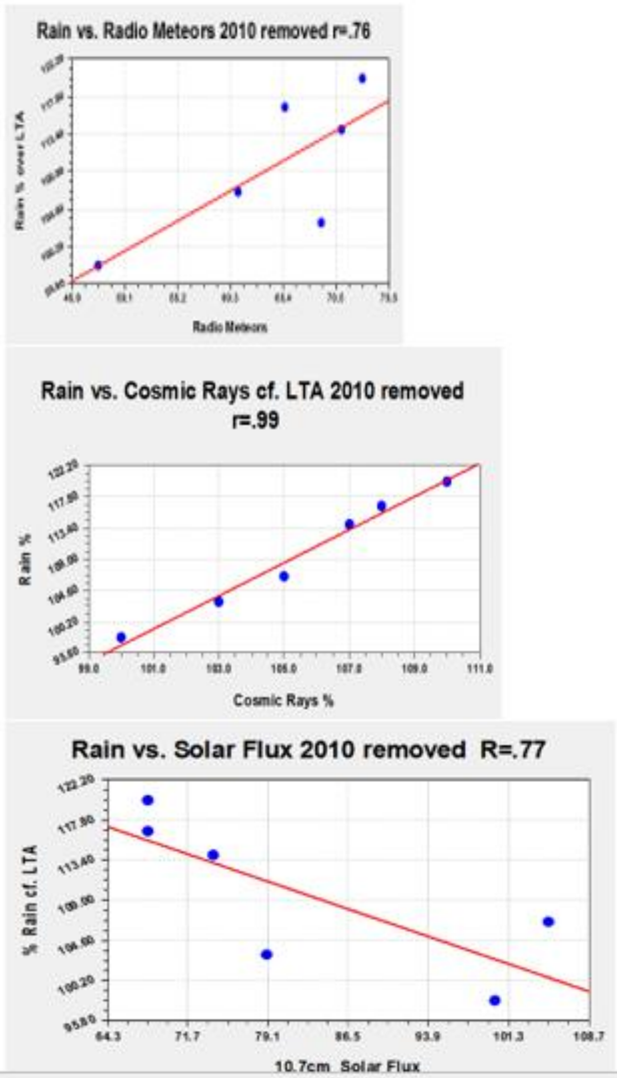


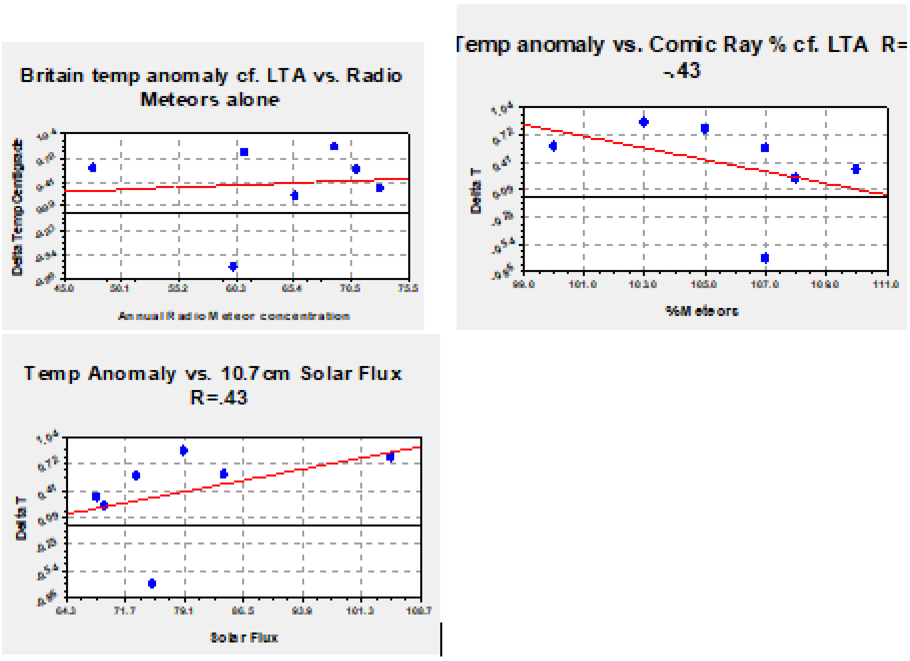
Figure 3

Although the result for cosmic rays gives by far the best correlation coefficient, the reality is possibly that all three extra-terrestrial phenomena have a concerted interplay which gives rise to rainfall as we know it. Using 130 years' worth of data Hiremath (2006)[24] has reached a similar conclusion regarding rainfall over India. It is further interesting to note that Hiremath (2006)[24] noted that his correlations were disturbed by intermittent volcanic eruptions. By value of correlation coefficient and behaviours of the residuals alone, it is feasible that the behaviour of radio meteors is on an annual basis acting merely as a mirror of solar activity, as outlined above.

3.2 Temperature corelations

Temperatures were treated in similar manner to rainfall by using three separate correlations.

The results for the annual temperature correlations are shown in Figure 4 below:



R =0.09

Figure 4

The regression coefficient for temperature versus radio meteors alone is particularly low, possibly indicating there are competing processes at work. The temperature anomalies versus Cosmic Ray and Solar Flux regressions have similar coefficients with a negative coefficient of temperature against % comic ray compared with LTA and a positive slope for Solar Flux. These data suggest that either the Sun controls climate directly or indirectly by deflecting cosmic rays at periods of high solar activity as would be in line with the theory of Svensmark. At least for the UK and taken with the rainfall result there is very strong support for Svensmark. Close inspection of the data also tends to suggest that 2010 was the coldest year in the data set and the Icelandic volcano Eyjafjallajökull could be to blame.

Since the cosmic ray and solar flux regressions are of opposite slope but with a subtly different 'non opposite' pattern with regard to residuals, it was decided to try and create a combine algorithm by simple normalisation and subtraction. Furthermore, since meteor showers are a Northern Hemisphere seasonal phenomenon known to be associated with the formation of noctilucent or Polar Mesospheric Cloud also a barometer of the solar cycle but with a surprising teleconnection to the Winter Stratosphere, see Karlsson et al (2009)[25] so perhaps relevant to LTA temperatures. There are many references to Noctilucent clouds as a barometer of climate change but since they are effectively mainly seeded by meteoric material, thus an attempt was made at a combined parameter linear algorithm which turned out to be surprisingly simple and to produce striking results, see Figure 5 below:

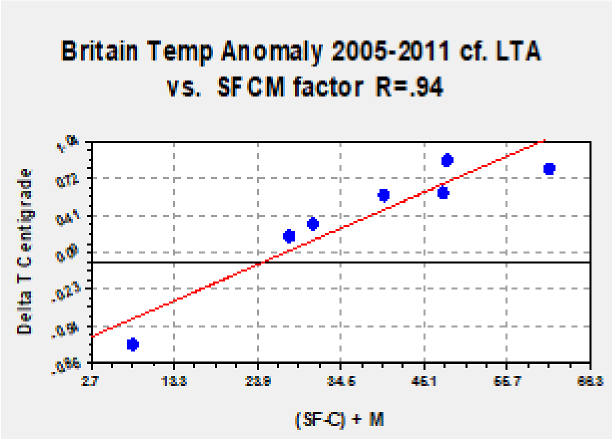


Figure 5

The algorithm used to fit the data in Figure 5 is very simple, see equation (1).

Delta Temp = -.707 + 2.916* SFCM ……………………………………………………………….(1)

Where SFCM = {(SF-C) +M}

Whereas the data due to 2010 remains one of the largest residuals it is perhaps somewhat surprisingly closer to the regression line than expected. Presumably this is due to the above teleconnection phenomenon and the way in which volcanic emissions interact with the stratosphere.

The conclusion is that at least for British Temperature anomaly over the short period from 2005-2011 a simple algorithm including just solar flux and extra-terrestrial sources of meteor and GCR flux appears to adequately be able to account for the observed changes.

3.3 Sunshine

Linearly correlations of the LTA sunshine anomaly data for the period were also explored with the three potential drivers, see Figure 6.

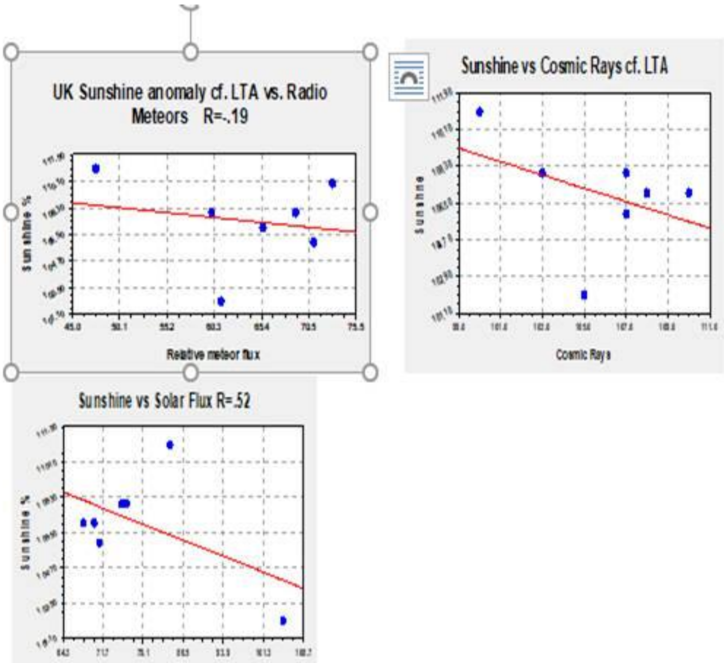


Figure 6 : Sunshine % versus the three extra-terrestrial drivers.

The regression factors for Radio Meteors and for Cosmic Rays improve substantially to R= .40 and .44 without 2010. The data were all also explored for higher order, polynomial fits. Only solar flux produced an improved

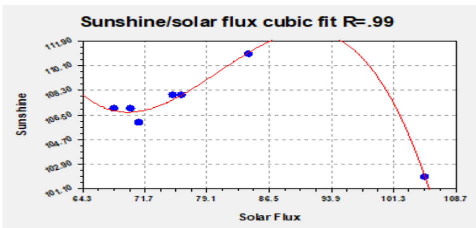


Figure 7

regression, figure 7.

Figure 7: Sunshine hours versus solar flux cubic plot.

Linear correlation regressions against all three parameters are not surprisingly poor. The maximum regression coefficient was 0.52 for Solar Flux with Cosmic Ray Flux and radio meteor flux lagging at 0.44 and 0.40 respectively. The regressions were all anti-correlated with sunshine.

For sunshine to be maximised there would need to be a lack of both high and low cloud and aerosol and as all three will have different seasonal behaviours in the UK and the Northern Hemisphere in general it is not surprising therefore that a single good linear correlation against any of the controlling potential extra-terrestrial factors does not follow in an annual versus LTA analysis. Ezekwe et al (1981)[26] has examined the seasonal variation of dust haze and sunshine and solar irradiance in Nigeria, for example. Sears et al (1981)[27] has found that sunshine can be predicted monthly for Davis, California with regression coefficients from .81 -.91. However, here an excellent correlation between sunshine and solar flux can be obtained by using a cubic fit giving a regression coefficient of .99. Cleary other factors are simultaneously driving cloud albedo changes to give this more complex relationship.

E. Pallé* and C.J. Butler (2001)[28] have emphasised the cosmic ray link to sunshine in the obvious way it is anti-correlated with cloudiness in the period 1984 and 1991 but it was found the correlation did not hold good in the period 1991–1994.

A significant Volcanic Eruption happened in 1990 in Redoubt, Alaska, see Casadevall (1994)[29] and in June 1991 Mount Pinatubo erupted, see Bluth and Doirin (1992) [30] whose measurements indicated that Mount Pinatubo has produced a much larger and perhaps longer-lasting SO2 cloud and climatic implications than those El Chichón. There has of course been an Icelandic volcanic eruption in 2010 during the period of this short-term study, and one would expect this to have influenced the form of the above fit.

3.4 Experimental Results : Monthly and Seasonal Effects

It was instructive to examine the monthly radio meteor distribution for each year in the study. Fourth order polynomial regressions were found to produce the best fits to the numerical data and have been shown for each year in the study and as an average, see Figure 8, below.

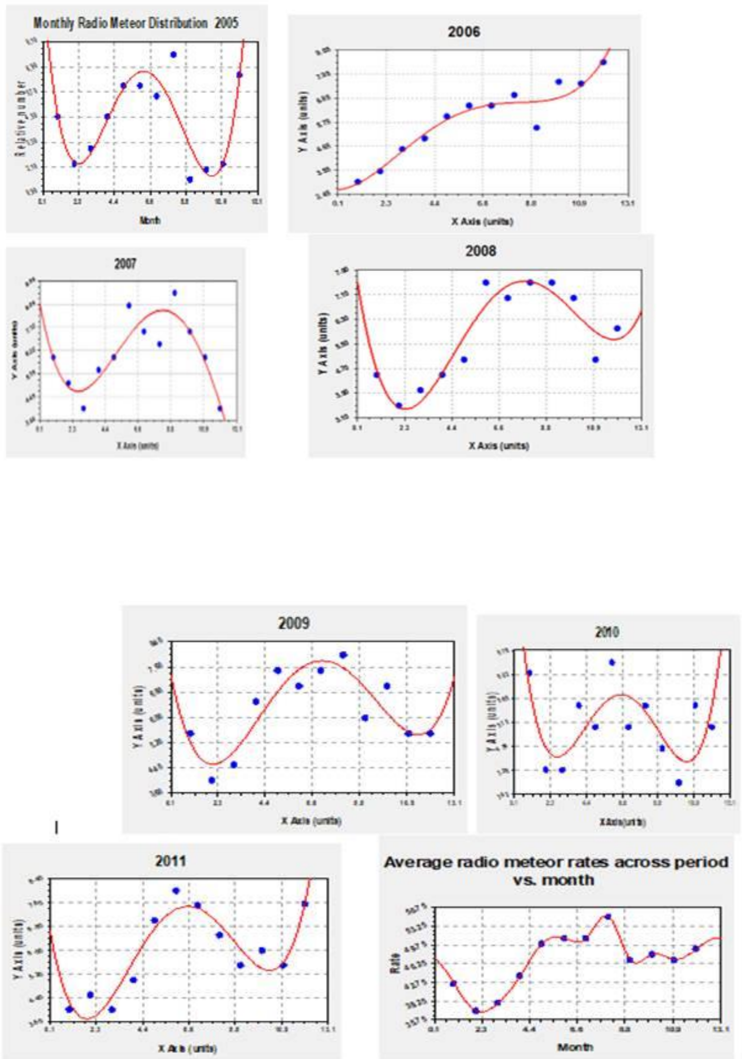


Figure 8

Figure 8: Average radio meteor rates for each year of the study.

Ellyett &Keay (1963) [31] were perhaps the first to conclude that meteor rates were greater during a 6-monthly period of each year. This conclusion is also approximately borne out by the present study but it should be noted that this is a 'sliding' period. . Meteor distribution has also been shown to vary with the lunar cycle, see Szalay et al (2015) [32] as well as the solar cycle and this to some extent may account for the shifting of the spring and autumn troughs as seen above.

3.5 Investigation into meteors and month by month sunshine for years of study 2005-2011

It has been shown above that sunshine is either uncorrelated or very weakly negatively correlated with meteor rate on an annual basis. However, since most meteors arrive in an approximately 6-month window and since the above distributions are rather non uniform it was decided to make a month-by-month investigation. Furthermore, as meteoric debris diffuses from the mesosphere into the stratosphere and troposphere it may, conceivably, have very different effects. To test this meteor rates were correlated against sunshine for both the month of entry based on radio detection and the subsequent month to allow for atmospheric diffusion. The results are only presented graphically for months in which there was any reasonable correlation, see Figure 9.

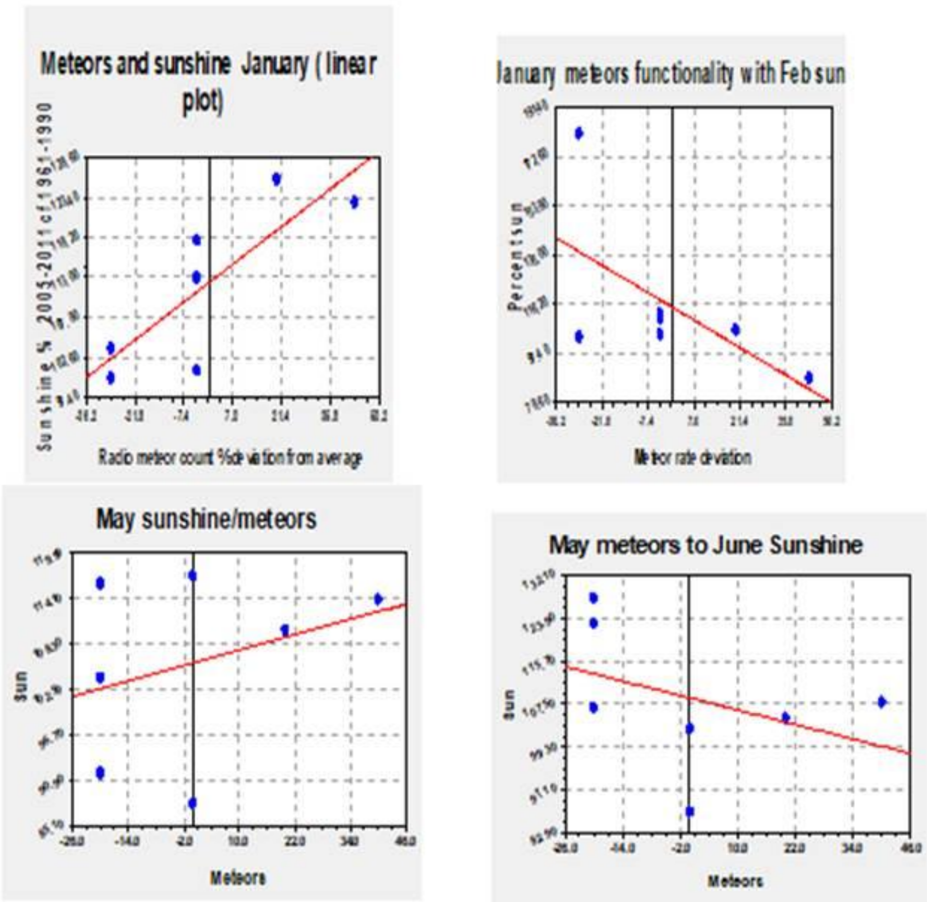


Figure 9

The January regression factor is strong .76 and positive. The May /June regression factors are of the order of .44. To a lesser extent October showed a positive correlation with sunshine and meteor rates whereas the month of November showed a negative correlation when its sunshine was plotted against October's meteor rates. As early as 1957 Bowen studied meteor rates and found a relationship with 30-31 days delay between significant meteor showers and enhanced rainfall. A negative correlation with sunshine is tantamount to increased cloudiness and possibly the advent of rainfall. Perhaps somewhat counter intuitively the present data set strongest effects seem to be when meteor rates are close to troughs on the above distribution curves rather than peaks. Presumably at the peak there is so much meteoric material that a saturation effect regarding rain nucleation may take place.

3.6 Investigation into meteors and the QBO (30 mb Equatorial Zonal Wind Index): January to July

Data is shown below, figure 10.

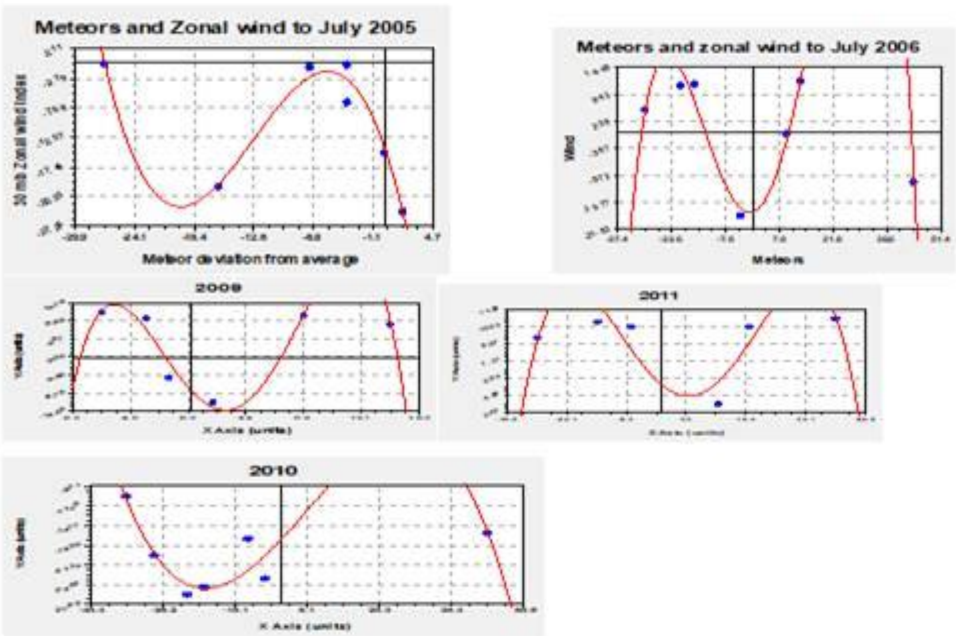


Figure 10

It is evident that when the zonal wind index changes sign and amplitude in a roughly symmetric manner and in either direction in the period January to July, for example 2006 and 2009, maximum positive values of QBO correspond with roughly symmetric maximum positive or negative deviations in meteor rate whereas negative values of QBO correspond with close to average meteor rates. On the other hand, when the QBO remains wholly negative, for example 2005 meteor rates are also mainly less than average.

The exception is 2010 which has a wholly negative QBO but with very large apparent deviations in radio meteor rate. Of course, 2010 coincided with the Eyjafjallajökull eruption. Ellyett (1977) [33] has commented on the *possibility* that an apparent meteor density gradient change in 1963 may have been due to volcanic dust. Indeed, there were several very relevant volcanic eruptions in 1962 and 1963 including those of Tokati, Hokkaido, Japan, June 1962, Kilauea volcano December 1962. It is thus possibly ***this*** same sort of phenomena which distorts the radio meteor rates in the 2010 plot above.

Radio Meteor rates measured in the UK only seemed to have a very strong correlation with the zonal wind (QBO) between the months of January and July. Statistically the zonal winds seem to change most in sign and magnitude round about July. The QBO has been shown to influence Atlantic Storminess and Jet Stream tracks so on that basis it was decided to reinvestigate the monthly effect of meteors on rainfall.

3.7 Monthly rainfall effects.

It has been suggested in the past that meteors are highly correlated with rainfall, particularly regarding a 31 day delay after major showers (refs). The same data sets referred to above have been employed. Direct month to month linear correlations have been examined as have correlations between radio meteor rates in an initial month, followed by the subsequent month's rainfall anomaly compared to the LTA.

The results have only been indicated herein below for the cases in which there was any reasonable correlation.

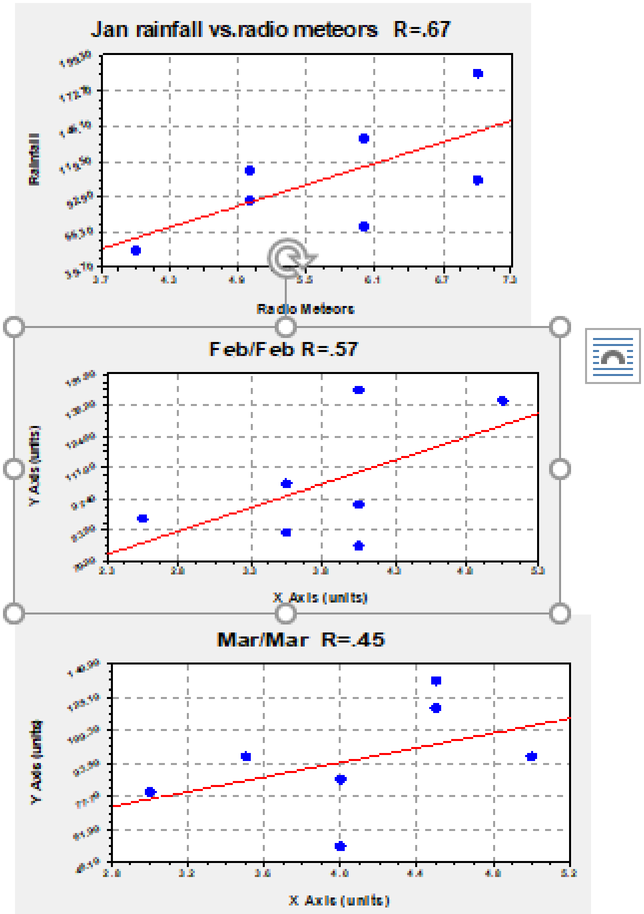


Figure 11

For the first three months, figure 11, there is a positive and diminishing linear correlation of rainfall with radio meteor concentration. One possible conclusion is that at least some of the meteoric material' residence time may be considerably less than 31 days in the winter and early spring. This is borne out in that no sensible correlations were observed for January's meteor input predicting February's rainfall or for February's meteors as a possible predictor of March rainfall. It is interesting to note that **these positive slope correlations all only take place when the time averaged meteor input rate is falling, see Figure 8.**

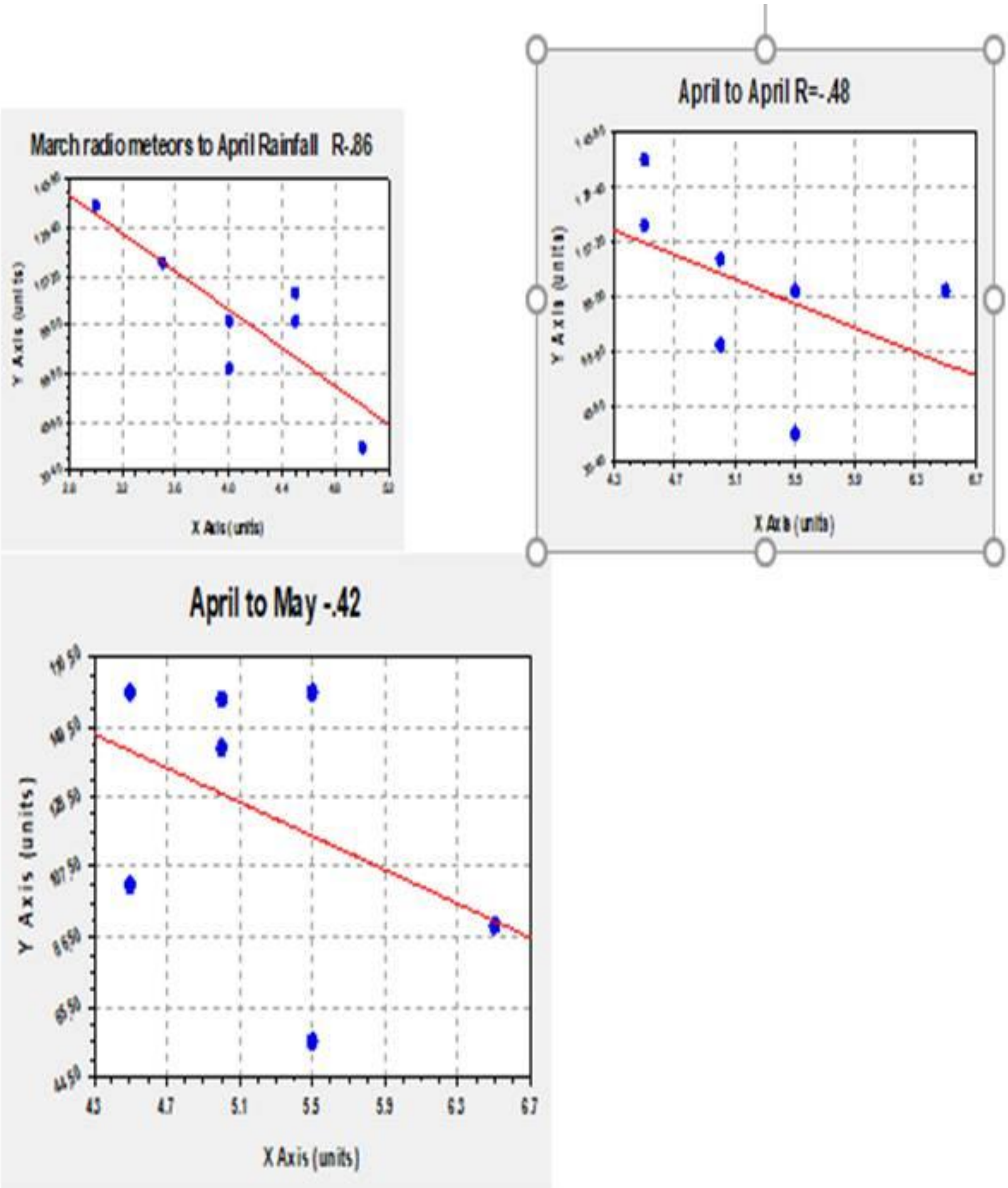


Figure 12

Also, March meteor input predicts an anti-correlation for April rainfall as meteor input starts to rise again. The anticorrelation even on a month-to-month basis continues as the meteor input rate rises until it levels out in May, see Figure 8. This is strongly indicative of two competing processes involving meteor input and output rates to different parts of the atmosphere. Since meteoric material must diffuse from the mesosphere to lower levels of the atmosphere to be effective in combination with galactic cosmic ray flux in cloud seeding processes then it is evident there is a competing process, at least in springtime, either in the mesosphere or at least higher in the stratosphere which either prevents cloud seeding or scavenges moisture. Such processes have been noted for the effects of aircraft contrails, for example. From May to July the regression factors fall to the point where they are insignificant. It is concluded therefore that at least in the UK and in these months, meteors do not control rainfall. These are the months when mainly noctilucent of PMCS (Polar Mesospheric Cloud) is observed. A typical PMC season begins approximately 20 days before summer solstice at 80° latitude, rises rapidly in occurrence frequency to 80–90%, and remains at that level until 50–60 days after solstice. Both occurrence frequency and brightness are latitude dependent, with higher values observed toward the poles. PMCs are normally observed at altitudes of 82–83 km, with higher altitudes at the start and end of each season, see DeLand et al (2006)[34]. It may be that meteoric input is tied up with these and that they either limit release of nucleating material to lower altitudes and/or change the chemistry and/or electrical properties of the atmosphere in a way in which meteors are no longer able to contribute to rainfall. This idea is strongly supported by the proposal of Bellan (2008) [35] who propose noctilucent clouds to be composed of tiny cold electrically charged ice grains located at about 85 km altitude, exhibit anomalously high radar reflectivity. They show that this observed high radar reflectivity is explained by assuming the ice grains are coated by a thin metal film because substantial evidence exists indicating that such a film exists and is caused by the deposition of iron and sodium atoms on the ice grain from iron and sodium layers located immediately above the noctilucent cloud layer. The number of conduction electrons in the thin metal film coating an ice grain is very large. When averaged over the volume occupied by many ice grains, the quivering of these metal film electrons provides a much larger contribution to radar reflectivity than does the much smaller number of dusty plasma electrons or electron holes. Using observations indicating that noctilucent clouds are the dominant sink for the summer-time iron and sodium layers, it is shown that a sufficiently thick metal layer should form on a typical ice grain in a few hours to a few days. Sodium and iron are of course components of meteoric material and hence this shows how NLCS could retain such metallic material and delay its diffusion to lower heights in the atmosphere. There is a very slight fall in radio meteor rates on average from July to August reflected in increased rainfall consistent with the hypothesis developed above, see Figure 13.

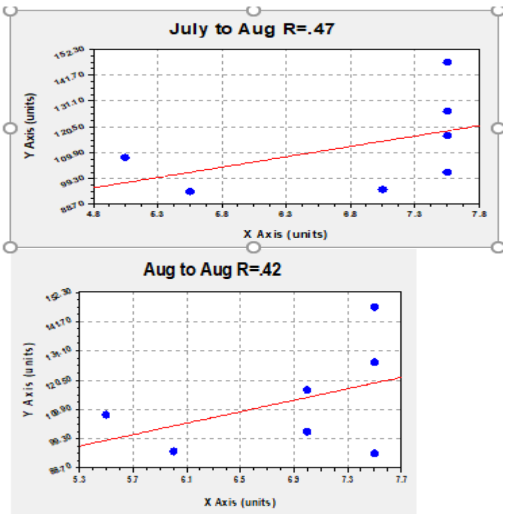


Figure 13

This is followed by an abrupt rise taking in August to September and presumably including the prolific and reliable August Perseids. This would seem to give rise to a fall in September rainfall, again consistent with the hypothesis developed above, see Figure 14 below.

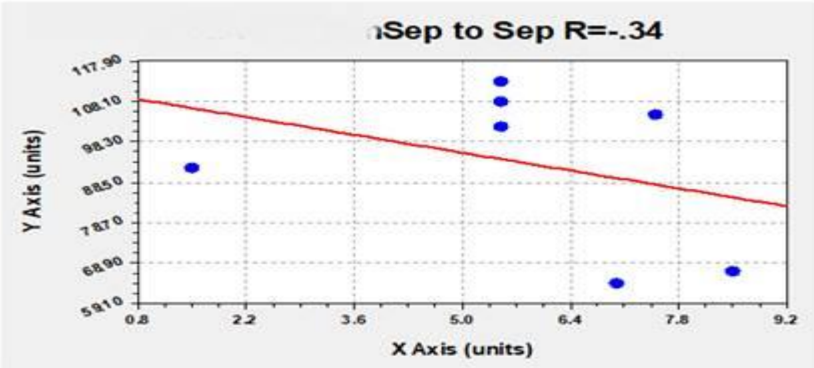


Figure 14

In October and November, the correlations appear to weaken consistent with the time averaged flattening of meteor rates again, see Figure 8.

However, in November to December, meteor rates seem to rise yet this time the rise producing increased rather than decreased rainfall, see Figure 15. **(check if anything in refs)**

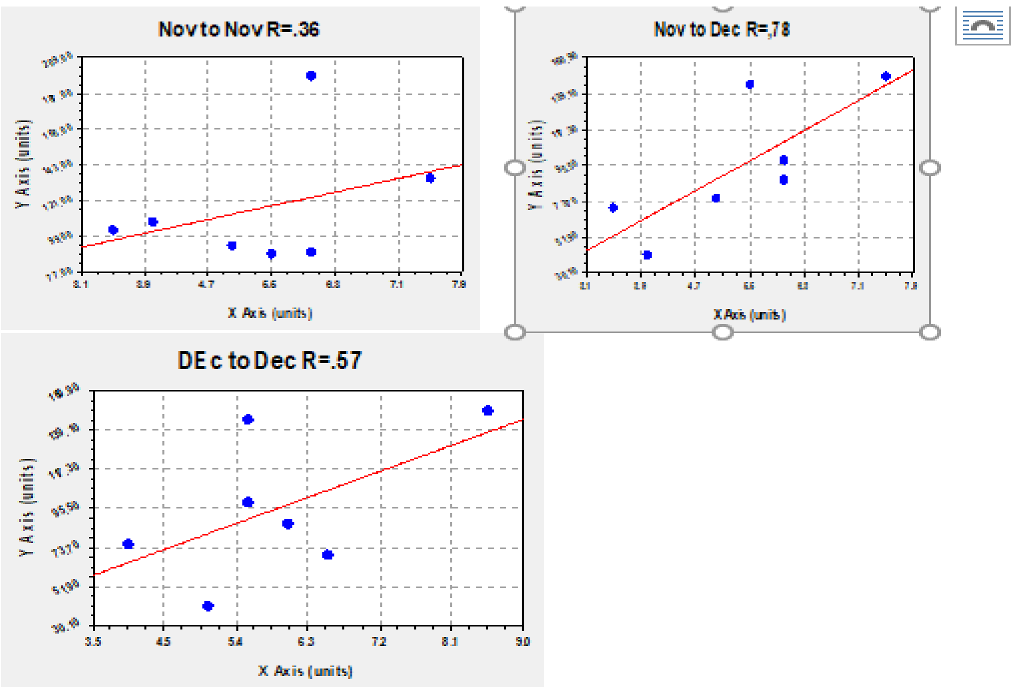
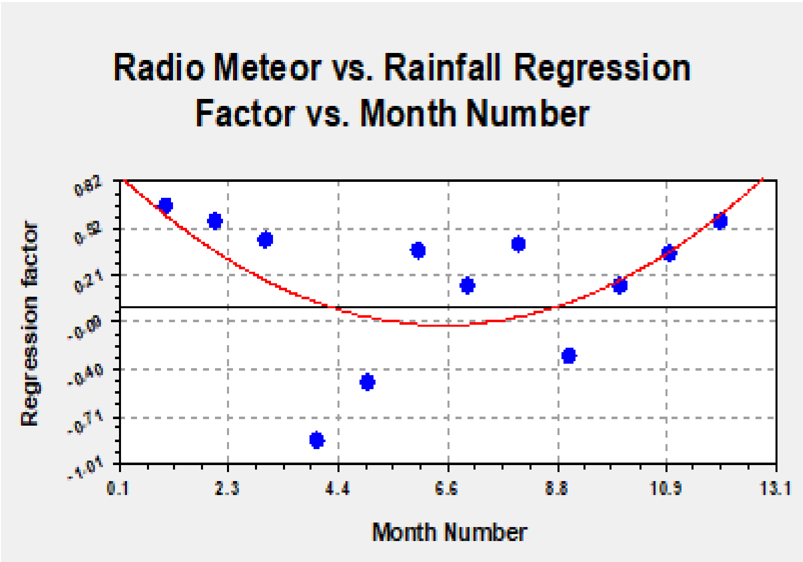


Figure 15

The improved month on month (November to December) correlation could also be significant as it would seem to suggest that meteoric material injected into the mesosphere in wintertime have a longer residency than those injected in springtime. Hervig et al (2017)[36] have suggested that extinction increase is due to H2SO4 condensing above the nominal stratospheric aerosol layer (~5 hPa).



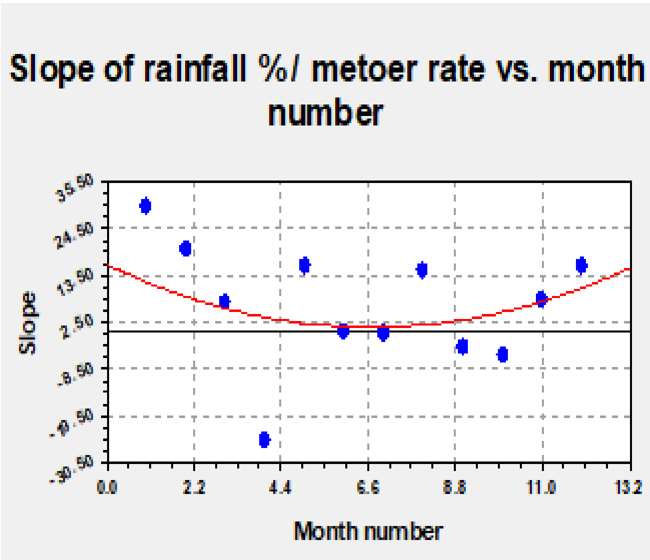


Figure 16

The slope of the rainfall anomaly percentages divided by meteor rates versus month number can be best fitted to a quadratic equation which shows some symmetry around the summer solstice. It is further very instructive to plot the slope of rainfall in every subsequent month divided by the prior month's meteor rate which shows a sensible and finite regression coefficient. When this is done a skewed distribution is seen in favour of the late autumn months. This seems to confirm that meteoric material entering the mesosphere at this time of year takes longer to diffuse down through to the stratosphere and troposphere, see Figure 17.

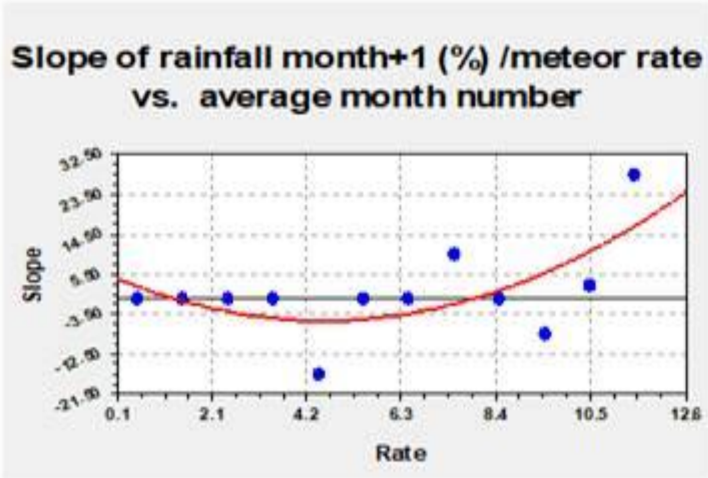


Figure 17

3.8 Monthly temperature Effects

In much the same way as rainfall effects can be studied, so can temperature.

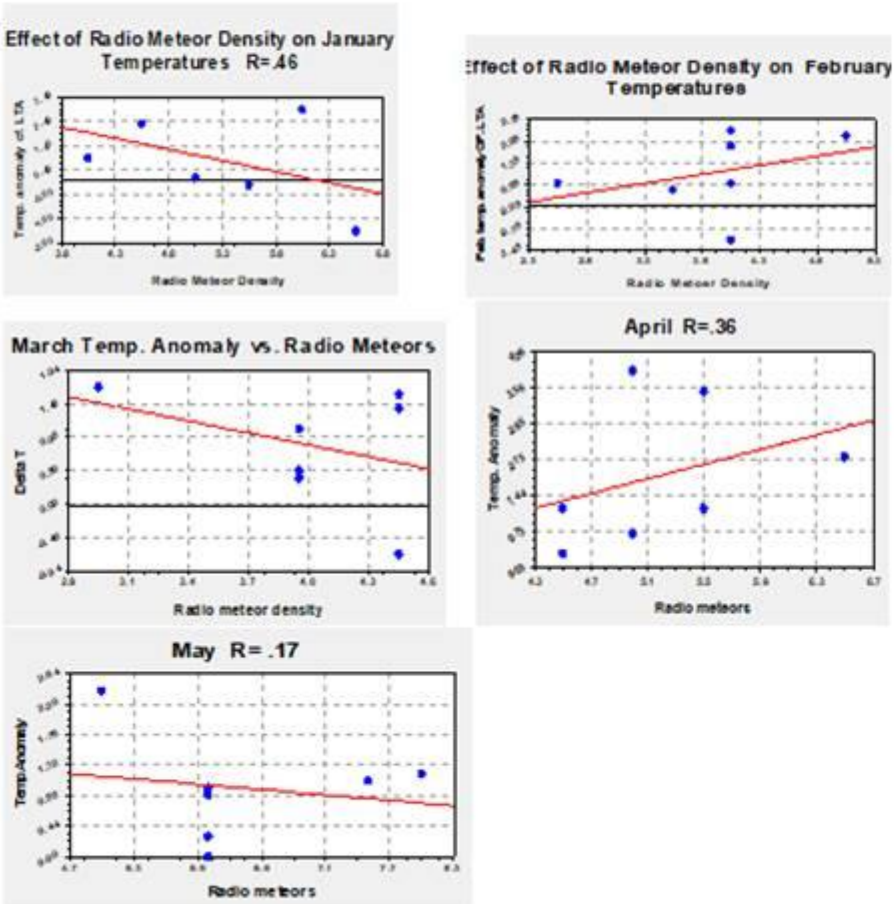


Figure 18

Very interestingly and almost intriguingly, figure 18 shows that from January to May the slope of the regression alternates monthly from negative to positive. Meteor rates are known to be correlated with the lunar cycle so possibly this is the connection here and such a connection might be the origin of the old-fashioned weather lore statement ‘change in the month, change in the weather’. The regression factors are, however, not that strong, varying between .17 and .46. This is followed by two months, namely, June and July where the coefficient of temperature with meteor rate is negative and indeed in June is strongly negative and highly correlated, see Figure 19. Clearly more meteors and a faster descent rate means more rainfall, hence more cloud and lower temperatures.

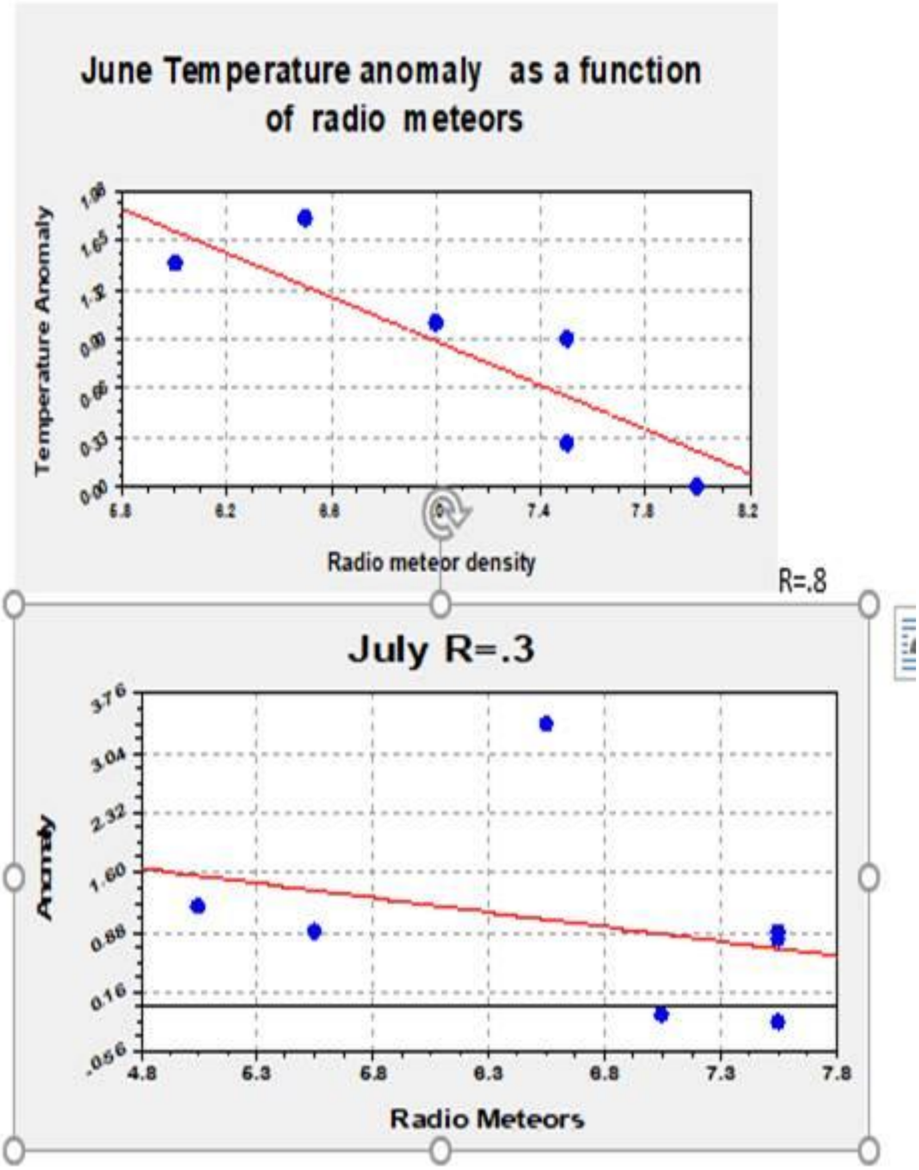


Figure 19

The oscillating trend then commences again with the exception of December which still has a positive coefficient, see Figure 20.

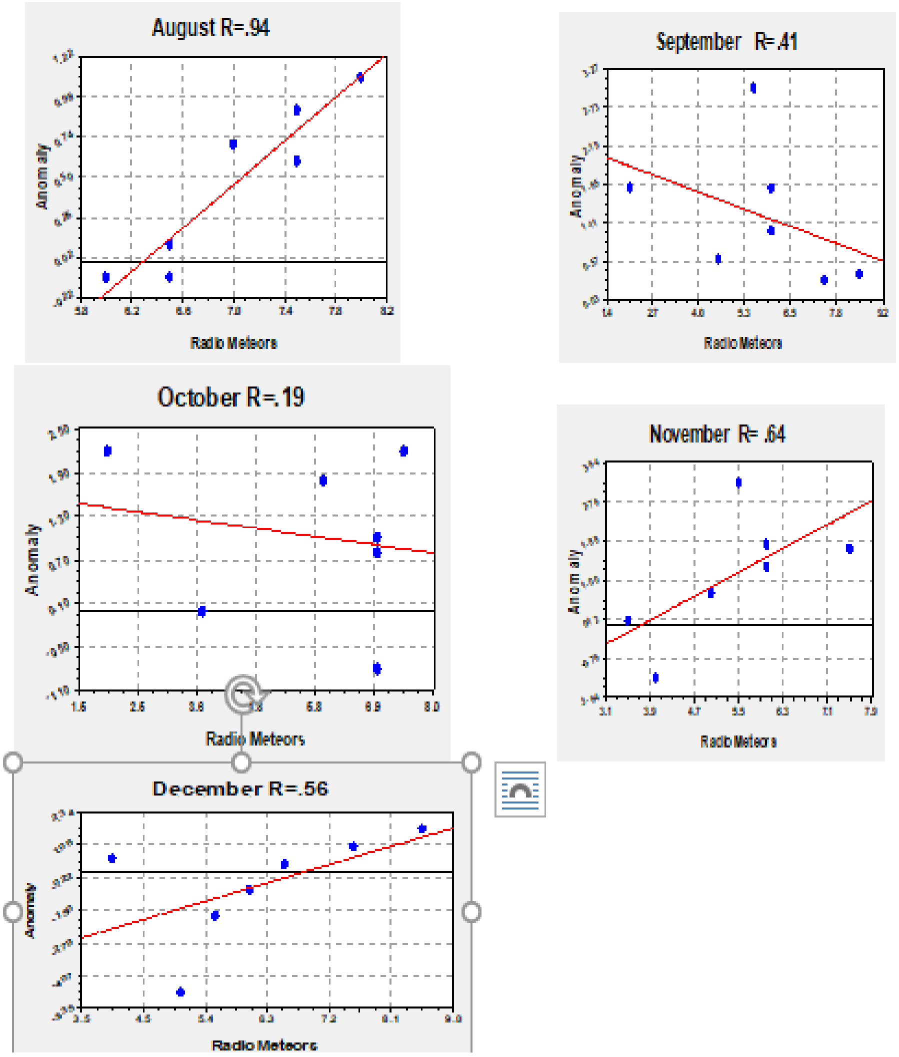


Figure 20

It is instructive to compare the overall slope of the meteor temperature effect plotted against month number with the average meteor rate across the entire period per month. Both sets of data fit well to a fourth order polynomial.

The meteor temperature function can best be described by comparison as being by visual inspection related to the meteor rate by 'corner to corner mirror inversion', see Figure 21

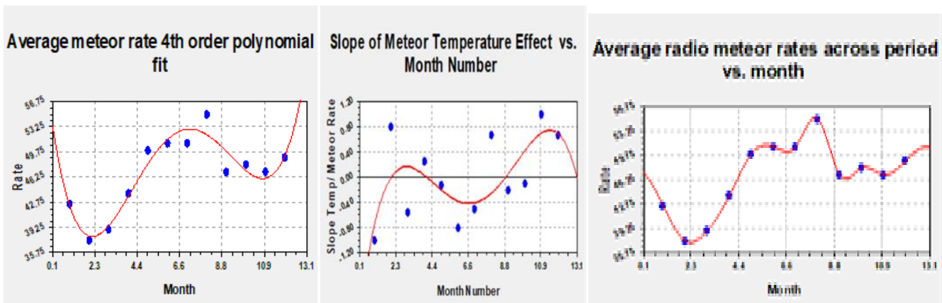


Figure 21

Of relevance is that the fourth order polynomial fits of the meteor rate and temperature slopes are mirrored. Moreover, in the temperature plot the positive and negative areas under the curve tend to cancel each other out. This is suggestive that **at least in the UK and for the short inter-decadal period considered there is no significant climate warming.** The approximate midsummer period wherein cooling appears proportionate with meteor input coincides with the summer formation of Polar Mesospheric Cloud (noctilucent cloud) and the peak of the radio Sporadic E propagation season.

This raises the prospect of an intriguing and exciting climate negative feedback system which could be protecting our planet. Whether it is the PMCS themselves are that feedback system or merely spectators or Harbingers of it, this is open to question. PMCS have been reported more at mid-latitudes of late and with more brightness. The theory is that their water component increases as methane pollution becomes oxidised (see DeLand et al 2003) [37] and can also trap lofted particulate sulphate pollution. The meteor theory suggests PMCS, or some related process cools the planet in June/July. So presumably if we have more PMCS we have more cooling. Volcanic eruptions are a source of natural sulphate discussed by Mills and Toon (2005)[38]. They found that the record of the number of NLC sightings in response to large volcanic eruptions is inconsistent. However, injections of water vapor and particles may result in positive, negative or neutral response in the visual brightness of NLC, depending on the magnitude of sulphur, water vapor, and particulate injections. They also calculated that variation in rates of meteoric debris should make no more than 8% difference to the total numbers of PMCS. McKay and Thomas (1982) discuss formation of NLCS by a large stellar impact and the dramatic climate cooling which would follow. Thomas (1996)[39] has discussed NLC/PMCS in terms of a 'miner's canary for global change', wherein reduced levels of CO2 and CH4 are found to confine the model NLC existence region to within the perpetually sunlit polar cap region, where the clouds would no longer be visible to a ground observer. A doubling of CO2 and CH4 could extend the NLC region to mid-latitudes, where they would be observable by a large fraction of the world's population. Thomas (1995) was one of the first to document that both solar and secular changes effect PMCS. PMCS scatter solar light at the poles 100% of the time in the PMCS season detectable by satellite and appear to be more dominant and about 1km lower in height in the Northern Hemisphere than the Southern hemisphere, see Perot et al (2010)[40]. Short period Acoustic Gravity Waves (AGWS) can be detected in PMCS, see Chandran et al (2012)[41]. Increased aviation and increased use of power systems and renewable energy (wind farms) are all sources of anthropogenic AGWS which may also, conceivably, impact on PMCS in as yet unforeseen ways. PMCS may correlate the QBO . Wave forcing of the QBO is certainly thought to come from gravity waves and it is essential to fit these in climate simulation models to produce a QBO, see Mengle et al (1995) [42] and Scaife et al (2000)[43]. Brighter cloud tops can cool the climate by increased albedo effects. The appearance of PMSC is known to occur on average about 20 days before summer solstice and to extend to about 40-60 days thereafter. This is roughly the same as a related meteor-controlled phenomena of so-called sporadic E or Es anomalous radio reflection propagation. Es has recently been shown by the present author to be correlated with the QBO [44] and with earth tides and planetary waves. The author expects PMSC/NLC to be similarly correlated. QBO is a barometer of both the stratosphere and the ocean atmosphere interaction and possibly longer-term solar effects (Holton 1994) [45]. It may amplify solar cycle influence, Mayr (2006) [46]. A QBO has recently been shown in both stratospheric Ozone and NO2 (Zawodny and McCormick 1991) [47]. There is now inconvertible evidence of 2 way coupling between the stratosphere and troposphere via waves, radiation and climate electricity, see for example Mohanakumar 2008 [48]. Additional NO2 from aviation and deep convection could enter the mesosphere and have effects.

It is interesting to note that the period in which there appears to be a cooling effect with incoming meteors is also approximately the same period in which their correlation with rainfall is minimised, see figure 16. Thus, as an alternative to a direct climate cooling effect of PMCS their changes could be merely indicative of tropospheric changes which have their own negative feedback processes which maximise at the same time as PMSC. One such possibly is aviation and other NOX. If there is less rain in the PMCS season there is less chance of NOX been washed out. Lawrence and Crutzen (1999) [49] have discussed NOx as follows: Emissions of nitrogen oxides (NOx, the sum of NO and NO2) from fossil-fuel burning dominate the NOx burden of the lower troposphere in many regions. These emissions increase tropospheric ozone and hydroxyl-radical concentrations over their natural 'background' levels, thereby increasing the oxidizing power of the atmosphere. Fossil-fuel emissions of NOx account for about half of the global NOx source to the atmosphere; other significant sources are from biomass burning, soil emissions, aircraft exhausts and lightning, all primarily continental. However, ocean-going ships burning fossil fuels may also contribute a significant fraction (>10%) to global NOx production. They used NOx emission data and a high-resolution chemistry–transport model to estimate that ship NOx emissions resulted in a more than 100-fold increase in surface NOx concentrations in heavily traversed ocean regions. This huge increase had a notable effect on modelled surface ozone and hydroxyl-radical concentrations. A predicted fivefold increase in the July hydroxyl-radical burden over the northern Atlantic and Pacific oceans would also reduce the atmospheric lifetimes of reactive greenhouse gases—such as methane—as well as to increase related SO2 aerosol production rates and cloud reflectivity, therefore exerting a cooling influence on the climate. For instance, others have shown that aircraft NOx net IRFs are spatially variable, with July values over the remote Pacific approximately balancing the IRF associated with aviation CO2 emissions (28 mWm^{-2} yr $(TgNO_2)^{-1}$). The overall climate impact of global aviation is often represented by a simple multiplier for CO2 emissions.

Another system which cools the planet and wherein this cooling maximises in general are simple tropospheric clouds. The NASA Earth Radiation Budget Experiment (ERBE), flying aboard multiple satellites, is providing new insights into the climate system. Monthly averaged clear-sky and cloudy sky flux data derived from the ERBE are used to assess the impact of clouds on the Earth's radiation balance. This impact is examined in terms of three quantities: longwave, shortwave, and net cloud forcing. Overall, clouds appear to cool the Earth-atmosphere system. The global mean cooling varied from 14 to 21 W m^{-2} between April 1985 and January 1986. Hemispherically the longwave and shortwave cloud forcing nearly cancel each other in the winter season, **while in the summer the negative shortwave cloud forcing is significantly lower than the longwave cloud forcing, producing a strong cooling.** The UK observations here concur. The question is how we square more cloud with less rainfall. The answer once again is aircraft and aviation cirrus and aerosol. Henderson and Sellers (1989) have assembled records of mean monthly total cloud amount from 143 locations in North America.. Generally, the low and middle latitude station records extend over the period 1900–1984 (U.S.A.) and 1900–1982 (Canada) but few Arctic stations have records before 1930 and some begin recording cloud amount as late as the 1960s. The low and middle latitude station records show a tendency for total cloud amount to increase over this century. Only one of the 77 continental U.S.A. stations does not show an increase. The high latitude stations record increasing total cloud amount in the summer **(June, July, August) s**eason but not in the annual mean. The records show the largest increase between about 1930 and 1950. They are temporally consistent but do not exhibit significant spatial coherence. The history of observing and reporting practice has been carefully examined; if any significant effect were to be expected from the changes documented it would be a decrease at the time when the greatest recorded increase occurs. Other factors associated with increased population are possible "explanations". The most likely cause of increased cloud amount (if the temporal trend is real) is anthropogenic clouds in the form of jet aircraft condensation trails.

Sassen (1997) [50] produced evidence indicates that the direct radiative effects of contrails display the potential for regional climate change at many midlatitude locations, even though the sign of the climatic impact may be uncertain.

The third and final mechanism for global cooling relates to deep convection. Wang(2013)[51] has noted that the global surface temperature has been relatively flat since about 2000 despite the still rising CO2 concentration in the atmosphere. He further notes this is most puzzling as most climate models predict clear rising temperature trend with increasing CO2. Wang's theory is based on the dynamic link due to the coupling between the lower stratospheric (LS) water vapor and stratospheric ozone. First, time series analysis shows that there is a lagged correlation between the ozone and LS vapor series from 1980 to the present, with the cross-correlation function greater than -0.8 at L = 4. This indicates the possibility of close link between the two variables. The ozone level has been increasing since ~ 1995 and the LS vapor has been decreasing since ~ 1999. At the same time, the global surface temperature is flat and not rising as most models have predicted. The theory he developed shows that the increasing ozone since mid-1990s results in a more stable stratosphere which then suppresses the injection of water vapor into the lower stratosphere by deep convective storms. More and more evidence show that the deep convective storms are likely the major source of water vapor in the LS. Thus, when such injection is suppressed, the LS water vapor concentration decreases. The smaller LS vapor concentration allows more surface IR to radiate away and thus is a cooling factor. This cooling factor compensates for the heating factor due to the increasing CO2 level. The net result is that the surface temperature has remained relatively flat since ~ 2000. The present author suggests that perhaps expanding and persistent contrails also scavenge water, and this has not been considered by Wang.

4. Scope for more prediction and testing by long and medium range forecasting

Random meteoroids which are tiny leftovers from the building of the universe ranging for tiny grain sized to huge rocks are often in themselves former parts of asteroids and of course as their name implies, cannot be predicted. They are either made of stone, stone and iron or iron alone.

Beyond the random, however, comes some modicum of predictability. Every year like clockwork, on certain dates to within a couple of days or so, the number of meteors seen in anyone's sky window per hour jumps upwards from its random 10 to around 60. This spectacle is called a meteor shower, as the meteors appear to shower down from above. Every few years however something even more special happens. A meteor storm may occur, showering upwards of 2000 meteors per hour down from the heavens. These predictable meteors are associated with comets.

As the ice of the comet melts on approach to the sun, some sand and material that was frozen in the comet is also released. The very small particles of comet dust are swept away with the tail whereas the slightly larger pieces are left in space. This can be conceived by imagining one has a handful of sand and gravel mixed
together and tossing it up into the air as you stand in a strong wind. The sand will blow away with the wind, but the gravel will just go up and fall to the ground without moving much. The gravel is analogous to the larger, pea sized chunks of debris left behind by the comet. The sand would be the dust that is blown away with the tail. These pea sized chunks are left in a trail behind the comet wherever it goes. Comets just as earht orbit the sun but the comet orbit is highly elliptical and often its period immense compared with that of the earth.
just like we do. The result is eventually Earth's orbit will intersect with this trail of debris in space. When this happens, these chunks hit the Earth's atmosphere and burn up becoming a meteor! The resultant meteor shower will occur about the same time every year. To understand this, see Figure 22.

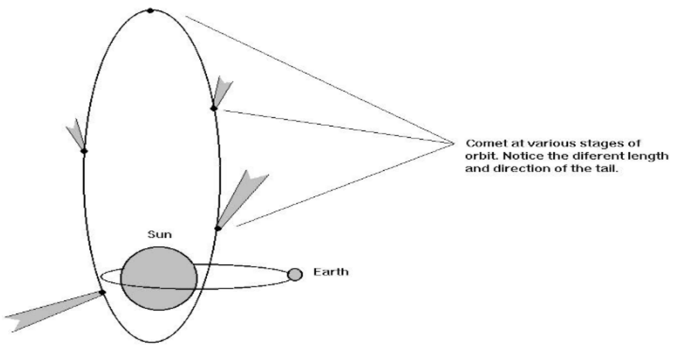


Figure 22. Comet orbit in relation to the Earth orbit. The point in which the two orbits cross indicates the expectation of the meteor shower.

Every so often the number of meteors per hour is so high that the shower becomes a meteor storm. A storm is caused due the Earth intersecting a particularly dense stream of debris. For example, the November 17th Leonid meteor shower is known to storm every 33 years.

There are records throughout the world indicating that the seasonal activity of certain of the well-known meteor showers can be traced back almost 1500 years and that their intensity always prioritises over random, sporadic meteors, see Sang-Hyeon Ahn, (2003) [52]. The representative meteor showers which were shown to behave reliably in this way are the Perseids (August 12th), the Leonids (November 17th) , and the η Aquarids (May) /Orionids(October 21st) pair formed by Halley's comet.

Some of the best-known meteor showers are :

Lyrids:
Active from April 16-25, with a peak around April 22-23, offering a potential hourly rate of 15-20 meteors.

Perseids:
One of the most popular showers, active from July 17 to August 24, peaking around August 12-13 with a high hourly rate of 100-150 meteors.
Draconids:
Active from October 6-10, with a peak around October 8, and a low hourly rate of about 5.
Orionids:
Active from October 2 to November 7, with a peak around October 21-22, known for bright meteors and persistent trains.
Leonids:
Active from November 6-30, with a peak around November 17-18, producing swift and bright meteors, sometimes with long trails.
Geminids:
Active from December 7-17, with a peak around December 13-14, producing bright and colorful meteors, often with a high hourly rate.

According to the Greenwich Observatory the Meteor shower dates for 2025 are:

Shower Name	Date of Maximum	Normal Limits	Possible hourly rate	Description
Quadrantids	4 January	26 Dec-12 Jan	120	Bluish- or yellowish-white meteors with fine trains
Lyrids	22 April	16-25 April	18	Bright fast meteors, some with trains. Associated with Comet Thatcher
Eta Aquariids	5 May	19 Apr-28 May	40	Low in sky. Associated with Comet Halley
Alpha Capricornids	30 July	3 July-15 Aug	5	Yellow slow fireballs
Delta Aquariids	30 July	12 July-23 Aug	25	Steady stream of meteors over several days but a low rate per hour
Perseids	12 August	17 July-24 Aug	150	Many bright fast meteors with trains. Associated with Comet Swift-Tuttle (1737, 1862, 1992)
Draconids	8 October	6-10 October	10	Associated with Comet 21/P Giacobini-Zimmer
Orionids	22 October	2 Oct-7 Nov	15	Fast with fine trains. Associated with Comet Halley
Taurids	Southern: 10 Oct	Southern: 10 Sep-20 Nov	5	Very slow meteors

	Northern: 12 Nov	Northern: 20 Oct-10 Dec		
Leonids	17 November	6-30 November	15	Fast bright meteors with fine trains. Associated with Comet Tempel-Tuttle
Geminids	14 December	4-20 December	120	Plenty of bright meteors, few trains
Ursids	22 December	17-26 December	10	Sparse shower. Associated with comet 8P/Tuttle

According to Wikepedia , as of January 2024, there are 110 established meteor showers but not all have an established source.

The proposed work would involve hindcasting and forecasting models based on the above dates and the algorithms developed in this work and previous weather and climatic records. Initially this could be done for the UK or interested parties may wish to make their own geographic studies.

This is something the present author may report on in the future if time permits.

5. Conclusions

1. In the UK in the inter-decadal period 2005-2011 annual rainfall is most strongly correlated with cosmic ray flux. The much higher correlation coefficient for Cosmic Rays is supportive of the notion of a stronger, real physical effect and is also supportive of the work of Svensmark. Alternatively, and/or additionally meteoric debris does provide the nucleation material for rainfall but cosmic rays provide the correct atmospheric electricity conditions, see Tinsley (2000) and Carslaw and Harrison (2002).
2. Annual temperatures can be correlated with a simple linear algorithm (SFCM) involving cosmic ray flux (C), solar flux (SF) and radio meteor flux (M) according to equation (1).

Delta Temp = -.707 + 2.916* SFCM ………………………………………………………………(1)

Where SFCM = {(SF-C) +M}

3. Sunshine totals are weakly anti-correlated with all three potential extra-terrestrial drivers but strongly correlated according to a cubic function with solar flux.
4. Average Meteor rate distributions (using the radio forward scatter method) are in approximate agreement with the findings of Keay (1963).
5. On a monthly basis, for sunshine, only January is strongly and positively correlated with radio meteor flux.
6. Radio Meteor rates measured in the UK only seemed to have a very strong further order polynomial correlation with the zonal wind between the months of January and July only.
7. The slope of the monthly rainfall anomaly percentages divided by meteor rates versus month number can be best fitted to a quadratic equation against meteor rates which shows some symmetry around the summer solstice.
8. The slope of rainfall in every subsequent month divided by the prior month's meteor rate which shows a sensible and finite regression coefficient. When this is done a skewed distribution is seen in favour of the late autumn months. This seems to confirm that meteoric material entering the mesosphere at this time of year takes longer to diffuse down through to the stratosphere and troposphere, see Figure 17. Thus for the UK, only in the late autumn months is the work of Bowen confirmed.

9. For monthly meteor /temperature anomaly effects compared with the LTA, from January to May the slope of the regression alternates negative to positive confirming a possible lunar influence. Most likely the Moon's gravitational influence can affect the trajectories of some meteoroids, potentially increasing or decreasing the number that strike the Earth or altering their arrival times.
10. In June and July where the coefficient of temperature with meteor rate is negative, in June it is strongly negative and highly correlated, see Figure 19.
11. Of relevance is that the positive and negative areas under the 'slope' curve appear to cancel each other out. This is suggestive that at least in the UK in the period considered there is **no significant climate warming**.
12. A negative feedback process is thus indicated possibly with PMSC as either its harbinger or direct cause.
13. Processes in PMSC will require much more investigation but under some instances lofted pollution could cause cooling.
14. NOX is a possible contender since the cooling period coincided with lower rainfall.
15. Aircraft contrail cloud is another possible contender.
16. Smaller LS vapor concentration allows more surface IR to radiate away and thus is a cooling factor. This cooling factor compensates for the heating factor due to the increasing CO2 level.
17. Expanding and persistent contrails may also scavenge water and this has not been considered by Wang.
18. The Icelandic volcano Eyjafjallajökul strongly perturbed the results in 2010, correlations were vastly improved when that year's data were removed.
19. Extra-terrestrial inputs and volcanism would appear to remain by far the strongest climate drivers in inter-decadal times in a polluted 21st Century Atmosphere where Mother Earth would still appear to have 'designer-like' feedback mechanisms protecting its inhabitants from enhanced greenhouse gas concentrations.

6. Acknowledgements

The author wishes to thank Mr Peter Van Doorn of Torro UK for interesting discussions on fireballs and bolides.

7. References

1. Bowen, E.G., (1956), A Relation between Meteor Showers and the Rainfall of November and December. Tellus, 8: 394-402. https://doi.org/10.1111/j.2153-3490.1956.tb01237.x
2. Fred L. Whipple and Gerald S. Hawkins, "On Meteors and Rainfall", Journal of the Atmospheric Sciences Volume 13: Issue 3, pp236-240, 1956.
3. Laurence A. Manning; The Theory of the Radio Detection of Meteors. J. Appl. Phys. 1 August 1948; 19 (8): 689–699. https://doi.org/10.1063/1.1698193
4. Bumba, V., "Variation saisonnière des altitudes météoriques", Bulletin of the Astronomical Institutes of Czechoslovakia, vol. 1, p.125, 1949.
5. Hughes, D.W., "Meteor rates, volcanoes and the solar cycle", Nature, 252(5480), pp.191-192., 1974.
6. Lindblad, B. A., "Meteor radar rates and the solar cycle", Nature, 259(5539), 99-101.,1976.
7. Ellyett, C., "Solar influence on meteor rates and atmospheric density variations at meteor heights," J. Geophys. Res., 82(10), 1455–1462, doi:10.1029/JA082i010p01455, 1977.
8. Šimek, M., Pecina, P., "Radar sporadic meteor rates and solar activity", Earth, Moon, and Planets 88, 115–122 (2000). https://doi.org/10.1023/A:1015816116844
9. Lindblad, B.A., Neslušan, L., Porubčan, V. et al., "IAU Meteor Database of photographic orbits – version 2003", Earth Moon Planet 93, 249–260 (2003). https://doi.org/10.1007/s11038-004-1953-4

10. A. Dubietis, R. Arlt, "Taurid resonant-swarm encounters from two decades of visual observations", Monthly Notices of the Royal Astronomical Society, Volume 376, Issue 2, April 2007, Pages 890–894, https://doi.org/10.1111/j.1365-2966.2007.11488.x -TERR PHYS. 71. 1225-1235. 10.1016/j.jastp.2009.04.012, 2009.
11. Singer, W., Latteck, R., Millan, L.F. et al., "Radar Backscatter from Underdense Meteors and Diffusion Rates", Earth Moon Planet 102, 403–409 (2008). https://doi.org/10.1007/s11038-007-9220-0
12. Raizada, Shikha & Rapp, Markus & Lübken, F.-J & Höffner, J. & Zecha, M & Plane, John. ." Effect of ice particles on the mesospheric potassium layer at Spitsbergen (78 N)", J. Geophys. Res. 112. 10.1029/2005JD006938, 2007.
13. Gumbel, J. & Megner, L., "Charged meteoric smoke as ice nuclei in the mesosphere: Part 1—A review of basic concepts", Journal of Atmospheric and Solar-terrestrial Physics - J ATMOS SOL
14. Saunders, R. & Dhomse, Sandip & Tian, Wenshou & Chipperfield, Martyn & Plane, John, "Interactions of meteoric smoke particles with sulphuric acid in the Earth's stratosphere", Atmospheric Chemistry & Physics Discussions. 12. 1553-1584. 10.5194/acpd-12-1553-2012, 2020.
15. Graly, Joseph & Reusser, Lucas & Bierman, Paul. (2011). "Short and long-term delivery rates of meteoric 10Be to terrestrial soils. Earth and Planetary Science Letters - EARTH PLANET SCI LETT. 302. 329-336. 10.1016/j.epsl.2010.12.020.
16. Henrik Svensmark, Eigil Friis-Christensen, "Variation of cosmic ray flux and global cloud coverage—a missing link in solar-climate relationships" ,Journal of Atmospheric and Solar-Terrestrial Physics, Volume 59, Issue 11, pp 1225-1232,1997.
17. Svensmark, Henrik ; Enghoff, Martin Andreas Bødker ; Pedersen, Jens Olaf Pepke, "Response of cloud condensation nuclei (>50 nm) to changes in ion-nucleation", Physics Letters A. 2013 ; Vol. 377, No. 37. pp. 2343-2347, 2013.
18. Barnes, C. " " ISROSET IJRSPAS
19. Barnes, C., " EarthArXIV ….
20. Trenberth, K. E., and A. Dai (2007), "Effects of Mount Pinatubo volcanic eruption on the hydrological cycle as an analog of geoengineering", Geophys. Res. Lett., 34, L15702, doi:10.1029/2007GL030524.
21. Fischer, E. M., J. Luterbacher, E. Zorita, S. F. B. Tett, C. Casty, and H. Wanner (2007), European climate response to tropical volcanic eruptions over the last half millennium, Geophys. Res. Lett., 34, L05707, doi:10.1029/2006GL027992.
22. Gudmundsson, Magnus & Thordarson, Thorvaldur & Hoskuldsson, Armann & Larsen, Gabby & Jónsdóttir, Ingibjörg & Oddsson, Björn & Magnússon, Eyjólfur & Hognadottir, T. & Sverrisdottir, G. & Oskarsson, Niels & Thorsteinsson, Throstur & Vogfjörd, Kristin. (2010). The Eyjafjallajökull eruption in April-May 2010; course of events, ash generation and ash dispersal (Invited).
23. Magnus T Gudmundsson (1), Armann Hoskuldsson (1), Gudrun Larsen (1), Thor Thordarson (2), Bjorn Oddsson (1), Thordis Hognadottir (1), Ingibjorg Jonsdottir (1), Halldor Bjornsson (3), Nina G Petersen (3), and Eyjolfur Magnusson (1) (1) University of Iceland, Institute of Earth Sciences, Reykjavik, Iceland (mtg@hi.is, 354 5528911), (2) University of Edinburgh, Edinburgh, UK, (3) Icelandic Meteorological Office, BustadavegiEyjafjallajökull April-June 2010: An explosive-mixed eruption of unusually long duration, Iceland The summit Geophysical Research Abstracts Vol. 13, EGU2011-12542, 2011 EGUGeneral Assembly 2011.
24. Hiremath, K.M., "Influence of solar activity on the rainfall over India" ILWS WORKSHOP 2006, GOA, FEBRUARY pp19-24, 2006.
25. Karlsson, B., C. E. Randall, S. Benze, M. Mills, V. L. Harvey, S. M. Bailey, and J. M. Russell III (2009), Intra-seasonal variability of polar mesospheric clouds due to inter-hemispheric coupling, Geophys. Res. Lett., 36, L20802, doi:10.1029/2009GL040348.
26. C.I. Ezekwe, Clifford C.O. Ezeilo, "Measured solar radiation in a Nigerian environment compared with predicted data", Solar Energy, Volume 26, Issue 2, pp. 181-186, 1981.
27. R.D. Sears, R.G. Flocchini, J.L. Hatfield,Correlations of total, diffuse and direct solar radiation with the percentage of possible sunshine for Davis, California, Solar Energy, Volume 27, Issue 4, pp. 357-360, 1981.
28. E Pallé Bagó, C J Butler, The influence of cosmic rays on terrestrial clouds and global warming, Astronomy & Geophysics, Volume 41, Issue 4, August 2000, pp. 4.18–4.22, 2000.
29. Przedpelski, Z.J., and Casadevall, T.J., 1994, Impact of volcanic ash from 15 December 1989 Redoubt Volcano eruption on GE CF6-80C2 turbofan engines, in Casadevall, T.J., Volcanic ash and aviation safety; proceedings of the first international symposium on volcanic ash and aviation safety: U.S. Geological Survey Bulletin 2047, pp. 129-135, 1994.

30. Gregg J. S. Bluth, Scott D. Doiron, Charles C. Schnetzler, Arlin J. Krueger, Louis S. Walter, " Global tracking of the SO2 clouds from the June", 1991 Mount Pinatubo eruptionsVolume19, Issue2, 24 January 1992, pp 151-154, 1992.
31. Clifton D. Ellyett, Colin S. L. Keay ,Meteors: An Unexpected Increase in 1963.Science146,1458-1458(1964).DOI:10.1126/science.146.3650.1458, 1964.
32. Szalay, J. R., and M. Horányi (2015), Annual variation and synodic modulation of the sporadic meteoroid flux to the Moon, Geophys. Res. Lett., 42, 10,580–10,584, doi:10.1002/2015GL066908, 2015.
33. Ellyett, C. (1977), Solar influence on meteor rates and atmospheric density variations at meteor heights, J. Geophys. Res., 82(10), 1455–1462, doi:10.1029/JA082i010p01455,
34. Matthew T. DeLand, Eric P. Shettle, Gary E. Thomas, John J. Olivero A quarter-century of satellite polar mesospheric cloud observations, Journal of Atmospheric and Solar-Terrestrial Physics, Volume 68, Issue 1, 2006, pp. 9-29, ISSN 1364-6826, https://doi.org/10.1016/j.jastp.2005.08.003., 2006.
35. Bellan, P. M. (2008), Ice iron/sodium film as cause for high noctilucent cloud radar reflectivity, J. Geophys. Res., 113, D16215, doi:10.1029/2008JD009927, 2008.
36. Hervig, M. E., C. G. Bardeen, D. E. Siskind, M. J. Mills, and R. Stockwell (2017), Meteoric smoke and H2SO4 aerosols in the upper stratosphere and mesosphere, Geophys. Res. Lett., 44, 1150–1157, doi:10.1002/2016GL072049, 2017.
37. DeLand, M. T., E. P. Shettle, G. E. Thomas, and J. J. Olivero (2003), Solar backscattered ultraviolet (SBUV) observations of polar mesospheric clouds (PMCs) over two solar cycles, J. Geophys. Res., 108, 8445, doi:10.1029/2002JD002398, D8., 2003.
38. Mills, M. J., O. B. Toon, and G. E. Thomas (2005), Mesospheric sulfate aerosol layer, J. Geophys. Res., 110, D24208, doi:10.1029/2005JD006242., 2005.
39. Thomas, Gary & Olivero, John & Deland, Matthew & Shettle, Eric. (2003). Comment on "Are noctilucent clouds truly a "Miner's Canary" for Global Change?". Eos, Transactions American Geophysical Union. 84. 10.1029/2003EO360008.
40. Pérot, K., Hauchecorne, A., Montmessin, F., Bertaux, J.-L., Blanot, L., Dalaudier, F., Fussen, D., and Kyrölä, E.: First climatology of polar mesospheric clouds from GOMOS/ENVISAT stellar occultation instrument, Atmos. Chem. Phys., 10, 2723–2735, https://doi.org/10.5194/acp-10-2723-2010, 2010.
41. Chandran, A., D. W. Rusch, G. E. Thomas, S. E. Palo, G. Baumgarten, E. J. Jensen, and A. W. Merkel (2012), Atmospheric gravity wave effects on polar mesospheric clouds: A comparison of numerical simulations from CARMA 2D with AIM observations, J. Geophys. Res., 117, D20104, doi:10.1029/2012JD017794.
42. Equatorial oscillations in the middle atmosphere generated by small scale gravity waves
J. G. Mengel, H. G. Mayr, K. L. Chan, C. O. Hines, C. A. Reddy, N. F. Arnold, H. S. Porter
43. Realistic quasi-biennial oscillations in a simulation of the global climate Adam A. Scaife, Neal Butchart, Christopher D. Warner, David Stainforth, Warwick Norton, John AustiFirst published: 01 November 2000 https://doi.org/10.1029/2000GL011625
44. Chris Barnes 'Examining Sporadic E: New methods for predicting the start of the UK Sporadic-E season 'RadCom plus' a Journal of the Radio Society of Great Britain, Vol No.1 pp 22-30, May 2015. http://rsgb.org/main/blog/front-page-news/2015/04/30/radcom-plus-vol-1-1/
45. Holton, J.R. (1994). The Quasi-Biennial Oscillation in the Earth's Atmosphere and its Links to Longer Period Variability. In: Nesme-Ribes, E. (eds) The Solar Engine and Its Influence on Terrestrial Atmosphere and Climate. NATO ASI Series, vol 25. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-79257-1_16
46. Mayr, H. G., J. G. Mengel, C. L. Wolff, and H. S. Porter (2006), QBO as potential amplifier of solar cycle influence, Geophys. Res. Lett., 33, L05812, doi:10.1029/2005GL025650., 2006.
47. Zawodny, J. M., and M. P. McCormick (1991), Stratospheric Aerosol and Gas Experiment II measurements of the quasi-biennial oscillations in ozone and nitrogen dioxide, J. Geophys. Res., 96(D5), 9371–9377, doi:10.1029/91JD00517., 1991.
48. Stratosphere Troposphere Interactions An Introduction Textbook Springer © 2008 Author K. Mohanakumar.
49. Lawrence, M., Crutzen, P. Influence of NOx emissions from ships on tropospheric photochemistry and climate. Nature 402, 167–170 (1999). https://doi.org/10.1038/460
50. Sassen, Kenneth. "Contrail-cirrus and their potential for regional climate change." Bulletin of the American Meteorological Society 78.9 (1997): 1885-1904.
51. Wang, W., Matthes, K., Tian, W. et al. Solar impacts on decadal variability of tropopause temperature and lower stratospheric (LS) water vapour: a mechanism through ocean–atmosphere coupling. Clim Dyn 52, 5585–5604 (2019). https://doi.org/10.1007/s00382-018-4464-0

52. Sang-Hyeon Ahn, Meteors and showers a millennium ago, Monthly Notices of the Royal Astronomical Society, Volume 343, Issue 4, August 2003, Pages 1095–1100, https://doi.org/10.1046/j.1365-8711.2003.06752.x