Climatology of the Malverns

Frank Hill BA(Hons) BSc FRMetS

Personal exposure:

Frank was born in Birmingham in 1939 and educated at King Edwards School, Edgbaston. The school was an official climate station and received the Daily Weather Report from the Met. Office, which he found very interesting. He bought his first raingauge at the age of 14. On completing A-levels, he joined the Met. Office and spent some time at Birmingham Airport before being promoted to forecaster. In 1968, he was posted to Singapore to carry out research using radar into the heights and distribution of thunderstorms (which posed a threat to Concorde flights). On completion of this study, he returned to England and spent the next 15 years at the Met. Office Research Unit based at the RSRE, Malvern. One of the research projects was to use radars and raingauges to study the formation of heavy rain over high ground, particularly in south Wales. (It was after this study that Frank was allowed to install the redundant raingauges around the Malvern Hills). The Research Unit then assisted RSRE technicians in producing real-time images of the rainfall over England and Wales using data from several radars, a system which was gradually extended to cover all of the British Isles.

The Research Unit was closed in 1986 and Frank was posted as senior aviation forecaster to such locations as Brize Norton and Strike Command until retirement in 1998.

Author's Acknowledgements

The daily accumulation of weather data during the periods when I was away from Malvern on duty elsewhere would not have been possible without the assistance of my wife, Edna, who shares my enthusiasm for meteorology. I am also grateful to those people who have allowed me to keep recording raingauges on their property for many years, notably Mary and John Roberts, Jill and Ira Clark, Sonia and Clive Pyne, and John Storey. I also receive daily measurements of rainfall from Claire Turner, Pauline and John Clements, Rosamund and Keith Ponting, and Garth Lowe. In the 1970s, the Met. Office provided me with rainfall data from sites around the local area, most of which had already closed or have done so since the study began. This booklet was published with help of David Arnitage from the Malvern Hills Area of Outstanding Natural Beauty in 2019. Finally, I am grateful to Les Clark for the photo on page 9 and to Matt Jones for his work on the graphs.

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RECORDING SITES

Shielded by Wales from the most persistent rain, drier and sunnier than north Worcestershire and the Cotswolds but not as dry as the east Midlands and East Anglia, the Malvern Hills are favourably located to enjoy some of the most pleasant weather in the British Isles. They lie between a fairly small rain-shadow zone that covers part of the Wye valley and a larger rain-shadow zone that extends across much of the Severn and Avon valleys.

Although there have been many raingauge sites in the Malvern area during the past 100 years, there have been only three climate sites. Observers at these sites measure not only rainfall but also temperatures and sunshine, and also make observations of cloud, weather and wind. Unfortunately, their locations indicate conditions only in a limited area of the Malvern Hills: on the lower slopes below Great Malvern. These sites were at:

Malvern Library	1912-1955 (not sunshine)
Pickersleigh Road	1955-2008
Charles Way	1977-2019

The two former sites were set up by the Met Office with the cooperation of Malvern Hills District Council, the latter by the author.

The main reason for the small number of climate stations is that the purchase of a Stevenson screen, several mercury thermometers, an anemometer and a sunshine recorder was a far more expensive exercise than just buying a raingauge. Few budding weather observers had the enthusiasm to embark on this additional commitment in the days before the advent of modern electronic instruments.

All the above sites can be described as over-sheltered by buildings and trees compared with what would be regarded as an ideal site. Unfortunately, the majority of people who own houses with very large gardens tend not to be enthusiastic enough to set up climate stations. Indeed, many gardens around Malvern are unsuitable due to steep slopes and tall trees, the annual growth of these often turning an initially suitable site into an over-sheltered one after several years.

MEAN MONTHLY TEMPERATURE 1981-2010

I am launching straight into the average maximum and minimum temperatures from 1981 to 2010 as measured at the Pickersleigh Road and Charles Way climate stations. Thirty-year periods are the standard lengths for calculating climate data. Temperatures on the upper slopes of the Hills are generally 2 or 3°C lower on warm days and 2 to 4°C higher on cold radiation nights. *The table below shows data from 1981-2010.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
°C Max	7.3	8.1	11.1	14.1	17.5	20.5	22.8	22.5	19.3	14.7	10.5	7.3
°C Min	2.6	2.1	3.6	4.7	7.6	10.6	12.6	12.8	10.2	7.6	4.8	2.7

TRENDS IN MEAN ANNUAL TEMPERATURE 1912-2017

Although only a brief overlap was made in transferring from the first climate site to the second, it is unlikely that there would have been much difference between them as regards mean temperature. The 'mean' is the average of the maxima and minima during the 24 hours preceding each 0900GMT observation. Higher sites tend to have cooler days and milder nights than lower sites, but the daily and monthly means are often similar. The overlap of many years at Pickersleigh Road and Charles Way showed that the difference in mean annual temperature recorded by the sites was usually no more than 0.1°C. Consequently, we are able to use the three sites to look for any long-term temperature changes. In particular, we can see if there is confirmation of the warming trend revealed by studies on a global scale.

(This is not necessarily so, as amounts of warming are likely to vary in different parts of the world).

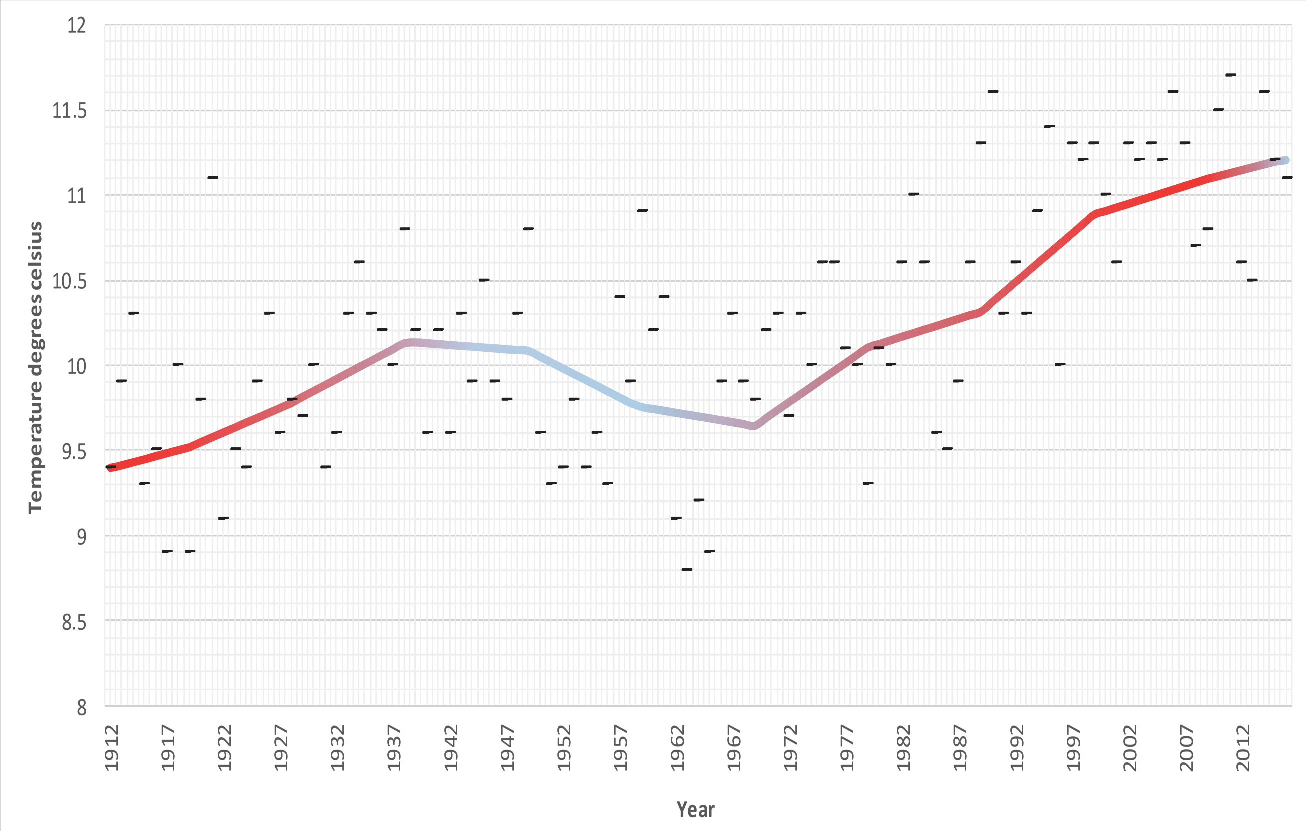
The mean temperature for each year from 1912 onwards is plotted in Fig.1. There has clearly been a warming of about 1°C over the whole period but the change does not appear to be gradual. There seem to be four different trends.

1912-1939	slow warming at about 0.20°C per decade
1940-1965	slight cooling at about 0.15°C per decade
1966-2007	marked warming at about 0.30°C per decade
2008-2016	slight warming at about 0.05°C per decade

These trends are to some extent evident in global data, but there is still debate over whether they are the consequence of El Nino events, fluctuations in sea temperatures due to changes in the strength of the Gulf Stream, sub-oceanic volcanic eruptions, or other internal or external factors.

With regard to temperatures on the upper parts of the hills, we would expect them to be typically 2 or 3°C lower during the day than over low ground (air cools at about 1°C on rising 100m). Conversely, temperatures overnight will often be somewhat higher than on surrounding low ground as the cooling air tends to sink and flow down the hillside to be replaced by milder air, whereas valley air radiates and cools without being replaced. This brings about the well-known fact that gardens on the lower slopes at heights of 50 to 150m (such as in Gt. Malvern and Malvern Wells) often experience milder nights, usually by 2 to 4°C, than those on low ground (such as in Upton and Mathon). However, gardens on the eastern slopes of the Hills lose out during the late afternoon due to the sun sinking below the hills much earlier than in the west or on open ground.

Figure 1: Mean and annual temperatures 1912-2017



RECORD MONTHLY TEMPERATURES

1912-2017

The next table shows the highest and lowest temperatures measured at any of the three climate sites since 1912, along with the years in which they occurred.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
°C Max	15.8	17.8	22.3	26.0	29.4	32.6	34.6	35.8	30.6	26.1	18.0	16.1
Year	2003	1998	2012	2003	1944	1976	1976	1990	1961	2011	1938	1974
°C Min	-19.0	-11.6	-9.4	-4.1	-0.5	2.2	6.6	5.0	1.2	-3.4	-9.0	-19.3
Year	1982	1956	1965	1990	1941	1991	1984	1919	1947	1997	2010	1981

It is interesting that six of the highest records have occurred in the last 30 years, twice as many as would be likely if some warming were not taking place. However, it is also notable that two record warm months date back to 1938 and 1944, and that the records for June and July are still held by the exceptional summer of 1976.

Of the lowest temperatures, the records were set by two spells of Arctic air that traversed the Midlands in Dec 1981 and January 1982, producing abundant snow and the record lowest temperature for England of -26.1C in Shropshire. These events caused considerable damage to trees, hedges and shrubs on the lower ground of the Malverns.

LENGTH OF THE FROST-FREE PERIOD

Of some interest, especially to gardeners, are the dates at which the first and last air frosts of the winter half of the year have occurred. From knowledge of these, the frost-free period can be calculated.

As stated at the start of this section, all official climate sites have been on fairly low ground to the east of Great Malvern. They are likely to have lower temperatures in the night and early morning than on higher ground, so that slight air frosts occur there which may not occur on the upper slopes. Nevertheless, the likely frost dates on low ground give a starting point for estimating the frost-free period on the hills. I will therefore give the frost data for the site at Charles Way, which, though only 44m above sea level, benefits from some outflow from the Hills on thermal radiation nights and so is not as cold as most sites on low ground in the Severn Valley.

FROST DATES AT CHARLES WAY FROM 1981 TO 2017

	Last spring air frost	First autumn air frost
Earliest	8th Mar	1st Oct
Median	15th Apr	1st Nov
Latest	14th May	9th Jan

Length of the frost-free period (days)

Shortest	158 in 1988
Median	196
Longest	254 in 2011

TREND IN LENGTH OF THE FROST-FREE PERIOD

With the evidence given earlier for some warming of the mean temperature, it would be no surprise if the frost-free period has been lengthening. This is supported by the data for each decade.

Median length of frost-free period each decade (days)

1980s	177
1990s	190
2000s	203

This trend appears to be continuing, with periods exceeding 230 in 2009, 2011, and 2015. However, there is still a lot of variability (only 180 in 2012). Much depends on whether or not an anticyclone forms over the NE Atlantic in October, which often leads to air frosts occurring earlier than usual.

ESTIMATE OF FROST-FREE PERIOD ON HIGHER GROUND

The first and last air frosts of the winter are often slight, sometimes by less than a degree, and would not have occurred at sites above, say, 100m, such as in Gt. Malvern, West Malvern and Colwall. On the other hand, frost is quite likely to occur there if the temperature at Charles Way is lower than about -2^{o}C. I have therefore analysed recent data to see how this affects the above results. On a few occasions, the first or last air frost was down to -2^{o}C but not both.

Period 2007 to 2017:

Median length of frost-free period (days):	215	(range 180 to 254)
Median no. of days warmer than Ms 2C:	245	(range 203 to 300)

ANNUAL RAINFALL

Daily measurements from standard Met Office gauges began in the middle of the C19 in an attempt to discover the amounts and distribution of rain in the British Isles. This took many years to build into a rainfall climatology but resulted in national maps of annual rainfall being published by the 1920s, although the rainfall contours (isohyets) were smoothed so as to show just broad variations between the main upland and lowland areas as there were few sites on high ground. The question of how much more rain fell on the Malvern Hills than on the surrounding low ground was frequently asked by local residents but not regarded as being of much importance. However, there was general agreement that it was unlikely to be much greater than on low ground because the Hills are very narrow and lie in an area where the upper air in westerly winds is tending to descend, which opposes rain formation.

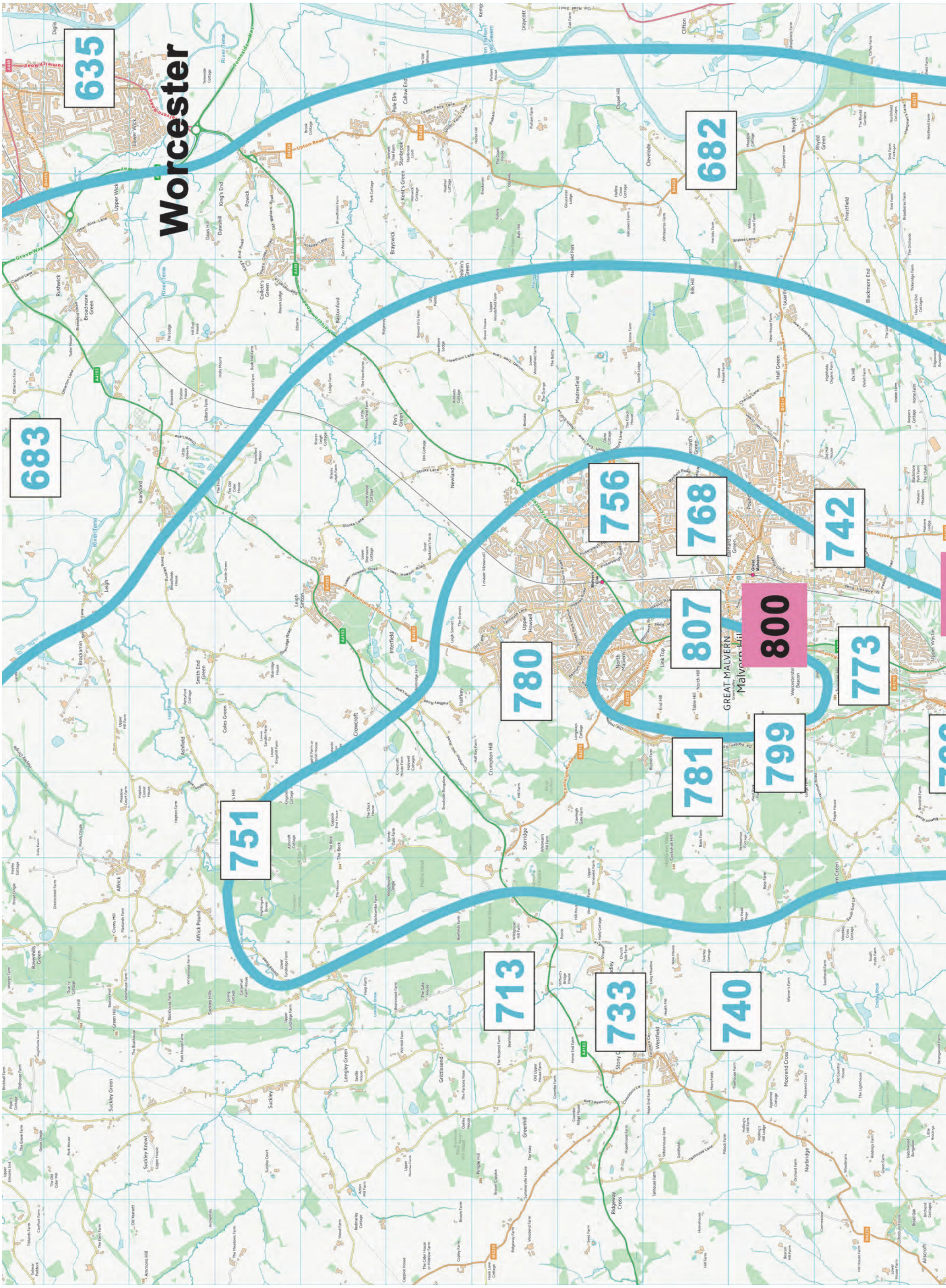
Nevertheless, the author considered the maps of UK average annual rainfall published by the Met. Office for the periods 1921-1950 and 1941-1970 lacked credible accuracy around the Malvern Hills and became interested in investigating the real rainfall distribution.

From 1975 onwards, I tried to supplement the available gauge network by installing gauges in several gardens. This was not as successful as I hoped as some of the gauges owned by the Severn River Authority were withdrawn in the early 1980s due to a rationalisation exercise associated with its merger with the Trent River Authority. As the years passed by, some of my gauges also had to be removed for a variety of reasons, but seven have survived for over 30 years. This has become the period chosen by the Met. Office to calculate average annual rainfall (AAR), the standard periods being 1916-1950, 1941-1970, 1961-1990 and 1981-2010. Annual rainfall is so variable that shorter periods can be heavily skewed by one or two exceptionally dry or wet years.

In order to produce a map of AAR for 1981-2010 around the Malverns, I have used a variety of methods. The main one was to use sites that were operating throughout the period. Where a site was operating for part of the period, its measurements were compared with a site that had operated for the whole period and a ratio of the average rainfall used to provide an estimated 30-year average. Reference was also made to annual publications of British Rainfall as far back as 1940, which include data from sites that have long since closed. I also acquired data from the Met Office for a few sites that existed during the early years of the C20, such as Belle Vue House in Gt. Malvern.

The result (Fig 2) indicates that a contour of 800mm embraces the Worcestershire Beacon and North Hill, including Great Malvern above Graham Road and probably Link Top. The western limit is the West Malvern Road. The more southern hills fail to reach 800mm but probably reach around 780mm as far south as Herefordshire Beacon (the only nearby raingauge was for many years at the lower site of British Camp Reservoir). Because the ground to the west and northwest of the Malvern Hills falls away more gradually than to the east and south, the AAR remains above 750mm at least as far as Old Storridge and the Suckley Hills, whereas it falls below 750mm beyond Malvern Link, Barnards Green and Little Malvern, and to below 700mm beyond Bransford, Guarlford and Welland. The amount falls to below 650mm over much of the Avon valley east of Evesham.

Hence the AAR on the upper slopes of the Malvern Hills is between 70 and 100mm more than in the Wye and Leadon valleys and 100 to 150mm more than in the Severn/Avon valleys. This can be accounted for by: a) triggering of instability in some rainfall systems as the low-level air is forced to rise by around 300m; b) the formation of lower cloud bases over the hills, which may enhance rainfall intensity; c) the formation of a separate layer of stratus on the hills, which reduces evaporation of falling rain; c) higher humidity on the hills compared with low ground, which reduces evaporation of droplets that land on the surface of the gauges.


Worcester
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GREAT MALVERN

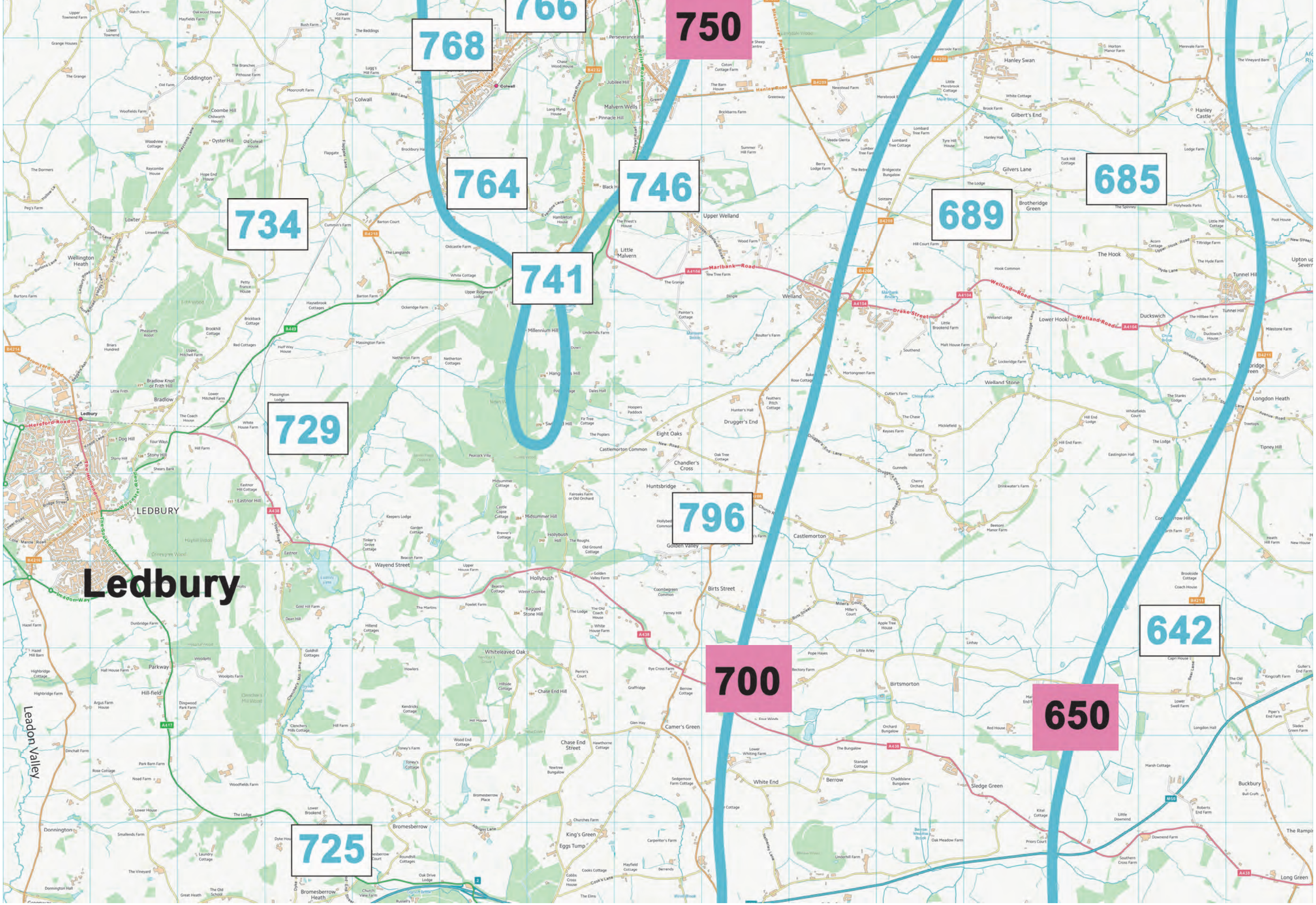

Fig2: Isohyets around the Malverns

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VARIATIONS IN ANNUAL RAINFALL

Short term variations.

There are clearly variations in annual rainfall from one year to the next. In most years it is within 20% of the 30-year mean, so if we take 750mm as a typical rainfall for much of the Malverns, we would expect most yearly totals to be in the range 600 to 900mm.

Falls of around 1000mm have occurred occasionally, these being in 1912, 1924, 1960, 2000, 2007, 2012, and 2014. Of these, the wettest was 1155mm at Belle Vue House in 1924. Probably as much as 1200mm fell on the Worcestershire Beacon that year.

Falls of around 500mm occur occasionally also. These years were 1893, 1921, 1963, 1975, and 2011, of which the driest was 1921 with only 469mm at Malvern Library. Some sites on lower ground would certainly have had below 450mm.

Of course, more extreme values for annual rainfall are obtained if one calculates totals for all consecutive 12 months rather than just calendar years (Jan-Dec).

The highest totals were:

1185mm at Belle Vue House from Dec 1911 to Nov 1912

1189mm at Belle Vue House from Mar 1924 to Feb 1925

1185mm at Belle Vue House from Oct 1929 to Sep 1930

1164mm at Beacon Lodge from Jun 2012 to May 2013.

The driest 12-month period was:

404mm at Pickersleigh Road from May 1975 to Apr 1976.

TRENDS IN 30-YEAR MEAN RAINFALL

The temperature data discussed earlier confirms a general trend towards slightly warmer air consistent with global measurements. Theoretically, as warmer air holds more moisture than cooler air, this could result in more rain. Global data is so far inconclusive. There is some evidence that short-period storms are becoming heavier and more destructive but this may be influenced by better means of observing the storms and the ever-growing extent of urban areas.

Ideally, we would need to have at least 100 years of data from the same site to be able to gather enough 30-year averages to detect any long-term changes. The site would also need to have been free from any change in exposure due to tree growth or construction of nearby buildings. Such a site does not exist in the Malvern area. However, the period from 1889 to 2008 is covered by three sites, namely at Belle Vue House (1889 to 1932), the Library in Graham Road (1912 to 1955) and Pickersleigh Road (next to the current Health Centre) (1956 to 2008). The overlap period from 1912 to 1932 showed that the annual rainfall at Belle Vue House was consistently more than at the Library by an average of 3%. Although there was no overlap between the Library and Pickersleigh Road sites, I had another site on Graham Road for several years which was on average 1.6% wetter than Pickersleigh Road. I have therefore used these percentages to produce a data-set standardised to the level of Graham Road. From all these figures, I have calculated the 10-year and 30-year averages, starting in 1891.

10- and 30- year mean rainfall at Graham Road, Malvern

Decade ending	10-year mean (mm)	30-year mean (mm)
1900	655	
1910	734	
1920	802	730
1930	797	777
1940	751	783
1950	691	746
1960	793	745
1970	731	738
1980	708	744
1990	732	724
2000	812	751
2010	793	779

These results indicate a more frequent occurrence of wet years in the 30 years from 1981 to 2010 compared with the middle of the last century when wet years were more than cancelled out by dry years. Indeed, this trend has continued beyond 2010, with the total exceeding 1000mm in 2012 and 2014. However, there were notable wet spells in the 1920s and 1930s which predominated over the occasional dry year. Hence it might well turn out that we are experiencing a long-term oscillation rather than a progressive trend to wetter weather.

MONTHLY RAINFALL:

LONG-TERM AVERAGES

It would be disappointing if, on average, months in the Spring and Summer were not drier than in the Autumn and Winter, and indeed this is the case. To illustrate, these are the monthly averages at Charles Way from 1981 to 2010:

J	F	M	A	M	J	Jy	Au	S	O	N	D	Total
72	50	55	59	58	59	55	59	61	82	73	73	756

Hence we find that February was the driest month (partly because it has fewer days than March) and October the wettest. Over earlier 30-year periods during the C20, the driest month was either February or March and the wettest either October or November.

It is worth noting that, in most years, the rainfall is below normal in more months than it is above. Typically, seven or eight will be below normal. This is, of course, because the monthly rainfall cannot be below zero whereas it may be well above 100mm.

Although the 30-year averages for the three summer months appear similar, there is a good deal of variation not only of course from year to year but also when averaged over 10-year periods.

	Jun	Jly	Aug	Summer
1981 to 1990	**65**	38	57	161
1991 to 2000	**59**	44	57	158
2001 to 2010	53	**83**	63	199

The variability in July rainfall is remarkable. Although it is the warmest month, it is not much warmer than August, and sea temperatures are higher in August. Some meteorologist talk about a ‘summer monsoon’ associated with temporary strengthening of the mid-Atlantic upper jet. Clearly this does not occur regularly during the summers, so it is no surprise that July has reverted to a drier regime in recent years, with the 2016 rainfall being only 13mm.

There has been a good deal of variation also among the autumn months when averaged over 10-year periods, especially in September.

	Sep	Oct	Nov	Autumn
1981 to 1990	56	**74**	61	191
1991 to 2000	82	80	**83**	245
2001 to 2010	46	**91**	73	210

The high average for September during 1991 to 2000 was ‘out of character’ with its reputation during much of the C20 for being a fine month in which to take a late summer holiday. This reputation took a hard knock in 1976 when, after a long dry summer, much of England had its wettest September of the century.

MONTHLY RAINFALL EXTREMES

There have been huge variations in monthly rainfall over the past 140 years, as would be expected, with hardly any in some months and over 200mm in others. Since knowledge of these extremes may be of interest to farmers and river managers, they are listed below.

Month	Driest (mm)	Year	Wettest (mm)	Year
Jan	11	1950	152	1939
Feb	3	1932	153	1923
Mar	2	1929	158	1947
Apr	0	1957	169	2000
May	6	1991	206	1924
Jun	2	1942	181	2012
Jly	5	1999	211	2007
Aug	3	1940	241	1912
Sep	3	1959	198	1976
Oct	7	1969	179	1960
Nov	9	1945	221	1929
Dec	11	1933	170	1929

FREQUENCY OF WET MONTHS

In most months, the rainfall is likely to fall within a range of 25 to 80mm. However, it is usual to have one or two months in the year when the fall exceeds 100mm. Indeed, on the Hills there have been only 8 years in the past 115 when none has occurred.

Number of months per year with at least 100mm (from 1901 to 2017)

One	107	
Two	39	
Three	22	
Four	8	
Five	3	(in 1912, 2000 and 2012)

These wet events are much more likely from August to January than in Spring and early Summer (e.g. only 6 in March but 25 in August and 29 in December).

Consecutive Very Wet Months

Monthly rainfall in excess of 100mm on and near the Hills occurs occasionally in consecutive months. Runs of three or four months have occurred seven times since 1901.

Four consecutive months over 100mm:

1929/30	Oct/Nov/Dec/Jan	521mm	Gt. Malvern Library
2000	Sep/Oct/Nov/Dec	554mm	Beacon Lodge

Three consecutive months over 100mm (excluding those above):

1912	Jun/Jly/Aug	475mm	Belle Vue House
1959/60	Nov/Dec/Jan	405mm	Pickersleigh Road
1960	Sep/Oct/Nov	404mm	Pickersleigh Road
2002	Oct/Nov/Dec	385mm	Beacon Lodge
2007	May/Jun/Jly	527mm	Beacon Lodge

In all cases, other sites nearby measured rainfall not much less than the amounts stated.

RECORD DAILY RAINFALL

The standard time for measuring rainfall has been specified to be 0900 GMT for around 100 years. This is because it is more convenient for the thousands of volunteers around the British Isles who make daily measurements. It has the disadvantage that, if most of the rain falls after midnight, it is credited to the previous day. Amounts falling from midnight to midnight are also recorded by those of us with recording gauges but these constituted only a very small minority before the recent advent of electronic equipment.

Daily rainfall is mostly between zero and 10mm. In most months, the wettest day is between 10 and 20mm. In most years, the wettest day is between 25 and 35mm. There have been only 32 days in the past 100 years when the rainfall exceeded 40mm. Because the extreme falls invariably cause flooding and traffic problems, the wettest days are listed below in chronological order.

Date	mm	location
31 May 1924	97 to 101	Gt.Malvern
10 Jly 1968	67 to 72	various
17 Jly 2001	63 to 70	various
20 Jly 2007	84 to 90	widespread
23 Sep 2012	65 to 73	various

Their occurrence in the summer indicates that they were due either to prolonged and slow-moving storms, probably thunderstorms, or a succession of such storms. There was a good account of the consequence of the 1924 storm in the Malvern Gazette published on 3 June, from which the following details are extracted.

‘The intense storm started about 7 p.m. and lasted overnight. Torrents swept down the hillside, gardens were ruined, poultry swept from the foul pens. The Rothwell and Milbourne garage was flooded and partly wrecked. Part of the railway embankment on the Malvern-Upton line subsided. Cellars were flooded, including those at the Public Library’.

The event of 20 Jly 2007 also started with thunderstorms (late on 19th and overnight) but heavy rain persisted through the 20th as a broad band of rain became slow-moving over the south Midlands to the north of a low over southern England. The total during the 36 hours at all sites in the Malverns was between 105 and 120mm.

ANNUAL VARIATIONS IN SNOWFALL

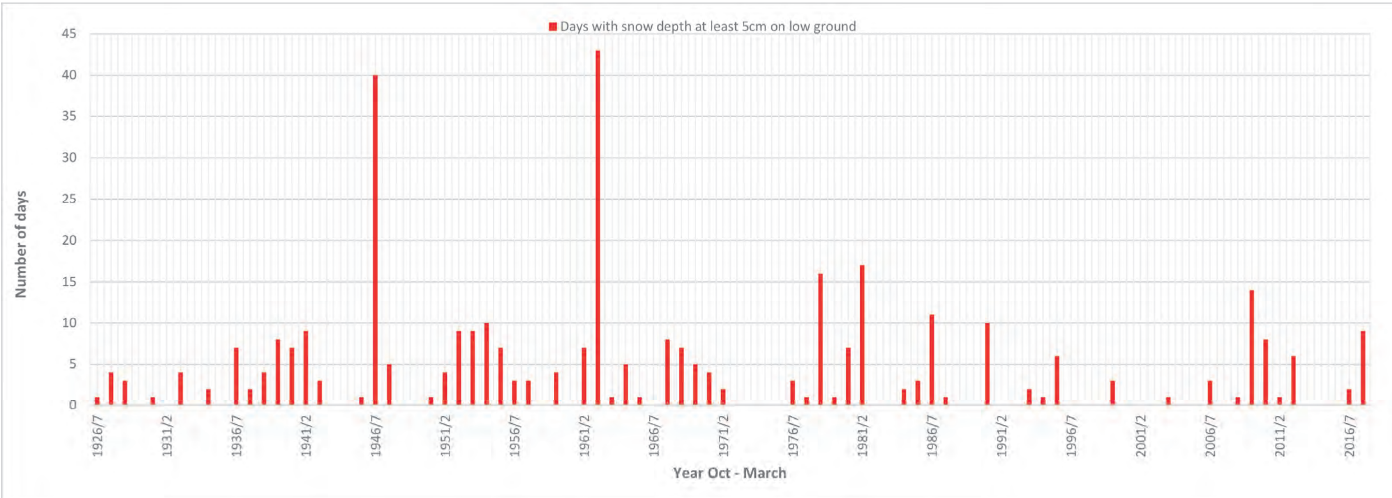
1925 TO 2018

It is well known that snowfall varies greatly from one winter to another. There is also a sense that instances of substantial snowfall are becoming less frequent.

Observers at Malvern weather stations have recorded the depth of any snow lying at the observing site at 0900 GMT every day since 1925 and have also noted variations during the day. In general, however, they did not comment on whether snow was lying elsewhere, so that instances of snow on the hills but not on low ground were not routinely recorded. This means that I am unable to estimate the number of days that snow lay on the hills before my wife and I took over making observations in 1975.

Nevertheless, there is enough information in the early records to identify when snow was lying and how deep it was at the weather station, and consequently I have analysed the data from 1925 onwards. I have used 5cm as a minimum, as this is a significant fall on low ground and would undoubtedly be associated with a substantial fall on the hills. Fig. 3 shows the number of days that this depth was recorded during the winter periods from 1st Dec. to 31st March.

Figure 3: Number of days with snow depth greater than 5cm on low ground (winters Dec-March)



It is no surprise to see 1946/7 and 1962/3 standing head and shoulders above the other years. The former, with 40 days, occurred mostly as a consequence of heavy snowfall in the first week of February. It would probably have endured for around 50 days had not a combination of mild air and heavy rain brought a rapid thaw after 12th March. The latter, with 44 days, started on 26th December and was replenished by several further falls which maintained the depth of 5cm or more until 7th February.

The frequency of snow-free, or almost snow-free, winters does appear to be increasing when viewed over the 90-year period. Accounts of snowy events in England during the 19th and early 20th centuries suggest that very snowy winters occurred once or even twice in most decades. However, the clusters of quite snowy winters around 1980 and 2010 show that they are by no means to be regarded as things of the past. Nor are they likely to be for a very long time.

Most of the heavy snowfalls in the Midlands occur when a depression moves east along the English Channel or southern England and generates widespread precipitation accompanied by an East wind. This draws in cold air from Russia via either the Baltic or Poland. Another favourable pressure pattern is a low that moves west across the southern North Sea, bringing cold air from Poland and the Baltic States while also drawing in cold air from Scandinavia or the Arctic. In view of the very slow rate of Global Warming, these scenarios will continue to produce widespread snowfalls for the foreseeable future, although there is a possibility that the snow may arrive at the lowest level as rain or sleet, as discussed below. Snowfall in northerly winds is generally lighter over the Midlands as we are often sheltered by the high ground of Scotland and northern England.

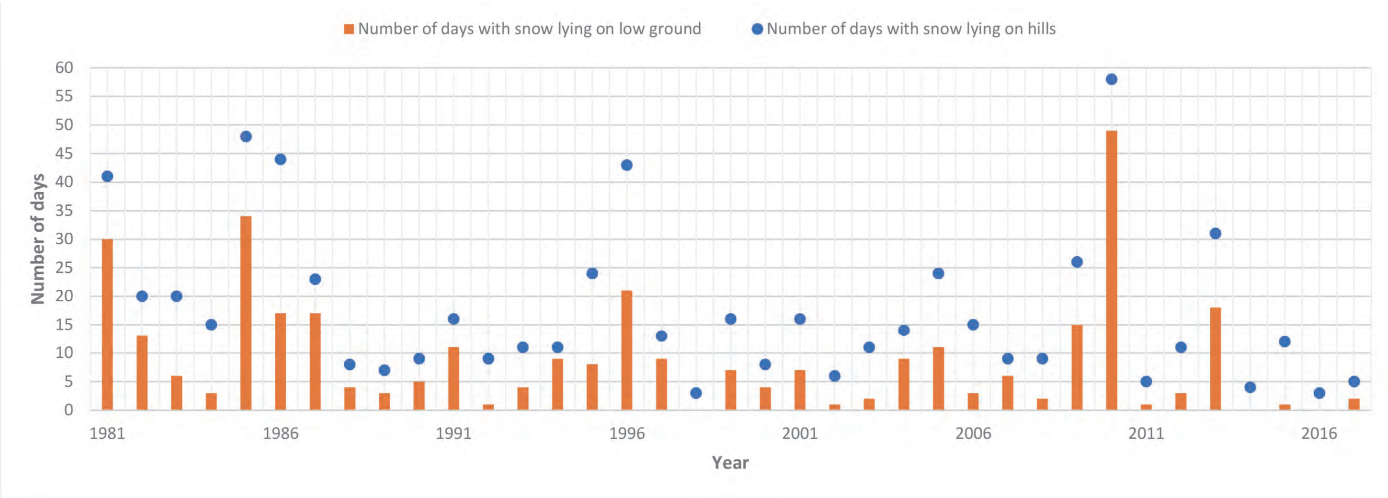
Falling snow begins to melt around 50m below the 0^oC level and melting is usually complete after falling another 100 to 150m. If the air temperature it is falling through is only a degree or so above zero, the snow will persist longer. Also, if the snow is moderate or heavy in intensity, it cools the air it is falling through so that the 0^oC level may be lowered and the start of melting delayed. In such cases, snow may survive for another 100 to 200m, so that what starts as rain or sleet on low ground may turn to snow. As a general guide, this is unlikely to occur if the temperature prior to the arrival of precipitation is above 4^{o}C. It is evident, therefore, that a quite small rise in the height of the 0^{o}C level and the temperatures below it could significantly reduce the incidence of snow on low ground.

Because the main falls of snow occur with winds from the east or northeast, and winds are stronger near the hilltops than on the lee side, snowflakes are often carried over the crest of the Hills and accumulate more on the western slopes than the east.

Fig. 4 shows the number of days each year from 1981 to 2017 that snow settled on low ground (below 100m above sea level) and on the hill tops (above 300m). To be included, the snow must have been at least 1cm. deep and covered at least half of most lawns and grassy areas. Snow lying on any of the Hills above 300m was accepted, but patches in gullies, etc, were not. Nor were small remnants of drifts.

In so far as average values are useful, the average annual duration of snow lying on low ground from 1981 to 2017 was 10 days, ranging from 0 to 49, and on the upper hill slopes was 18 days with range 4 to 58.

Figure 4: Number of days snow lay on low ground and hills 1981-2015 (at least 1cm deep)



THUNDER AND THUNDERSTORMS

The occurrence of ‘thunder heard’ is noted by observers at most climate stations every day, where the ‘day’ means midnight to midnight. This enables the average number of days with thunder per month and per year to be calculated.

The total number of days with thunder at Malvern for the 30 years from 1989 to 2018 was 258. The average of 8.6 per year is fairly typical for most parts of the west Midlands, which vary from 8 to 10. The east Midlands and SE England have more frequent days with thunder, generally in the range 10 to 15. This is because they are more prone to storms moving north from around Paris and NE France in the late afternoon and evening, whereas most of the storms over Worcestershire originate over Biscay and NW France.

No. of days per month that thunder was heard at Charles Way, Malvern during the 30 years from 1989 to 2018.

Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep	Oct	Nov	Dec
1	2	4	23	43	41	51	55	23	12	0	3

As expected, thunder occurs mostly in summer, but there is a significant frequency in April. In 14 years, the first instance of thunder occurred in April.

Because thunder is essentially a phenomenon caused by the lifting of warm moist air, one might expect more to occur in warm summers than in cool summers. This is true of summers which were warmer than normal overall but comprised short unsettled spells, in which case there may be around ten days with thunder, but the very warm summers of 1995 and 2018 had only 4 and 2 days respectively.

However, such data does not tell us how often the thunder was associated with a significant thunderstorm. Because thunder can be heard for several miles from its source, it can often be heard without it passing directly over the observing site. This is particularly relevant to the Malverns as most thunderstorms approach us from the south ahead of a trough or cold front which is moving from the west. The front may be moving quite quickly, so that there is only an hour or two for storms to occur. Further, the slight descent of the air over the Severn Valley sometimes causes storms to weaken for a while before intensifying again as they traverse the rising ground of NE Worcestershire.

I have therefore examined the daily records to determine how many of the 258 days with ‘thunder heard’ included a period of heavy rain totalling at least 10mm (56), or a period of frequent thunder and lightning lasting at least an hour (17), or both (10). This relatively low occurrence of severe storms should give some comfort to those people with astraphobia, although one can never predict when the next one will occur!

SUNSHINE DURATION

The measurement of sunshine duration throughout the C20 was made with the Campbell-Stokes recorder, which comprises a glass sphere that focuses the sun on to a card which is specially manufactured to record bright sunshine but not diffuse sunshine. It remains the standard recorder at long-term climate stations although modern electronic instruments are now more popular as they are easier to mount in elevated positions.

The main problem with recording sunshine is to find a site that is not shaded from the sun at various times during the day. Nearly all gardens lose sun early or late in the day and even the most open climate stations are prone to this. Buildings with accessible flat roofs are sometimes used. The problem is particularly relevant to the Malvern Hills as locations on or near the hills (even those on buildings) may lose up to two hours of sunshine in the morning or evening.

We are fortunate, therefore, that, from about 1910 to 1954, measurements were made from an elevated site in West Malvern, north of the Wyche Cutting, at a height of 303m ASL. This site lost only a short period of sun early in the morning. I regard it as providing the best estimate of average monthly and annual sunshine duration we are likely to obtain in the Malverns, and therefore quote the data, even though it refers to the period from 1921 to 1950. There is no reason why amounts of sunshine should fundamentally change, even though some small variations over 30-year periods are inevitable.

Mean monthly and annual sunshine, West Malvern, 1921 to 1950 (hrs)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
hrs	58	72	123	154	188	201	187	180	139	105	64	54

This gives an annual mean hours of sunshine 1,531 hrs.

This compares favourably with the data I obtained from an electronic recorder mounted on the south side of our house, which gave a mean of 1,476hrs during the period 1981 to 2010.

Malvern's sunshine is not greatly different from that at most sites in central southern England. The 1921-1950 publication by the Met. Office gives 1,442hrs at Cheltenham, 1,482hrs at Oxford and 1,460hrs at Kew Observatory. Sunshine at sites in smoky cities was much lower at that time (e.g. Bradford 1,217hrs). The sunniest sites were (and still are) near the south coast, including Sandown (IoW) 1,840hrs and Worthing 1,838hrs. Measurements for 1981 to 2010 include Weymouth 1834hrs, Hove 1870hrs and Eastbourne 1888hrs. These consistently higher values are not just because it is easier to find sites with open views to the south but also because convective cloud develops inland during the summer rather than over the coast.

Monthly totals in summer vary greatly from year to year, from around 300hrs at best to around 100hrs at worst. The sunniest months on record are June 1925 with 316hrs and June 1957 with 307 hrs. The dullest summer months were June 1997 (97hrs) and August 2008 (106hrs).

OCCURRENCE OF 'POOR' AND 'FINE' SUMMERS

The very warm and dry weather which has occurred in the summer of 2018 has sparked renewed speculation regarding the impact of global warming, with some 'experts' speculating that this will become a more frequent occurrence in the future. Not long ago, after very wet summers in 2007 and 2012, we were warned to expect summers to become wetter due to global warming. I have examined the evidence provided by Malvern data since 1951.

For brevity I shall describe the summers as 'poor' or 'fine'. The former were either wet or cold so the description is acceptable to most people. The latter were notably warm, dry and sunny, which can create problems for farmers, gardeners, river and water managers.

Following the warm and dry summer of 1995, I devised an 'index' which incorporates temperature, sunshine and rainfall. The objective was to produce one that gives a score of around 500 for an average summer and could range from around zero to 1000 for the extremes. I decided to use:

Index = S + T* - R where S is the (total sunshine in June, July and August) divided by 2 and R is the total rainfall in mm. T* is the (average daily maximum temperature minus 18) X 100, The resultant values are plotted in tabular form below and in graphical form in fig 5

	Summer indices (June, July, August) from 1951 to 2018									
1951	248	274	170	-110	448	120	308	239	650	338
1961	454	229	263	334	106	248	506	179	453	323
1971	249	193	420	296	781	943	117	180	333	142
1981	522	334	907	800	203	258	304	246	794	718
1991	429	349	450	602	929	664	477	354	560	480
2001	486	447	721	460	574	812	132	313	320	442
2011	476	83	646	484	402	516	478	846		

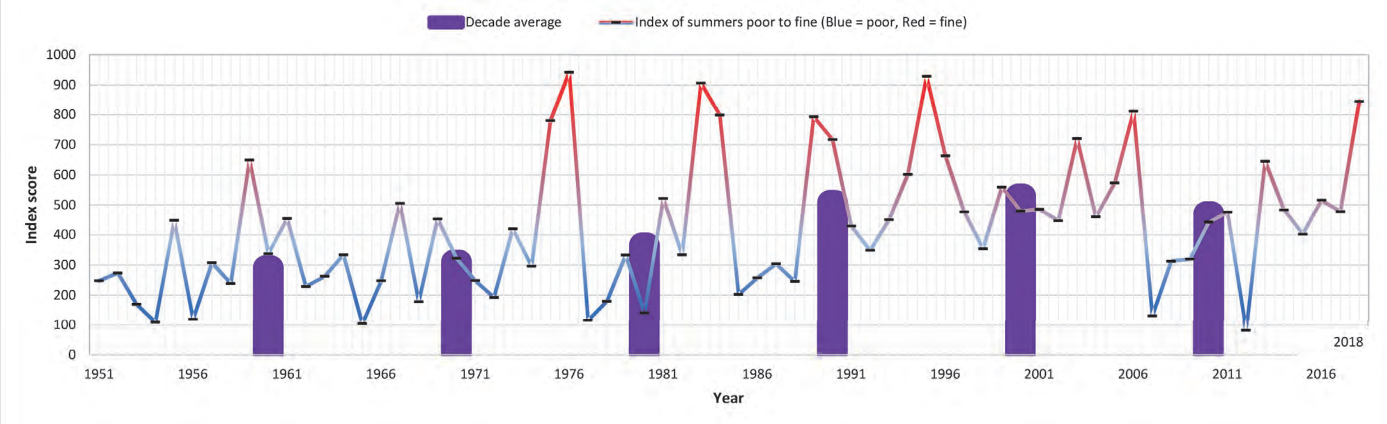
There are 12 summers with scores of around or below 200 (in blue) and seven with scores of around 800 or above (in red).

Most of the poor summers occur in the top half of the table and reflect the lower temperatures that were experienced before the warming trend that set in during the 1970s. 1954 was the only summer with a mean maximum temperature below 18^{o}C. In recent years, the low scores of 2007 and 2012 were due to very wet summers, with rainfall of more than twice the normal.

The summers with the highest scores were in 1976, 1983, 1995 and 2006. It is evident that at least one exceptional summer occurred in each decade from the 1970s onward. Hence I prefer to regard the 2018 summer as being an overdue event rather than a fore-runner of more frequent warm summers.

The main characteristic of the ‘finest’ summers is that they usually include a quite long period without rain. Periods of around 10 dry days are normal in most summers and are often welcomed by farmers if there has been unsettled weather, but those that continue to beyond 20 days invariably cause problems for farmers, gardeners, river and water managers.

Figure 5: Annual and decade average index of summers



I need to define what I call a dry spell. It is a period in which there has been no measurable rain for at least 10 consecutive days and it does not end until there has been a fall of at least one mm of rain in 24 hours. Hence it is permissible for a very slight shower to occur without breaking the dry spell.

Here is a list, in chronological order, of the longest dry spells on the Malvern Hills since 1970.

1975	16th June to 8th July	21 days 6 hours
1976	21st July to 28th Aug	37 days 21 hours
1989	9th July to 29th July	20 days 12 hours
1995	17th June to 10th July	23 days
1995	31st July to 23rd Aug	22days 4 hours
2018	17th June to 13th July	26 days 4 hours

FOG FREQUENCY

The view from the Malvern Hills of the top of fog, stretching as far as the eye can see across Herefordshire and/or Worcestershire, is an unforgettable sight. It occurs quite frequently in autumn and winter, and is most memorable when the adjacent low ground is shrouded in freezing fog while the upper slopes are in sunshine with a temperature above 10^{o}C.

Fog is defined as a visibility of less than 1000m caused by the suspension of very small water droplets. It is subdivided into thick fog (less than 200m) and dense fog (less than 50m). About half of autumn and winter fogs are thick for a time, but dense fogs are quite rare.

Statistics on fog frequency in any area are more difficult to obtain than might be imagined, as climate stations routinely record its presence only at the 0900GMT observation. Fog that occurred earlier or later in the morning might be noted by the observer but there is no column in the climatological summary for it to be recorded. Anyone who is out and about early in the day will know that many fogs disperse before 0900GMT. With this in mind, I have kept statistics of fog at any time of the day as seen from our observing site at Charles Way since my wife and I began to make hourly observations for the Met. Office in 1983. This was a good observing site when Townsend Fields lay to the east, but the building of houses, commercial buildings and a retail area on these fields has obstructed the view of some fogs. I am therefore quoting statistics for the period 1983 to 2002 only.

NUMBER OF MORNING FOGS OBSERVED AT CHARLES WAY

1983-2002

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
100	73	66	46	36	18	25	31	63	92	123	116
Total 789											

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NUMBER OF FOGS OBSERVED AT 0900GMT 1983-2002

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
48	39	18	4	2	0	0	1	11	38	37	35
Total 318											

As expected, very few early-morning fogs survive until 0900GMT from early April to mid-September.

This gives a good idea of fog frequency on the eastern side of the Malverns. Most of them originate during the night or early morning over the damp fields of Longdon, Castlemorton and Guarlford and drift north or west onto the lower slopes of the Hills. They are most likely to occur when winds are very light and from the east or southeast. The formation of fog close to the Hills overnight is, however, either delayed or prevented if the air is flowing from the NW or north, as this encourages a katabatic down-flow over the eastern slopes which disrupts cooling of the air to below the fog-point. In such circumstances, fog may arrive on the eastern slopes of the Malverns around mid-morning in the form of drifting fog or low stratus once the katabatic has died away.

Fog frequency over the Herefordshire valleys is roughly the same as over Worcestershire, judging by data from Bromyard, but does not usually occur on the same nights as easterly winds are unfavourable for its formation.

Of course, fog may become widespread enough to produce the extensive layer seen from the hills. The fog top is typically around 100m in the early morning and gradually rises, reaching around 250m by late morning. On some occasions, only the peaks of the hills may remain visible. Meanwhile, the fog clears from low ground and lifts to stratus before clearing away.

malvernhills
Area of Outstanding Natural Beauty

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