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Studies of snowfall and thunderstorms in the four seasons.

by

William S. Pike & Jonathan D. C. Webb

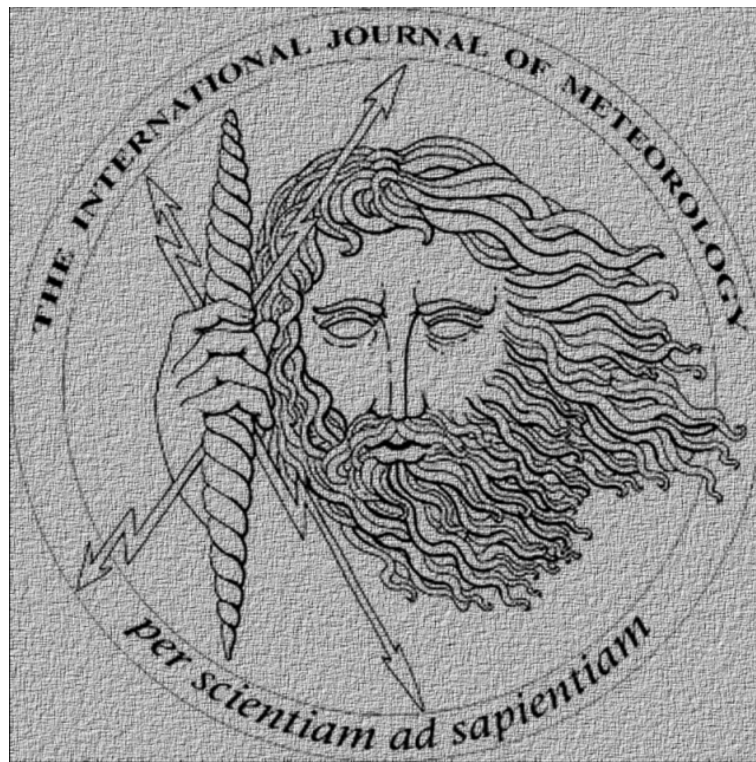
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Part I REMEMBERING A DETACHED DUTY AT RAF FAIRFORD FIFTY YEARS ON. PART ONE— FA CUP FINAL SATURDAY 18 MAY 1968, A LATE SEASON POLAR LOW.

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Abstract

The late-season polar low of 18 May 1968 can be identified by firstly its similar track to the early-season feature of 8 December 1967 and secondly by its characteristic double-tropopause on soundings, indicating the presence of polar maritime (Pm) and arctic maritime (Am) airmasses. A snowfall occurred over high ground from Wales and the English Midlands northwards (for example above 1000ft (300m) elevation on Clee Hill, Shropshire). Precipitation associated with a 'wrap-around' frontal system became re-invigorated during the day on Saturday as the many spectators watching the F.A. Cup Final would have testified. The polar low engaged air from over the relatively warm waters of the Bristol Channel and the English Channel during the day. Embedded thunderstorms then occurred near the 'triple point' of this frontal system as it moved eastwards during the morning. South Farnborough, Gatwick Airport, West Malling and London Heathrow Airport all recorded over 20mm of rainfall, most of which fell before the Cup Final kicked-off at Wembley in North West London at 3 PM.

1 Why Fairford? An historical introduction.

An original 1940s design, the Blackburn Beverley C1 aircraft were assigned to No.47 Squadron Transport Command, RAF Abingdon and had been in worldwide service since March 1956 (Bowyer, 1983, pp 59-60). Some ten years on, the airframes were getting "worn-out" and becoming the butt of jokes with aircrew calling them "twenty-thousand rivets flying in loose formation". After a farewell fly-past at the September 1967 Battle of Britain air display, most of these elderly Beverleys, apart from a few that were destined for museums, departed from Abingdon to be broken-up at Shawbury. I watched them go during November 1967, often in pouring rain.

The squadrons of Handley-Page Hastings, by then at RAF Colerne (near Bath), were also suffering age-related problems (e.g. metal fatigue) and were being re-equipped with new Lockheed Hercules C-130s the first of which had arrived at Cambridge Airport on 19 December 1966 (Marshall, 1994, p 303). Colerne was designated the main engineering base for the Hercules which were flown in from the United States from April 1967 (Ashworth, 1982, p 68) before they entered squadron service at RAF Lyneham. New techniques of re-painting and other technical modifications were accomplished by Marshall of Cambridge (Marshall, 1994, pp 302–312) and, as the potential of these amazing new aircraft was realised, RAF Transport Command was renamed Air Support Command on 1 August 1967, with the headquarters then at Upavon, Wilts (Ashworth, 1983, p 199)¹

¹Incidentally, Sir Arthur Marshall's autobiography is a mine of information, and tells us the specifications of Sir John Mason when the Met Office Research Flight made the order for a modified Hercules Mk.2 (nick-named 'Snoopy') which was made in 1971 (see Marshall (1994), pp 307–309).

Since it started operational life as a 38 Group Transport Command airfield in March 1944, RAF Fairford had had a chequered career. At first, two squadrons of Short Stirling aircraft were worked-up for towing Horsa gliders carrying airborne troops involved with D-Day operations on the 5th and 6th of June 1944 and later with the ill-fated Operation Market Garden from the 18th September 1944. These Stirling aircraft suffered grievous losses in attempting to re-supply airborne troops beleaguered at Arnhem on the 21st of September (Bowyer, 1983, p140).

After the war the Americans took command of RAF Fairford (under their Marshall Plan in 1950-51) then enlarging the base and lengthening the main runway². The RAF re-possessed Fairford in June 1964 and, after a relatively quiet interlude, it seemed to fit in perfectly with the base's wartime history that Abingdon's old No.47 Squadron should re-equip with Hercules aircraft there from mid-February 1968. A Mobile Met Unit (MMU) had covered RAF flying requirements periodically at Fairford since 1964, but when the station rejoined 38 Group Air Support Command from 1 March 1968, staff from other 38 Group stations could be tasked with *detached duties* subsequently and a more permanent Met Office was established there.

With its long-established *public service duties*, Abingdon was still my permanent station in 1968, but the MOD (Ministry of Defence) (Air) paid our wages and after three years service I was considered experienced enough to complete such a detached duty planned for three weeks (i.e. 13 May to 4 June) to be part of a team of three Scientific-Assistants who were covering flying at Fairford. This duty was to record and report actual weather conditions on the airfield as accurately as possible to Air Traffic Control (ATC) at times when they were open. The safety of life on board aircraft, especially during the potentially hazardous times of take off and landing, depended on this information.

For this responsible job, I was asked to volunteer by our then Senior Scientific Assistant at Abingdon, George Giles, who explained, by way of background, that a second squadron (No. 30) of Hercules was due to be formed at Fairford in June, prior to future Concorde testing due on Fairford's long runway in 1969. George emphasised that the full Civil Service Subsistence Allowance for a Detached Duty would pay for my board and lodging at the local White Hart Hotel in Fairford Village. Although 19 years old I had yet to pass my driving test, but was obviously considered capable of staffing a met office by myself on weekends and public holidays. So, after discussion with my parents, I had to rely on my father to transport me, plus a fashionable blue Moulton bicycle, plus less-fashionable waterproofs, in our family Austin A30 car to the White Hart Hotel in Fairford on Sunday May the 11th 1968.

2 The Met Office at Fairford, Gloucestershire

Our instruments at Fairford seemed very basic compared to those at a fully-equipped station (for example Abingdon or Little Rissington in 1968). The instrument enclosure contained a Met Office standard large Stevenson Screen, with the four usual liquid-in-glass thermometers then used for recording.

- Dry bulb temperature.
- Wet bulb temperature.
- Maximum temperature.
- Minimum temperature.

Also, there was an over-reading thermograph (which I took on myself to adjust on May 20th), a hygrograph, and inside the office, a barograph beside our standard *Station Kew Pattern* barometer.

First thing on Monday the 13th, I familiarised myself with all of our local *visibility points* (the indispensable list of objects which were at known distances from the office) that we needed to estimate the visibility. I was glad to have done so when required to open up the office, having collected our keys from the base guardroom,

²Goodness knows what stories they had heard about how thick the fog could get there in the Upper Thames Valley, because our American allies seemed to take a particular liking for our *cats' eyes* and installed these useful visual aids for drivers at approximately one-foot (about 30cm) intervals on several of the more-important base roads, especially around corners!

on Thursday the 16th, when there was an early morning patch of fog in sight for the 0500 UTC observation. There were no ‘luxuries’ such as a grass minimum thermometer, nor did we have a Campbell-Stokes Sunshine Recorder, nor (more importantly in my view) did we have any kind of rainfall event recorder (for example a Dines Tilting-Syphon or a Tipping Bucket Rainfall Recorder) to judge intensities with. We did have one proper five-inch diameter rain gauge, well-exposed in the enclosure, but we were only required to read this ‘religiously’ at the main synoptic hours (i.e. 06, 09, 12, 18 & 2100 UTC).

On the ‘upside’, our Met Office building at Fairford had an extremely useful armoured-glass skylight window in the roof overhead, which, with practice, gave the diligent observer a clear idea of precipitation type and intensity.

3 A polar low forms: the surface synoptic situation 17-18 May 1968

From the large-scale surface charts (see the relevant Met Office Daily Weather Reports (DWR) or Royal Meteorological Society (RMS) Weather Log) a large anticyclone (‘High G’) was well-established and slow-moving with central pressure over 1036hPa in the vicinity of southeast Greenland and Iceland on Friday the 17th of May 1968. With low pressure over much of eastern Europe, a cold north to north-easterly airflow was becoming established over the British Isles. It was our winter’s last ‘swipe’ at us!

The fall of pressure and light south-southwesterly wind first noticed by 1200 UTC on the 17th at Belfast Aldergrove Airport suggested that a new feature (‘Polar Low P’) was beginning to form nearby over Northern Ireland, with a modest central pressure of 1027hPa by then (see Figure 1 for continuity).

By 1800 UTC on the 17th, there was a definite ‘Polar Low P’ being analysed on the DWR, with closed circulation and central pressure down to 1024hPa near Dublin (see Figure 1 also). This was a much less deep feature than that of 8 December 1967 (see Pike, 2013, p 25). Its track, from Belfast to Dublin to the Pembrokeshire Coast and the initial rate of deepening (i.e., by 1hPa hr⁻¹) was remarkably similar to the characteristics of the early-season feature.

The rate of deepening of the warm-cored feature appears to have been arrested as the centre passed over the land surface of South Wales, but it then re-invigorated as it crossed the warmer waters of the Bristol Channel, and we find the lowest central pressure associated with ‘Low P’ was 1018hPa recorded at Bournemouth Hurn Airport at 1200 UTC on May 18 1968 when it reached the English Channel. A ship reported a sea surface temperature of 13°C near the Channel Islands (see Figure 1).

Figure 2 is intended to give a clearer idea of the frontal system wrapped around ‘Low P’ at 1200 UTC. Embedded thundery activity had passed eastward during the morning (see observations in next section) apparently associated with the *triple point* of this system. Sea temperatures in the southern North Sea were still at a bracing 9°C, and only hardy souls were attempting paddling let alone bathing this year on Cup Final Saturday.

Figure 3 shows that the occlusion wrapped around ‘Low P’ was regressing southward by 1400 UTC, although the triple point was still making good progress east-southeastwards near Dungeness at this time, while the centre of ‘Low P’ was passing out over the English Channel, filling slowly. Locations of the main observing stations (mentioned in the next section) are shown here in Figures 2 and 3.

4 Observations on Saturday 18 May 1968

The Met Office at RAF Shawbury, Shropshire is on low ground at 76m a.s.l. so never reported anything more solid than cold rain with a minimum temperature of 2°C just before 0600 UTC (see the DWR). We find that this was approximately when Bob Prichard (and his milkman) saw snow falling at Keele, Staffordshire, which is situated on a ridge above 500ft (195m altitude) (Prichard, 1992, p 476). Keele is also only about 8 miles (12km) from the higher ground of around 300m where the Pennines begin to the north-east of Stoke-on-Trent .

The general snow-line appears to have been at about 300m in the area because for some time between 0600 and 0900 UTC observations snow was reported to have fallen and settled to a depth of “half-an-inch” above the

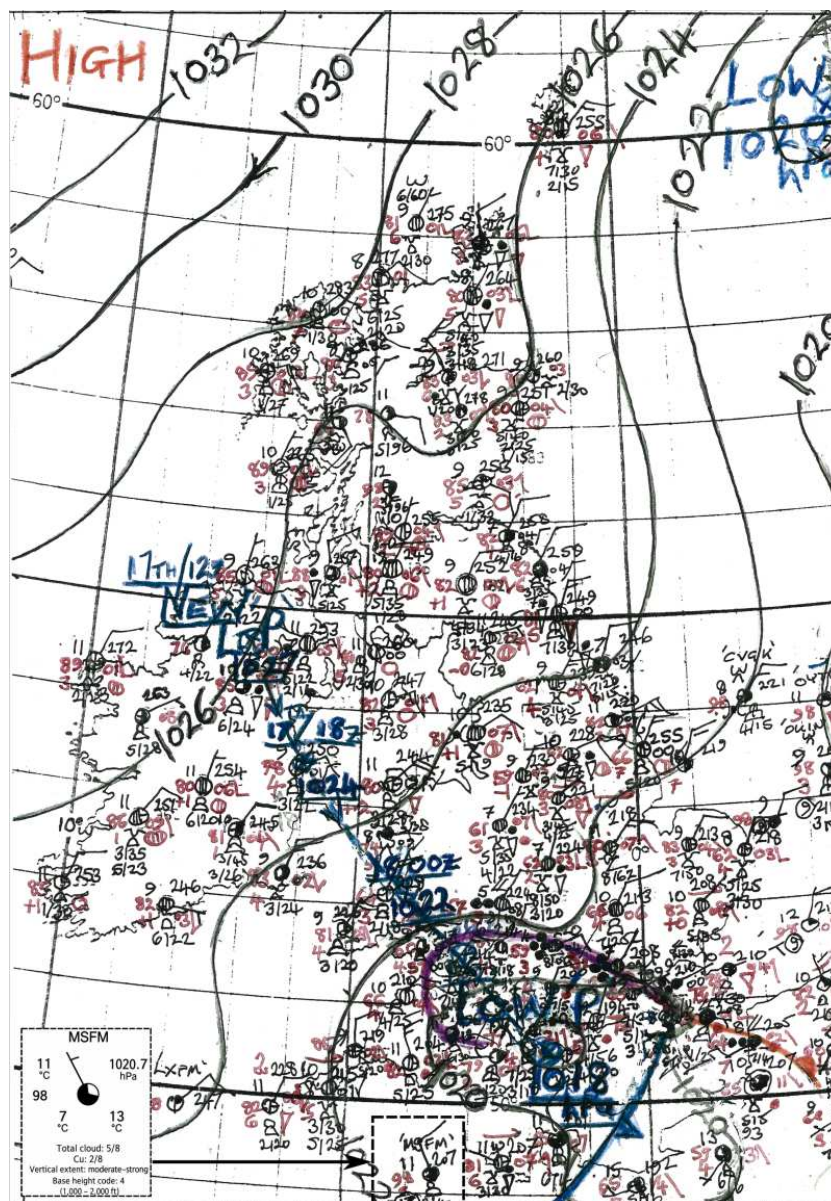


Figure 1: British Isles surface synoptic chart for 1200 UTC on Saturday 18 May 1968, with the continuity of the centre of ‘Polar Low P’ indicated at 6-hour-intervals. The ship ob mentioned in the text is highlighted by the dashed box and inset. Plotted and analysed by the author, based on information supplied by the Met Office. Drawn on an enlarged section of METFORM 6737, as amended June 1971 by the Met Office Cartographic Section, Met.O 18d, Bracknell. Crown copyright 1971.

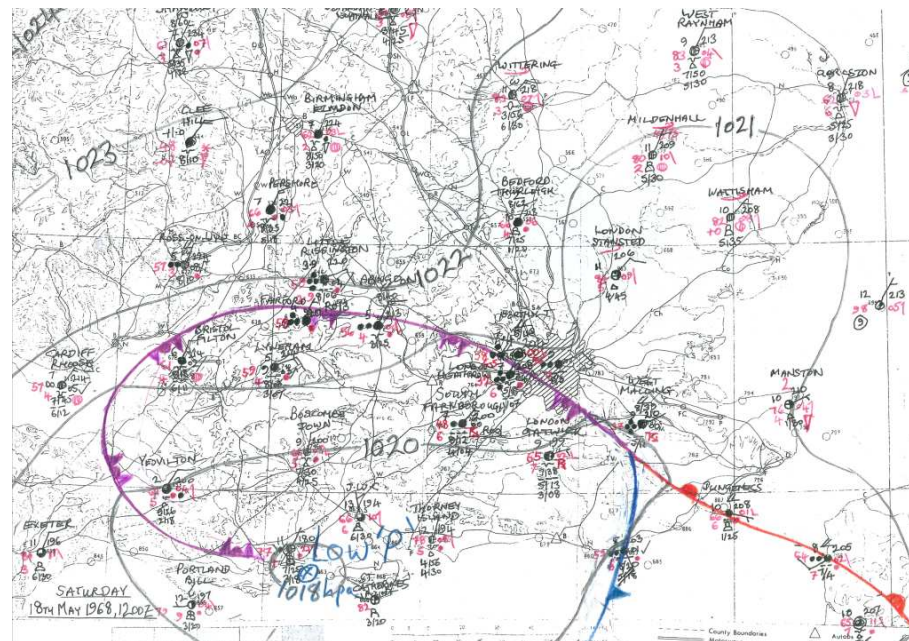


Figure 2: Enlarged section of the surface synoptic chart for 1200 UTC on Saturday 18 May 1968 for England and Wales. The isobars are drawn at 1-hPa intervals. Plotted and analysed by the author on METFORM 6791B. Crown copyright 1968.

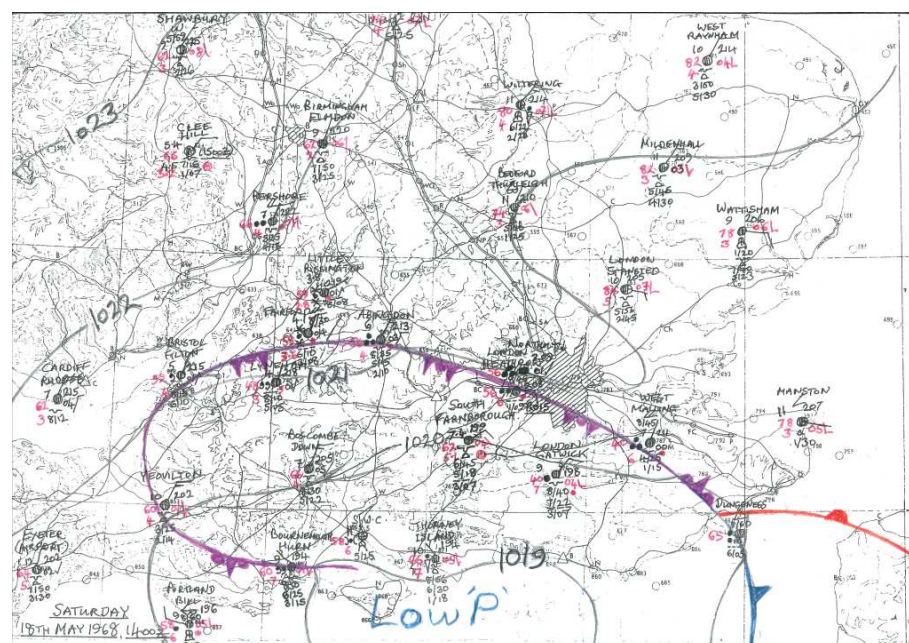


Figure 3: Enlarged section of the surface synoptic chart for 1400 UTC on Saturday 18 May 1968 for England and Wales. The isobars are drawn at 1-hPa intervals. Plotted and analysed by the author on METFORM 6791B. Crown copyright 1968.



Figure 4: Selected surface observations from 0600 to 1500 UTC on Saturday 18 May 1968. Plotted by the author from information supplied by the Met Office. All Times are UTC.

elevation of the radar station on Brown Clee Hill (172ft/540m a.s.l.) in Shropshire (see remarks column of the Daily Register).

It was also pouring with cold rain at Fairford when I donned my waterproofs to cycle the two miles into the met office, attempting to get there in time to make the 0600 UTC observation. I was late, but still managed to open the office, make and transmit the readings (dry bulb temperature 5.9°C, minimum 4.5°C, rainfall 4.0mm) by 0608 UTC. Fairford must have been just inside the wrap-around occlusion which was pushing westwards at that time, as the temperature was rising slowly then. After an early aircraft movement took off shortly after 0800 UTC, ATC closed for the time being and I was able to return for a late breakfast.

Further evidence that the situation was ‘frontal’ in nature came when the triple point was moving eastward and embedded thunderstorms in association with its passage began to be reported. Figure 4 shows the sequence of observations that were reported, mostly at the routine hourly times (but at Gatwick the half-hourly reports are also given). We find thunder being reported firstly at South Farnborough, northeast Hampshire from 0755 to 0840 UTC, then at Gatwick Airport, East Sussex, from 0900 to 0915 UTC, and finally at West Malling in Kent, from 1028 to 1040 UTC, where the observer described the electrical activity as a “moderate thunderstorm” in the remarks column. These storms occurred where warmer air from the English Channel had been engaged within the warm sector and forced to rise.

Figure 4 also shows that rainfall totals were not all that great at Gatwick and West Malling, where the frontal system passed eastwards relatively rapidly, compared to those hourly totals of between 6–7mm at Heathrow Airport around midday, when the occlusion was quasi-stationary nearby (see Figure 2). They recorded a maximum total of 20.2mm from 06 UTC to 18 UTC. Most of this fell before the kick-off of the F.A. Cup Final at Wembley in London. The first half of the match was described by Barber (1981) as “littered with trips, body-checks and sliding tackles” and by Greaves (1992, p 181) as having been “bogged down in midfield where there were too many players fighting for space”.

Back at Fairford, I was unable to watch the match because of having to cover flying during the afternoon. I’d discovered it was turning colder as the occlusion was slipping southward again (see Figures 2 and 3) during another wet cycle-ride into work. The thermograph confirmed my feeling that it was becoming fresher (see also

Figure 4) and, back in the Met Office, the skylight window now became invaluable. I saw some partly-melted snowflakes and, what the 1969 edition of *The Observer's Handbook* would have described as 'ice pellets type a' (defined as "frozen raindrops or largely melted and re-frozen snowflakes" (Meteorological Office, 1969, p56), which fell between 1300 and 1445 UTC with the rain. I could hardly believe my eyes, but the 1400 UTC observation from Little Rissington (just 12 miles/19km) to the north-northeast on the nearby Cotswolds, corroborated what I was seeing, by also reporting "ww=69". Later, I checked their remarks in the Daily Register which said "A little snow in the rain, 1325–1420" (UTC), but then they didn't have the benefit of an office skylight, in all probability, through which to view the wintry mix. I checked the minimum thermometer at Fairford, which told me the snow had reduced the reading to 3.1°C during the hour it was falling.

With the last aircraft movement made and ATC closing at Fairford, I was surprised the sleety mixture had penetrated down to the level of the station (260ft/79m a.s.l.). I closed the met office just after 1530 UTC, and (although underage³) was allowed into the Sergeants' Mess for a late tea, just in time to see Jeff Astle (1942–2002) score the 93rd-minute winner for West Bromwich Albion against Everton in the Cup Final. The mess had a colour television, still a rarity in 1968, so it seemed that my luck was in.

However, the day was not yet done and I was to find what 'covering flying' meant when you had to man the office single-handed at the weekend! ATC informed me that there was to be an evening arrival so could I please supply them with a 2100 UTC observation. This particular Hercules had flown a long-distance and developed a problem en-route from the continent, so it had "gone U/S" (declared unserviceable) at the nearest home diversion airfield, which was Manston in Kent, to await repair for as long as it took 'Engineering' to fix it! So, could I be good enough to send hourly observations and any "special reports" until such time that he arrived back home in Fairford!?

Of course I did my duty and the skies had completely cleared with a ground frost developing when the missing aircraft eventually returned under its own power to Fairford shortly after 0100 UTC on Sunday the 19th. The hotel would have been locked up for the night then and I decided not to disturb anyone, so spent the night getting what sleep I could on the met office camp bed that the S.Met.O (Senior Met Officer) had very thoughtfully provided in case there were any other problems to cover. I think it was my longest day duty ever from 0600 to 0100 (19 hours with breaks)!

5 The upper air

Figure 5 gives two soundings that would have been available to the forecasters at midnight 17–18 May 1968, from Hemsby (in blue) and Aughton (in red). Both are cold and unstable to sea temperatures. Hemsby is further into the arctic maritime (Am) air mass and is therefore drier and colder (1000–500 hPa thickness of 526.7 Dam) than Aughton (528.3 Dam) where there was a complete cover of low cumulus and stratocumulus clouds. Both ascents show the characteristic *double tropopause* which are similar to but less marked than those found to be associated with the polar low of 8 December 1967 (see Pike, 2013, Fig. 10 on p133).

The lower tropopause is associated with the Am airmass; the upper tropopause (with strongest winds just beneath it) belongs to the Pm airmass. Figure 5 also shows us that the dry bulb freezing level was down to around 940hPa, or approximately 2000ft (600m) at Hemsby on the Norfolk coast at around midnight. This is certainly low enough to be talking about snow penetrating down to 500ft (150m) given the air was relatively dry and would have had a lower height of the wet bulb freezing level (see Pike, 2001).

If we draw a low-level 850hPa contour chart (Figure 6) it can be seen that a trough at that level was extending westwards as it travelled southward, so the air from over the east Norfolk coast at midnight would have been approaching central southern England at midday, given the 15 knot winds being reported, with rain turning to sleet even at low levels in the vicinity of the Cotswolds between 1300 and 1400 UTC.

Figure 7 gives the soundings made at Crawley, which is quite near Gatwick Airport in East Sussex. Both midnight and midday ascents are very unstable to higher sea temperatures of above 10°C in the English Channel,

³You were supposed to be 23 years old to enjoy these privileges!

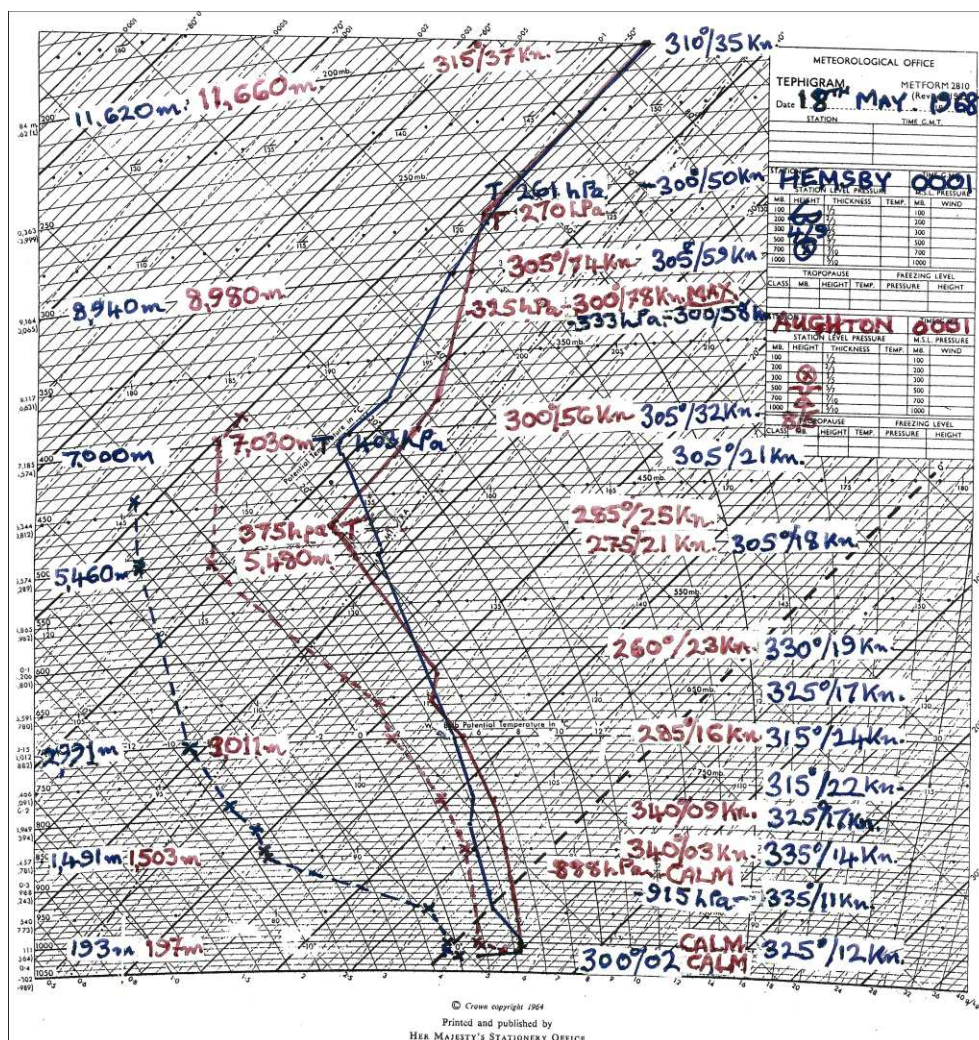
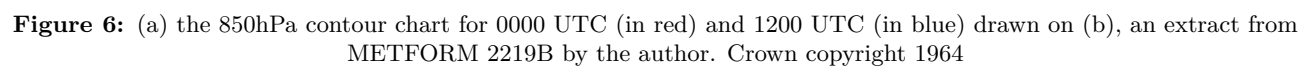


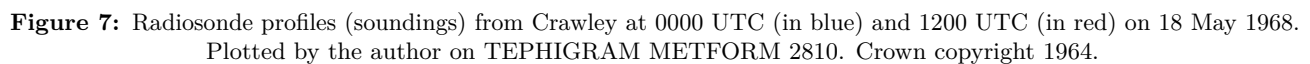
Figure 5: Radiosonde profiles (soundings) for midnight 17/18 May 1968 for Aughton (in red) and Hemsby (in blue). Plotted by the author on TEPHIGRAM METFORM 2810. Crown copyright 1964.

with a strong west-northwesterly jet stream in excess of 100 knots at around 300hPa which was driving the frontal system east-southeastwards at midnight. The double tropopause again became evident on the midday (red) ascent, the air becoming even colder and more unstable below about 20,000ft, hence the thunderstorm reports.

6 Remarks and conclusion

It was just 'bad luck' that the F.A. Cup Final fell on what the RMS Weather Log described as the coldest May day at Kew since 1954, with the temperature there only reaching 9°C on the 18th. It fails to mention the 20.2mm of rainfall recorded between 0600 and 1800 UTC during the day at nearby Heathrow Airport, where the temperature struggled up to 8.6°C during a dry interlude between 1700 and 1800 UTC, after which there was a further 1.8mm of rain as the occlusion moved south again during the evening, making a total of 22.0mm between 0600 and 2100 UTC there. The rainfall at Kew was a little less than at Heathrow, at 14mm between 0900 and 2100 UTC on the 18th. However, Wembley Stadium is actually closer to Northolt Airport, where, although 12.8mm had fallen, the rain had actually stopped by 1554 UTC, shortly before the second half started,





and a maximum of 9.6°C was recorded. So, conditions were improving during the match as time progressed.

It could have been worse, and might have been snowing, as keen-eyed weather observers had noted, to the south-east of high ground in the prevailing northeast winds, just downwind of the Pennines (Prichard, 1992) and in partly-melted form towards mid-afternoon at Fairford, downwind of the Cotswolds. In the light of present knowledge, with its double tropopause, this ‘Low P’ was a late-season polar low, which became re-invigorated when its circulation crossed the relatively-warm waters of firstly the Bristol Channel towards 0600 UTC and secondly the English Channel during the early afternoon of Saturday the 18th. A more-marked feature had passed south-eastwards just over five months earlier, giving more troublesome snow in the Abingdon area during an early-season northerly outbreak on 8 December 1967 (Pike, 2013). Similar problems were noted on the main A34 road, fifty years later, on Sunday 10 December 2017.

In May 1968, Weather Log tells us that “northerly winds kept temperatures well below normal until the 23rd when winds backed to south-east”. Thereafter, conditions became mild and changeable, with the last few days in the month being “sunny and warm”.

Although the DWR does not analyse a frontal system associated with ‘Polar Low P’, there seems little doubt that there was one between the Am and Pm air masses, with the reported thunderstorms moving eastward with its triple point during the morning, from northeast Hampshire to Kent. The increasing moderate to heavy intensities of precipitation recorded at Little Rissington over higher ground just after 12 noon on 18 May 1968 most probably brought down a near-zero-degree-celsius isothermal layer (see Stewart and King, 1984; Stewart et al., 1987) to a height where snow flakes were observed in the rain on lower ground level downwind of the Cotswolds at Fairford, Glos..

Acknowledgements

Special thanks are due the Met Office archive staff at Exeter (Catherine Ross, Mark Beswick and Duncan Ball) who have all contributed by kindly providing the observations used here. I’d also like to thank the former archivist Mick Wood, who allowed me access to charts at Bracknell when the Met Office Archives were in Scott House. I’d also like to thank Jonathan Webb of TORRO for encouraging me to write this article and for digitizing it for publication in the International Journal of Meteorology.

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Part II A RADAR STUDY OF THE SNOWFALL ACROSS THE ENGLISH MIDLANDS ON SUNDAY THE 24th OF JANUARY 2021, WITH A NOTE ON THE THUNDERY PRE-FRONTAL SHOWERS WHICH AFFECTED THE WINCHESTER AREA OF HAMPSHIRE.

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Abstract

Radar magery helps confirm surface observations that snowfall on January the 24th, 2021 reached a maximum depth of 15–23cm in a narrow belt from Staffordshire through Derbyshire, then stretching towards the Peterborough district of north Cambridgeshire, close to where a polar low's frontal systems had stalled. There was a secondary snowfall maximum of 10cm or more to the south of this main belt and running east to west through Warwickshire and Worcestershire from the south Birmingham area towards Tenbury Wells leading to the conclusion that a 'double structure' had probably been involved, with most of the snowfall associated with the leading occluded front. A coastal fringe of land adjacent to the warmer waters of the English Channel remained largely snow-free and saw cold rain falling instead. The 0600 UTC rainfall radar network image confirms the presence of a pre-frontal shower cluster over southern Hampshire, with an intense cell coming ashore in the Hurst Castle to Lymington area. Hail and thunder were reported soon afterwards, just west of Southampton at Ashurst Bridge and Totton. The cluster moved north-northeastwards (with the low-level pressure gradient wind) to affect the Winchester area by around 0630 UTC.

1 Introduction

According to the early-morning Shipping Forecast (broadcast at 0520 AM on BBC Radio 4, 22 Jan 2021) a deep low, *Storm Christophe* was centred over sea area *Tyne* at 951hPa by midnight, and was expected over sea area *Forties* (as a filling feature of 969 hPa) by midnight 22nd-23rd January 2021.

Figure 1 shows the remains of *Storm Christophe* still filling up at 988hPa between the Faeroes and Shetland, over the Norwegian Sea, by midnight on the 23rd to 24th, a mere shadow of its former self that had battered Merseyside and the Peak District of England 48–60 hours earlier. The cold Polar maritime (Pm) airmass on its western flank subsequently invaded much of north-western Europe, with the Tropical maritime (Tm) air associated with *Christophe* giving Ukraine and Belarus unseasonal warmth.

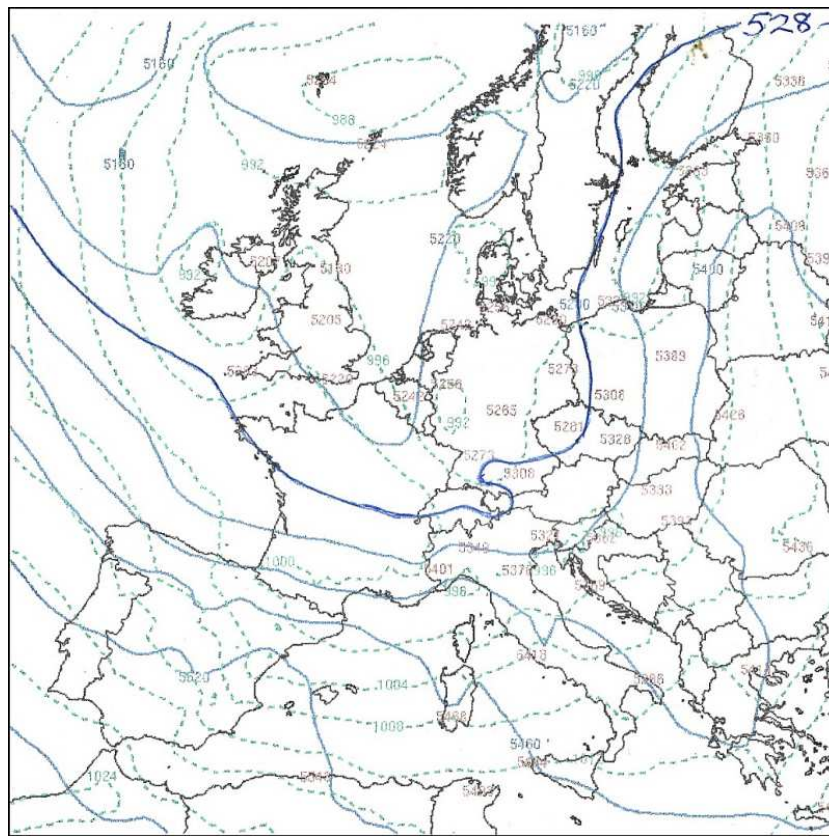


Figure 1: 1000-500hPa thickness (solid lines) and sea level pressure (dashed) chart for midnight 24 January 2021. Courtesy University of Wyoming, USA.

In the meantime, concerns were raised by UKMO Forecasters about an (‘old-fashioned’) polar low moving south-eastwards over County Mayo in north-west Ireland, centred at 992hPa in Figure 1. This feature was expected to bring snow to parts of southern Britain, probably as far north as the Midlands of England during Sunday the 24th of January 2021.

2 The midnight upper air soundings

At a corresponding time to Figure 1, the midnight ascent for Camborne, Cornwall, in Figure 2, shows a cold, moist Pm airmass, which was very unstable to the relatively high local sea-surface temperatures of +10/11°C. Above the low-level temperature inversion over the land surface, the air is best described as ‘returning Polar maritime’ (rPm) with winds from a south-westerly direction up to about the 450hPa level, above which the air becomes generally drier, with stronger winds of over 50 knots from the west-northwest. Some speed-shear is evident, reaching 80 knots just beneath the tropopause at about 320hPa. This would allow scattered cumulonimbus to develop over the sea producing heavy showers with the possibility of hail and thunder. The dry bulb freezing level is at 760m (2,500ft), with some wintry content expected in heavier showers, especially when they came inland over the moors of Cornwall, Devon and Somerset with cloud tops 25,000ft.

This ascent was made some distance ahead of the frontal systems associated with the polar low, then over north-west Ireland. However, the latent instability to sea temperatures goes some way to explaining the “copious hail” experienced in some southern coastal locations (e.g. by TORRO’s Mike Rowe, just after 0600 UTC at Lymington, who reported much small hail with some larger stones of 4-5mm across which were still lying for his 0900 UTC observation).

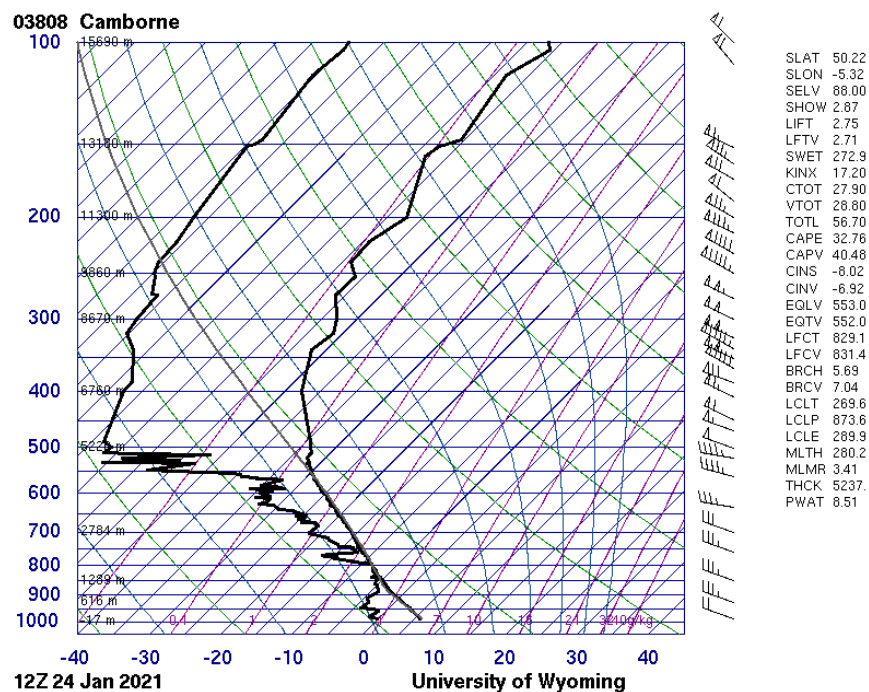


Figure 2: Camborne sounding for midnight 24 January 2021. Courtesy University of Wyoming, USA.

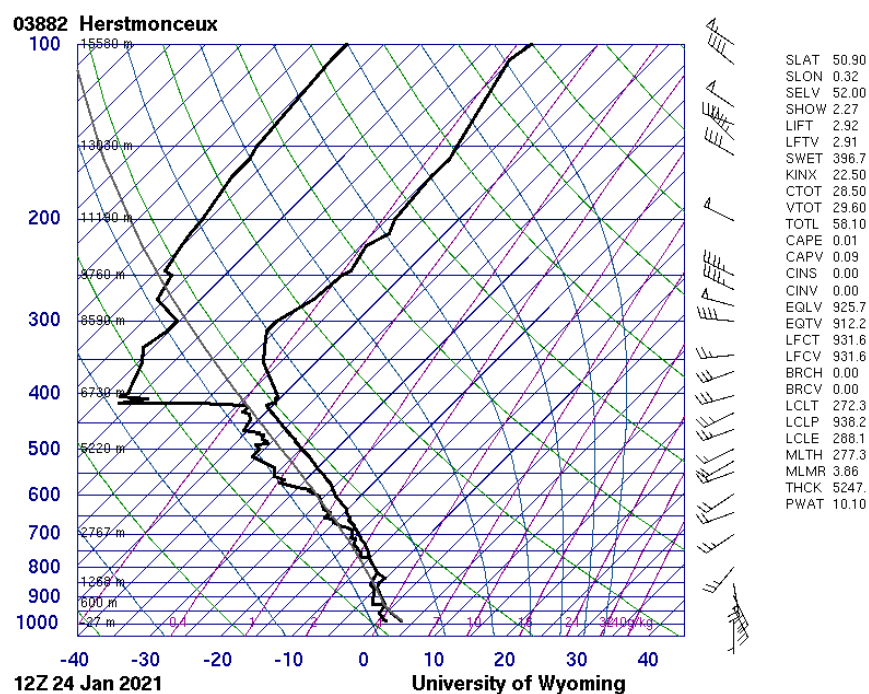


Figure 3: Herstmonceux sounding for midnight 24 January 2021. Courtesy University of Wyoming, USA.

Figure 3 gives the midnight profile for Herstmonceux, East Sussex with a small subsidence inversion from 880hPa (where the temperature is near isothermal at -5°C) ahead of a short-lived ridge of high pressure approaching from the west. With fairly clear skies, there is a radiation frost developing beneath a surface inversion, where the north-westerly wind has ‘dropped out’ to near-calm, or light westerly. The freezing level is at about 940hPa for the dry bulb but closer to 960hPa for the wet bulb temperature, with surface pressure of 993hPa, at 52m asl. This was fairly typical winter-time Polar maritime air, clear and cold with an off-shore northwesterly airstream.

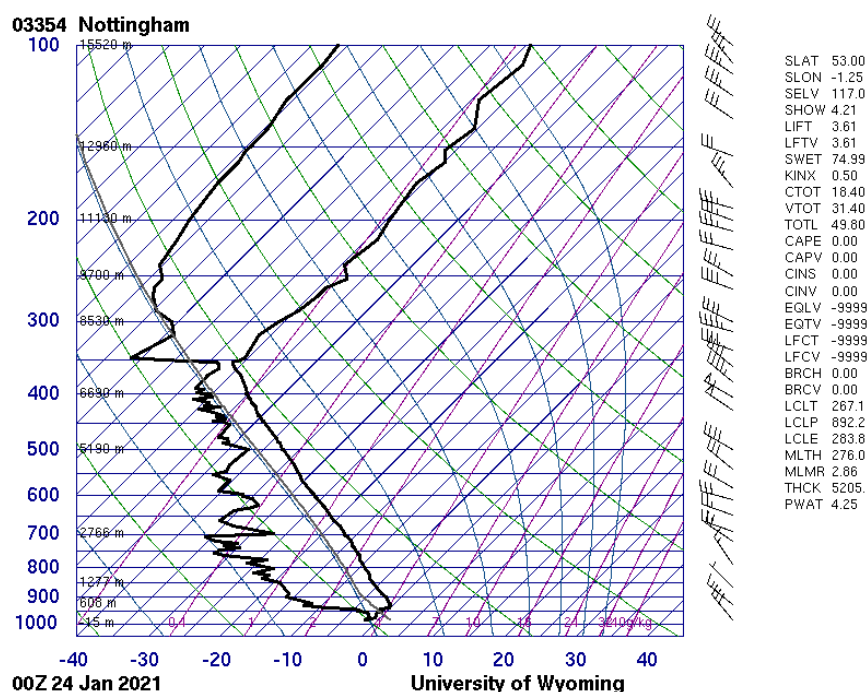


Figure 4: Nottingham sounding for midnight 24 January 2021. Courtesy University of Wyoming, USA.

Figure 4 gives the ascent for Nottingham, which is in the same Pm airmass, but is even drier than Herstmonceux due to air at lower levels having descended in the lee of the Pennines. There is a stronger low-level inversion near the surface, and a more severe frost was developing, exacerbated by the persistent wind continuing to blow from the north-west. In the wake of Storm Christophe, the Pennines had become snow-covered, and Leek/Thorncliffe (Staffs) was reporting 4cm lying at this time, with a patchy cover in parts of Birmingham also, due to snow showers coming through the Cheshire Gap from the Irish Sea. Care should be expressed in dealing with snowfall amounts during the 24th through parts of Staffordshire and the West Midlands due to a pre-existing 4–6cm (2–3in.) due to these ‘Cheshire Gap’ snow showers.

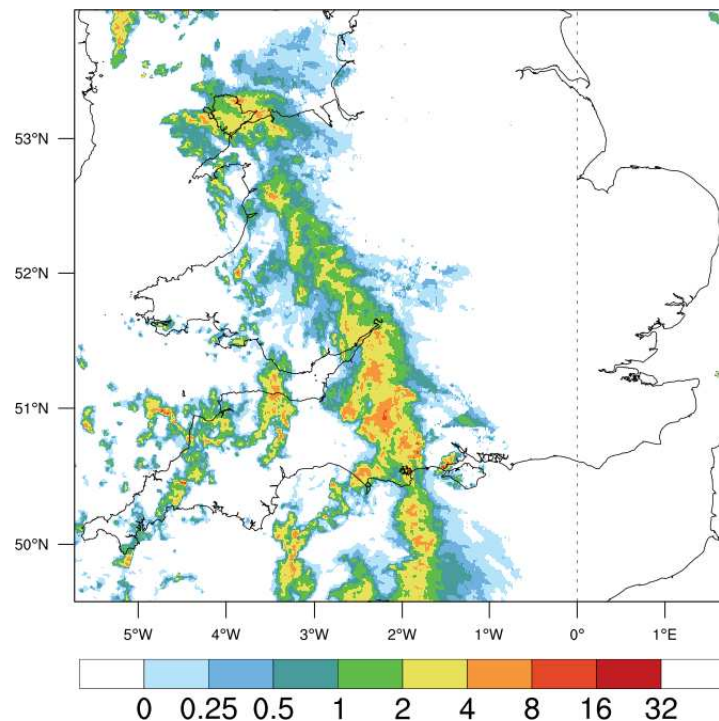


Figure 5: UK Met Office rainfall radar network image for 0600 UTC +10°C. (mm hr⁻¹). +10°C. Plotted from UK Met Office data archived at the Centre for Environmental Data Analysis (CEDA).

3 Radar imagery and mesoscale-synoptic charts

Representative ‘snapshots’ at three-hourly intervals of mesoanalysis surface charts and UKMO rainfall radar network imagery give an indication of the development and movement of the precipitation on Sunday 24 January 2021.

Figure 5 shows shower bands and areas of precipitation that were already affecting much of south-western England and Wales from Anglesey to the Severn Estuary by 0600 UTC. There is some evidence for a double frontal structure, with a second frontal band from the Llyn Peninsula to eastern Exmoor (around Minehead) at this time, and there are signs of these two frontal features merging into a single occluded frontal zone in the north around Snowdonia. Shower clusters and bands make frontal analysis more difficult over the warmer waters of the English Channel (where sea-surface temperatures were around +10°C). A red-coloured, small area of heavy precipitation actually containing hail (personal correspondence with TORRO’s Mike Rowe at Lymington) can be identified coming ashore over the Hurst Castle area of the Hampshire coast at this time.

Figure 6 shows a surface analysis of these features, with the polar low now centred at 993hPa and approaching western Wales, having travelled southeastwards from County Mayo in Ireland in six hours (see Figure 1). Heavy snow was being reported at RAF Valley on Anglesey, and there is a band of frontal snow associated with the leading occlusion stretching southeastwards towards Bristol and Somerset. Although it had reached western parts of Bournemouth, this frontal band of precipitation (mostly falling as a cold rain near the south coast) had yet to reach Hurn Airport by 0550 UTC, and therefore, the convective precipitation over the Lymington area of Hampshire should be classified as ‘pre-frontal showers’. Several correspondents subsequently reported that these showers had produced hail and claps of thunder over the Ashurst Bridge-Totton area (just west of Southampton) and had come inland as far as the Winchester area by around 0630 UTC, when thunder was last heard. If it had moved north-northeastwards with the low-level winds ahead of the incoming front, the red area mentioned in Figure 5 could well have been the beginnings of this storm. Figure 6 also shows that it had been cold and frosty further east and north with temperatures as low as -7°C reported in the Vale of York.

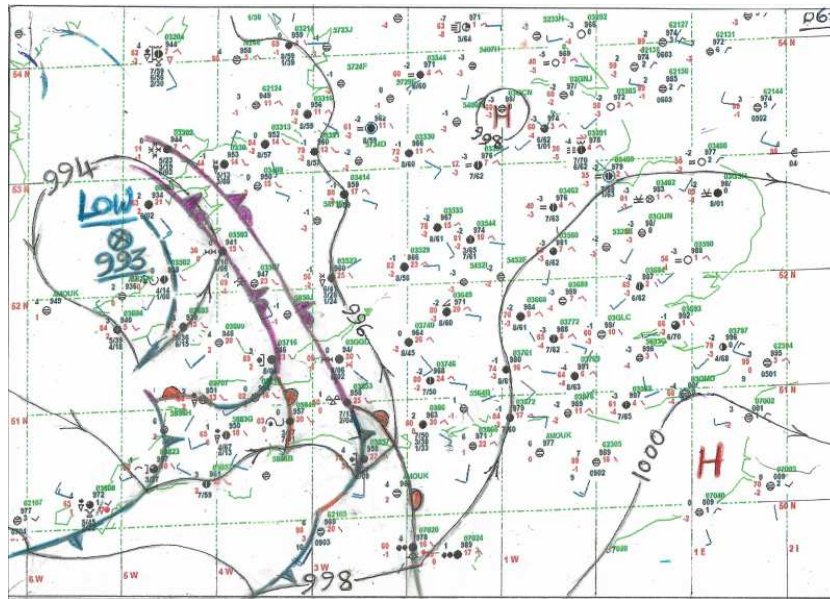


Figure 6: Mesoscale-synoptic surface chart for 0600 UTC, with analysis by the author, based on information supplied by the Met Office via the Centre for Environmental Data Analysis (CEDA).

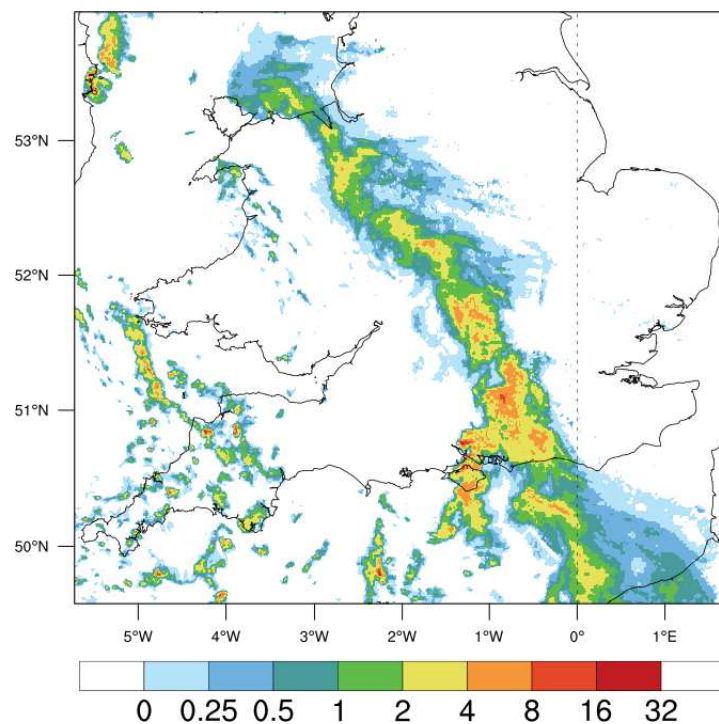


Figure 7: UK Met Office rainfall radar network image for 0900 UTC (mm hr⁻¹). Source: UKMO/CEDA.

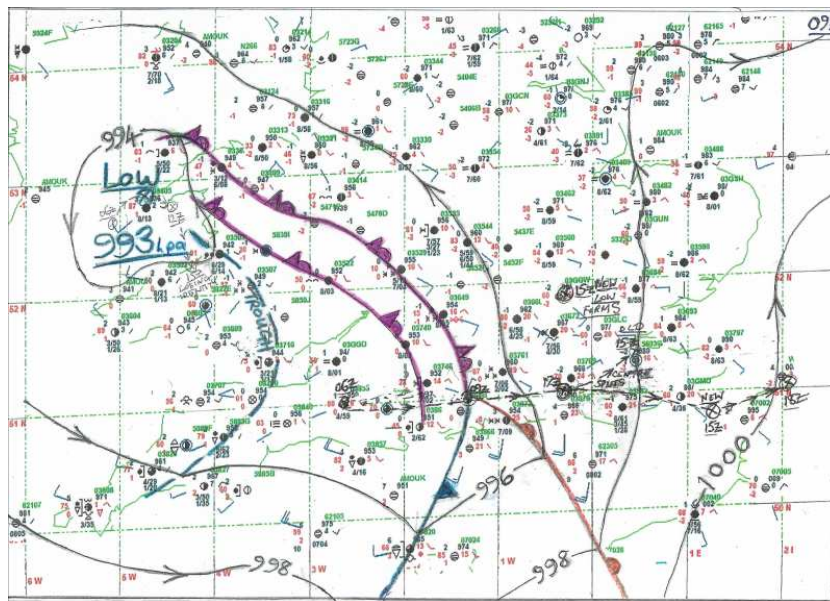


Figure 8: Mesoscale-synoptic surface chart for 0900 UTC, with analysis by the author, based on information supplied by the Met Office via the Centre for Environmental Data Analysis (CEDA).

Figure 7 gives the rainfall radar imagery for 0900 UTC, with the main band of frontal precipitation having moved on eastwards more quickly in the south than in the north. Many observers were reporting snow depths by this time, and, notably, Tenbury Wells (Worcs) reported that 11cm had accumulated in just two hours, whereas further south in Oxfordshire, RAF Brize Norton measured 5cm as having fallen in the previous hour since 0800 UTC.

Figure 8 confirms that there was probably something of a *triple-point low* forming over Hampshire at this time, with less-cold returning Polar maritime (rPm) air in the warm sector near the south coast. The dividing line appears to have been close to the crestline of the North Downs, which separated the snowfall to the north (East Horsley, Surrey, reported 9.5cm) from the cold rain further south, although, generally speaking, more-modest snowfalls (e.g. 5cm at Winchester and 6cm at RAF Odiham) had been reported by 1000 UTC across central Hampshire, having fallen in 2 to 3 hours. In the Midlands, Bromsgrove (Worcs) recorded 11cm as fallen in the three hours from 0700 to 1000 UTC. Ludlow had 9cm of snow by 0900 UTC.

Figure 9 gives the rainfall radar composite imagery for 1200 UTC with some heavier snow over the Chiltern Hills in the vicinity of Luton at this time. However, there were signs of the frontal zone slowing down and stalling, because although snowfall had extended to the Bedford area at around 1130 UTC, it continued there all afternoon and only eventually stopped by 2100 UTC, by which time there was some 9cm lying, compared to 6cm in the Luton area.

Figure 10 shows frontal activity continuing apace eastwards along the South Coast with the triple-point low. Cold rain was falling at Herstmonceux in East Sussex where the temperature was up to +2°C briefly in the short-lived warm sector (see Figure 10 and also the mid-day sounding in Figure 11). Over the Midlands, there were also signs of the leading occlusion slowing down and even returning south-westwards over Cheshire, with it having produced 9cm of snow at Coleshill (station No. 535 in Figure 10), east of Birmingham, by midday. There were an increasing number of road problems; all six Covid-19 vaccination centres in Birmingham were closed for the afternoon and an *Amber Warning of Snow* was issued for Staffordshire by the Met Office.

Figure 12 gives the rainfall radar composite imagery for 1500 UTC when the frontal precipitation had reached its approximate northernmost extent through the Midlands, where the occlusions stalled and then returned slowly back south-westwards again. Figure 13 indicates several low centres had formed along the frontal zone:

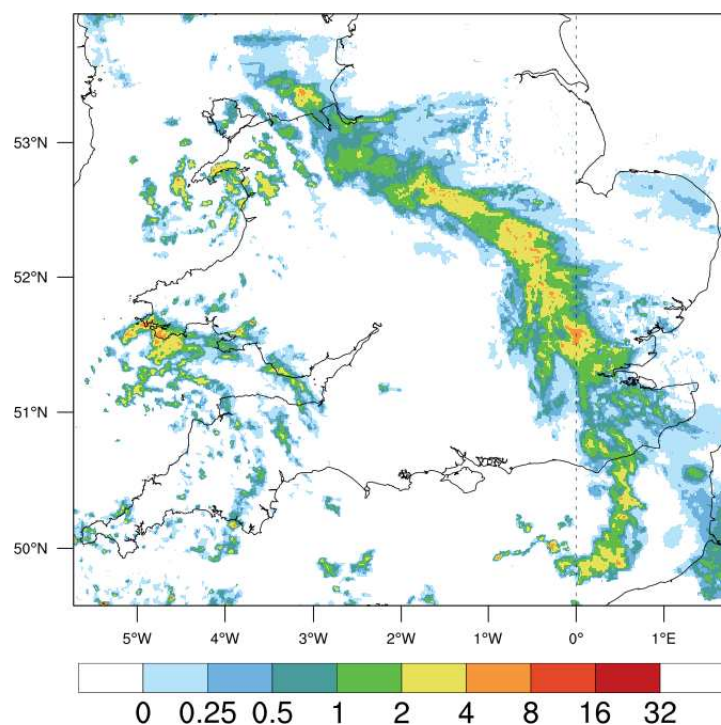


Figure 9: UK Met Office rainfall radar network image for 1200 UTC (mm hr^{-1}). Source: UKMO/CEDA

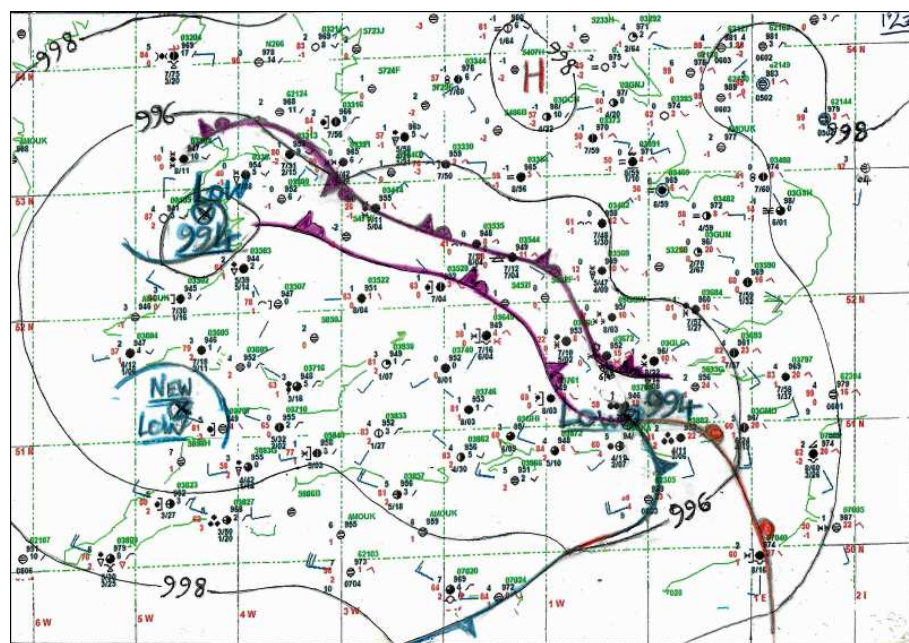


Figure 10: Mesoscale-synoptic surface chart for 1200 UTC, with analysis by the author, based on information supplied by the Met Office via the Centre for Environmental Data Analysis (CEDA).

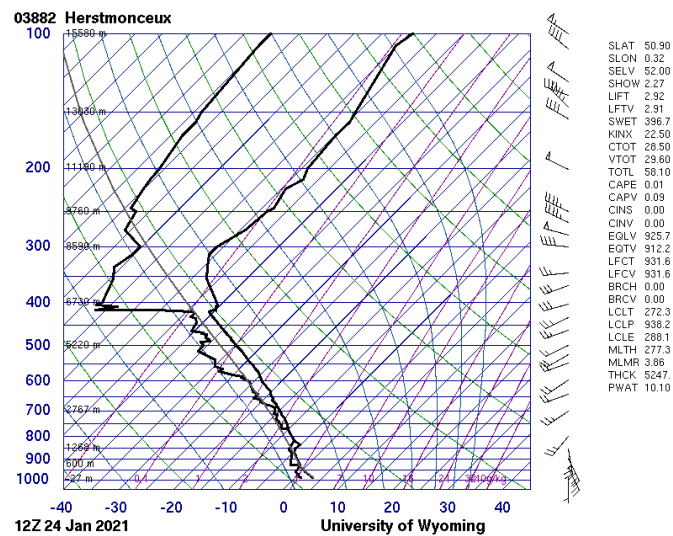


Figure 11: Herstmonceux sounding for mid-day 24 January 2021. Courtesy University of Wyoming, USA.

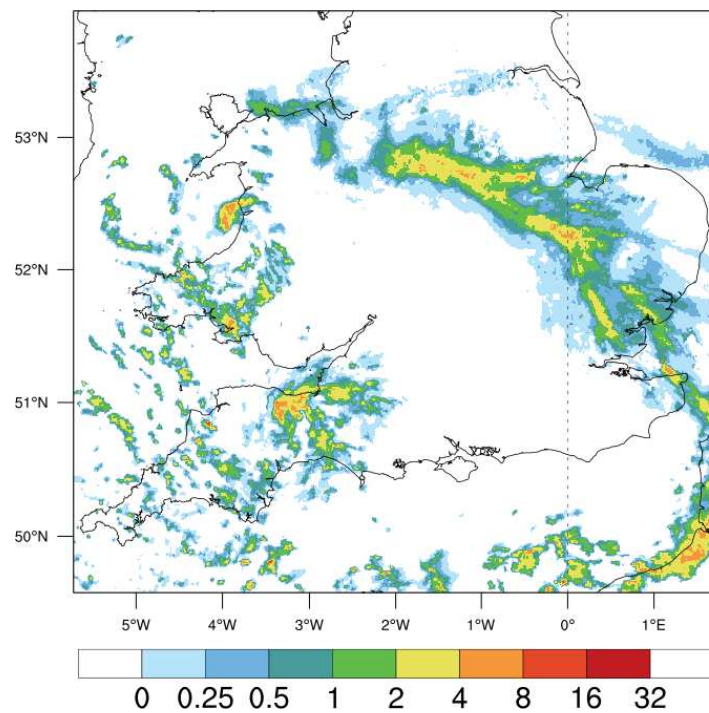


Figure 12: UK Met Office rainfall radar network image for 1500 UTC (mm hr^{-1}). Source: UKMO/CEDA.

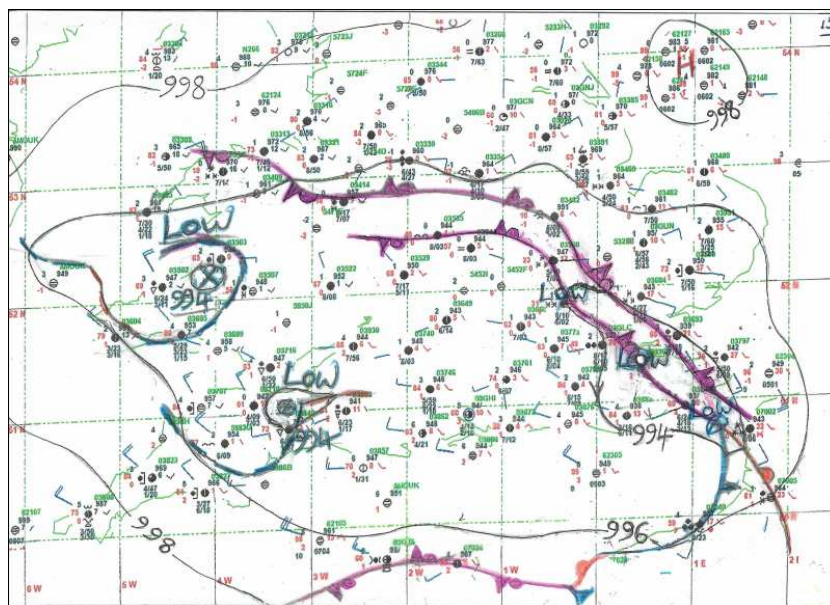


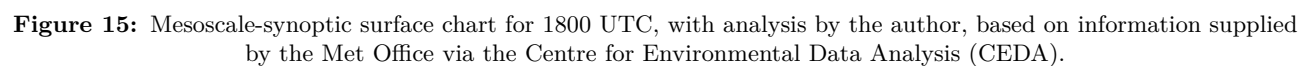
Figure 13: Mesoscale-synoptic surface chart for 1500 UTC, with analysis by the author, based on information supplied by the Met Office via the Centre for Environmental Data Analysis (CEDA).

one near Luton, another near the Thames Estuary, and the southernmost (*triple-point*) centre was over the English Channel near Boulogne. There was a dusting of snow over the King's Lynn area of Norfolk, but that was as close to East Anglia as the snowfall came. Snow had started falling lightly at Wittering (just north-west of Peterborough) by 1200 UTC, and then began accumulating there from 1300 onwards, to give 5cm by 1500h, 10cm by 1600h, 15cm by 1800h, then eventually reaching a maximum of 18cm of lying snow by 2000 UTC. A BBC Red Button TELETXT News report (next day) reported that there were 70 school closures in Cambridgeshire, of which 50 were in the Peterborough district of the county (on Monday the 25th).

Figure 14 gives the rainfall radar composite imagery for 1800 UTC, and although the frontal zone was by then covering Suffolk (see Figure 15), the air temperatures had risen a degree or two above 0°C over East Anglia and the danger was past. Over the Midlands the occlusions were moving southwards again and giving renewed snowfall in the Birmingham area, having reached as far north-east as Nottingham, where 5cm snow cover was reported at Watnall at 2000 UTC, after 3cm was given by RAF Cranwell, Lincs at 1800 UTC.

A note of caution should be expressed about the pre-existing falls of 4–6 cm where wintry showers of hail and snow had come through the 'Cheshire Gap' (between the mountains of North Wales and the Pennines) and affected some parts of the Midland counties previously (e.g., Birmingham/Quinton reported 6cm still lying from the 23rd and Leek/Thorncliffe in Staffordshire recorded 4cm at midnight on the 23rd/24th). The afternoon falls during Sunday the 24th were undoubtedly greater, especially where the two occluded fronts had slowed, stalled and ground to a halt (see Figure 13 and Figure 16). Derby/Chaddesden reported that 15cm had fallen in the six hours, 1200 to 1800 UTC. There were reports of deeper accumulations in Staffordshire (with up to 23cm at Uttoxeter), but these were likely to have included the previous day's snowfall. Nevertheless, they have been included in the snow depth chart for the 24th (here, Figure 16) which gives maximum accumulations reported during the 24th of January. Note the 'double-maximum' bands through the western Midlands, merging down towards the west of Peterborough (although records are rather sparse) associated with the two occlusions.

Throughout Sunday afternoon, the BBC Red Button TELETXT Service commendably gave important information of the travel delays and disruptions due to the snow blocking roads, albeit temporarily. The A6 was closed to the north of Bedford (between Bletsoe and Rushden) for a while during the late afternoon and evening; similarly, the A38 between Burton-on-Trent and Derby. Also there were major problems on the motorway system



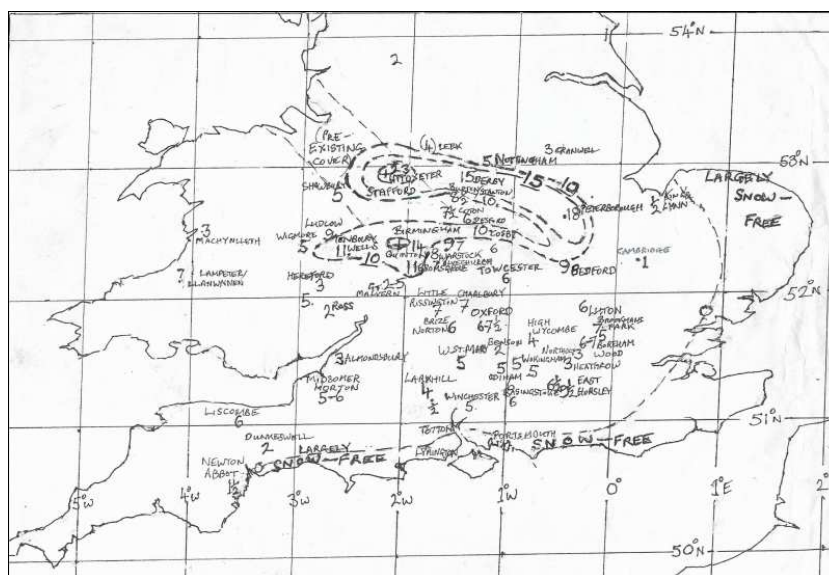


Figure 16: Snow depth chart for 24 January 2021, giving maxima reported in cm, where known, and including pre-existing falls to give measured total depths. Drawn by the author with dashed isohyets at 5-cm-intervals from 10 to 20cm. Based on information supplied by the Met Office, TORRO, Weather Observers' Network (WON) and Climatological Observers' Link (COL) volunteers. See also COL Monthly Bulletin for January 2021.

to the north of Birmingham. One reason for the problems was given as the lack of traffic to spread the road salt and keep the carriageways free of snow. The next morning, the 25th of January 2021, black ice was a problem on the main roads as well as the minor ones that had been cleared of snow cover, due to the low temperatures. Some patches of this dangerous hazard were found on the A3338 to Wantage. The site of the entire Oxford Clay Vale as seen from the Ridgeway south to north, entirely white with snow cover, was most unusual and strikingly beautiful!

Acknowledgements

Thanks are due to Paul R Brown for synoptic charts, radar imagery and extra synoptic observations from Luton Airport during the afternoon of the 24th. I am indebted to Jonathan Webb, also of TORRO, for kindly sending COL and WON Observers' information and reports, plus other useful information. Also, I am very grateful to Mark Beswick at the Met Office Archives, Exeter, for the snow depth spreadsheet which helped me construct Figure 16, as did Christopher Batstone with his report of a road journey from snow-free Portsmouth to a snow-covered Basingstoke on Monday the 25th January 2021. The radar imagery figures were prepared by David Smart from Met Office Nimrod data obtained via the Centre for Environmental Data Analysis.

Part III THE EXCEPTIONAL TWO-DAY AND SEVEN-DAY RAINFALLS OF 22–23 AND 20–26 SEPTEMBER 2024 ACROSS THE SOUTH MIDLANDS.

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Abstract

At the Radcliffe Meteorological Station, Oxford, where rainfall records are available from 1827, the two-day rainfall from 0900 UTC on 22 September 2024 to 0900 UTC on 24 September 2024 was 119mm, comfortably above the previous highest falls in 48 hours from the official climatological observation time of 0900 UTC and a record two-day rainfall in 200 years of records there. This 2024 episode was certainly not a localised event as there were notable 48-hour rainfall totals across a large area of the southern Midlands. Indeed, this was probably the most extensive ‘warm season’ heavy rainfall event in the south of the UK since July 2007. The event also occurred in the context of an abnormally wet 7-day period across this region.

1 Introduction

At the Radcliffe Meteorological Station, Oxford the two-day rainfall from 0900 UTC on 22 September 2024 to 0900 UTC on 24 September 2024 was 119mm. This was comfortably above the previous highest falls in 48 hours from the official (climatological) observation time of 0900 UTC and therefore a record two-day rainfall in 200 years of records at the site (1827–2026). Previous highest two-day falls were 98mm: on both 9–10 July 1968 and in another more recent event on 2–3 October 2020. The 2024 episode was certainly not a localised or isolated event as there were notable 48-hour rainfall totals across a large area of the southern Midlands. Indeed, this was probably the most extensive ‘warm season’ heavy rainfall event in the southern UK since July 2007. The event also occurred in the context of an extraordinarily wet 7-day period from the 20th to the 26th of September across this region.

2 Phase one: an exceptional wet spell beginning with two days of heavy thunderstorms on 20–21 September

By the 20th of September, a large area of high pressure over Scandinavia, which had dominated the UK weather for several days, was declining as pressure fell over Biscay. The initial trigger for this eventful day’s weather across the southern UK was a westward moving upper cold pool (temperature below -20°C at 500hPa), which moved from Belgium at midnight to central-southern England by midday. A cluster of showers reached the Folkestone, Kent area just before 0700 UTC, intensifying as it moved west with the first thunder evident over the Weald

⁴TORRO, Tornado and Storm Research Organisation.

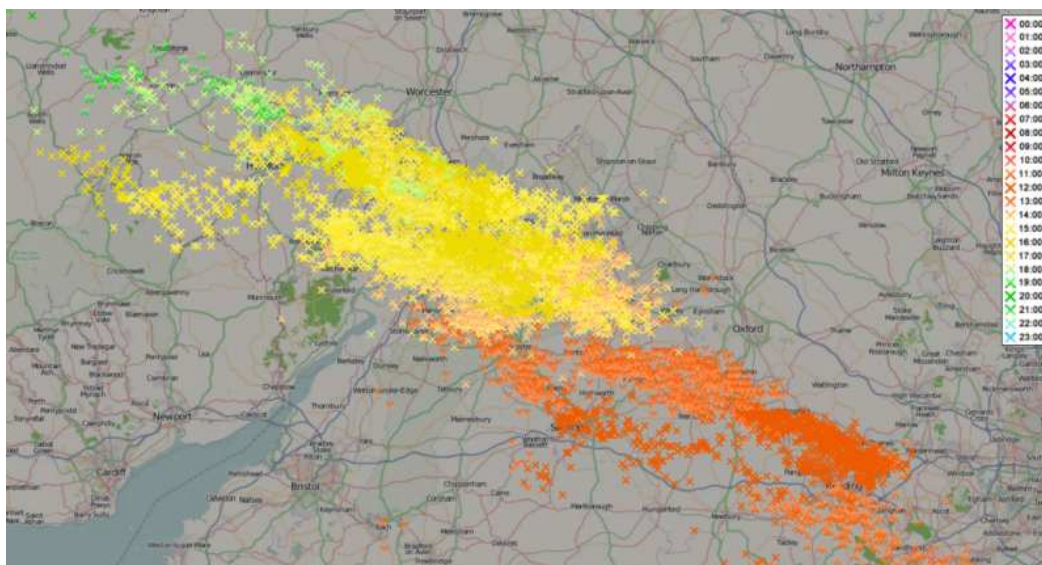


Figure 1: Lightning discharges (sferics) 0000 to 2359 UTC on 20 September 2024 over the south and southwest Midlands. Source: Met Office LEELA system, Crown copyright 2024, courtesy Netweather.

of Kent just before 0830⁵. This storm cluster grew further and continued, broadly, in a west-northwestwards direction across Sussex, northwest Hampshire, central and west Berkshire, southwest Oxfordshire, north Wiltshire, Gloucestershire and Herefordshire. Frequent electrical activity (Figure 1), flash flooding and some intense falls of hail were reported widely along this swath. A tornado hit Aldershot, Hampshire (Horton, 2024a). Hail 20mm or more fell in places, notably around Burford, Oxon and Northleach, Glos where hail 20 to 30mm in diameter was photographed⁶. The storm cluster both expanded (Figure 1) and slowed over the southwest Midlands and it was here that the highest rainfalls and worst flooding were reported. Storm rainfall totals from official EA gauges included 59mm at Dowdeswell, Cheltenham (with a huge accumulation of hail at nearby Bishops Cleeve) and 71mm at Ledbury in Herefordshire where 41mm fell in the hour to 1700. Lightning struck the roof of a house in Quedgeley near Gloucester. Away from this main swath, more localised thunderstorms broke out over the Bournemouth area, east Dorset and east Devon with a brief thundery shower near Plymouth.

On the 21st pressure continued to fall across England and Wales as a broad surface trough extended north from the developing Biscay depression. Aloft, the previous day's cold pool was slow-moving near southwest England with much of western Europe in the circulation of the associated upper vortex. During the early hours, another cluster of thunderstorms moved northwestwards across West Sussex and southwest Surrey, north Hampshire and Berkshire, petering out over northwest Wiltshire soon after 0600 with the residual rain area drifting on west into south Wales. A tree in Petworth Park, West Sussex, was split in two by lightning. Further west an area of intense thunderstorm activity drifted slowly west-northwestwards across west Cornwall after 0300. More than 30mm of rain fell in places. The Lizard, Penzance and St Ives areas experienced several hours of near continuous thunder up to late morning. A shed at Newlyn was set on fire by lightning. By midday, a further band of showery activity was drifting north-northwestwards over southern England and less than a couple of hours after the Cornwall storm episode subsided, the first thunder in the afternoon broke out in the Luton area just before 1230, on the leading edge of this latest shower band. Further thunder was reported at various places from Hertfordshire across to Herefordshire before 1300. The thunderstorms continued to intensify as they drifted slowly north and north-west (fed by warm air from the east, where 25°C was recorded around Cambridge) and by 1400 there was an arc of often severe activity from Hertfordshire then west-northwestwards across the Midlands to mid-Wales. Hailstones 20–30mm diameter fell in the Wolverhampton area and also at Lichfield (Staffs) where

⁵All times in this article are UTC.

⁶See this link (courtesy Dan Holley) [GOOGLE MAPS](#) [Accessed 23 July 2026]

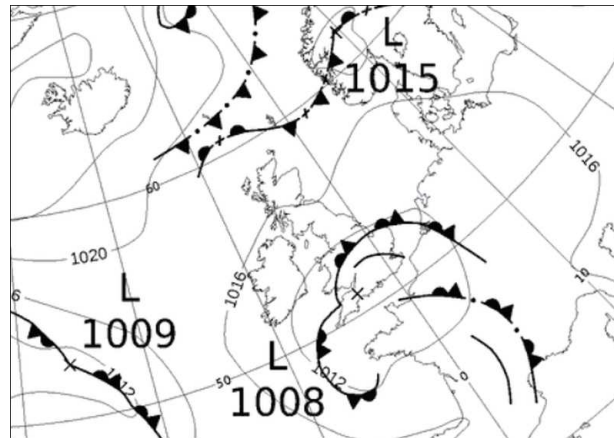


Figure 2: Met Office surface analysis 22 September 2024, 1800 UTC.
Crown copyright 2024. Source: <http://www.wksat.info/wwp7.html>

plastic roofs were punctured and metal outbuildings dented. Lightning cut power to 45,000 homes around Market Bosworth and Desford in Leicestershire and struck and started fires at homes in Desborough (Northants) and Longton (Staffs). Further north, a house in Gresford near Wrexham was also struck by lightning and set on fire.

By early evening the main thunderstorm zone, still intense in places, was focused across the north Midlands and North Wales, with Liverpool and Manchester near the northern edge. This activity persisted right through to late evening (circa 2200) before fading out. In Derbyshire, three homes suffered damage when an internal wall collapsed after lightning struck a block of flats in Melbourne; in the same county, houses were struck in Ripley and Littleover, the latter incident starting a fire. There were also some brief thundery showers around the Bristol Channel during the afternoon. Meanwhile, further storms spread north-northwestwards across East Sussex and Kent during the evening, this pulse reaching south Essex for a time. From around 2130 another thundery outbreak began in the Hertfordshire/Cambridgeshire area, with a slow drift north-westwards so that in the hour before midnight storms were affecting the Huntingdon, Peterborough, Rutland and Stamford areas. Further south, yet another pulse of thunderstorms affected areas between Folkestone and Eastbourne. Overnight of the 21st to the 22nd the late evening thunderstorm activity over the East Midlands continued for a while after midnight before petering out in the Corby area of Northamptonshire between 0100 and 0130. However, some patches of heavier rain remained slow moving over the Midlands and, before daybreak, further thunder broke out in areas between Northampton, Leicester and Birmingham, persisting until just after 0900. Early thundery activity over Kent continued before ceasing around the Thames Estuary by 0300; however, as the associated area of heavy rain drifted north-westwards, there was further occasional thunder around the Chilterns (including Luton) and Bedford (a sign of things to come later in the day). 24-hour rainfall totals included 81mm at Burton-on-the-Wolds (Leics), and 74mm at Bedford where thunderstorms occurred between 1240 and 1400 and at 2330 on the 21st and again from 0815 to 0845 on the 22nd (COL, 2024).

3 Phase two: a major rainfall event 22–23 September, beginning with convective storms on the afternoon of the 22nd

This event was broadly associated with the slow progression north-northeastwards of the (initially) shallow depression, which moved slowly from Biscay at 0000 UTC on the 22nd to the North Sea by 0600 on the 24th, whilst steadily deepening from 1012hPa to 999hPa.

On the 22nd, the early thundery activity near the Chilterns had ceased by 0930 UTC and it was then relatively ‘quiet’ for about five hours, although a further band of sporadic showery rain did push northwards over southern England later in the morning. Meanwhile, the Biscay low moved into the South West, to be centred over Somerset

Table 1: Times of COL and TORRO reports of thunder on 22 September 2024 (UTC)

Great Gaddesden (Herts)	1447
Charlbury (Oxon)	1500
Cranfield (Beds)	1520–1650
Luton (Beds)	1545
Towcester (Northants)	1610–1630
Combe (Oxon)	1630
Great Gaddesden (Herts)	1800
Sindlesham (Berks)	2255
Wokingham (Berks)	2330

(MSLP 1008hPa) by 1800 (Figure 2). Mesoanalysis of surface observations in mid-afternoon indicated a subtle convergence zone with a swath of particularly backed surface winds (north-northeasterly) from Oxfordshire to Bedfordshire, overlapping with significant CAPE⁷. With the 850hPa flow being from the south-east at around 20 to 25 knots, there was also reasonable low-level shear⁸. While residual areas of rain circulated around some western areas, cloud breaks enabled temperatures to exceed 22°C in Suffolk and with some advection of this warm air westwards, fresh heavy showers broke out over the South Midlands and drifted north-northwestwards with thunder around the Luton/Leighton Buzzard area and in north Oxfordshire by 1500. Indeed, the main 48-hour rainfall event began with quite a banded cluster of these heavy showers and thunderstorms from mid-afternoon on the 22nd, which became slow-moving. At Woburn (Beds), thunderstorms deposited 59mm of rain in two hours from 1500–1700 (Figure 3). Thundery outbreaks continued to affect the East Midlands until about 1930 (Table 1).

Several tornadic events were reported that afternoon. A brief tornado accompanied a developing heavy shower on the eastern outskirts of Oxford soon after 1400, causing minor damage with large branches “whirling” through the air. A further cell developed just north-west of Oxford around 1620, turning thundery as it then moved northwards (Figure 4), and at the village of Combe, a funnel cloud was filmed just to the east where it probably briefly touched down. The most active storm area on the 22nd was, however, further east over north Buckinghamshire and Bedfordshire. A tornado damaged roofs in the Bury Park area of Luton while brief touchdowns of funnel clouds evidently occurred near Oakley (Bucks) and to the north-northeast of Tingrith, Beds.

4 Synoptic development and evolution of the main rainfall event on 23 September

By 0000 on 23 September the low was centred near the Chilterns (1006hPa) while the 0600 Met Office chart (Figure 5) shows that the low had continued to slowly deepen as it drifted into Cambridgeshire (1003hPa) with a ‘wrap around’ front now evident curling around west and south of the centre. Subsequently, the low remained quasi-stationary around the Fens through the daytime, deepening to 999hPa by 1800UTC. The depression was over The Wash at midnight before drifting very slowly northeast into the North Sea where it reached a minimum pressure of 994hPa at 1200 on the 24th before being absorbed by a new depression over Sweden. The 500hPa pressure level charts (not shown) show a broad upper trough over the UK and France at both 0000 and 1200 on 23 September. At 700hPa, the 1200 chart showed the axis of a trough directly over the UK with a vortex centred over the south Midlands (Figure 6). By 2000 (on the 22nd) a developing area of rain, already with some heavy showers on the leading edge, had drifted north-west from the English Channel into Sussex. As fresh pulses of heavy rain moved northwest to the west of London, local thunder occurred in east Berkshire either side of 2300 UTC (see Figure 4 and Table 1). By 0200 (Figure 7), there was a broad band of moderate to heavy rain

⁷Convective Available Potential Energy

⁸Knightley, P and Clark, M – personal communications via the TORRO forum.

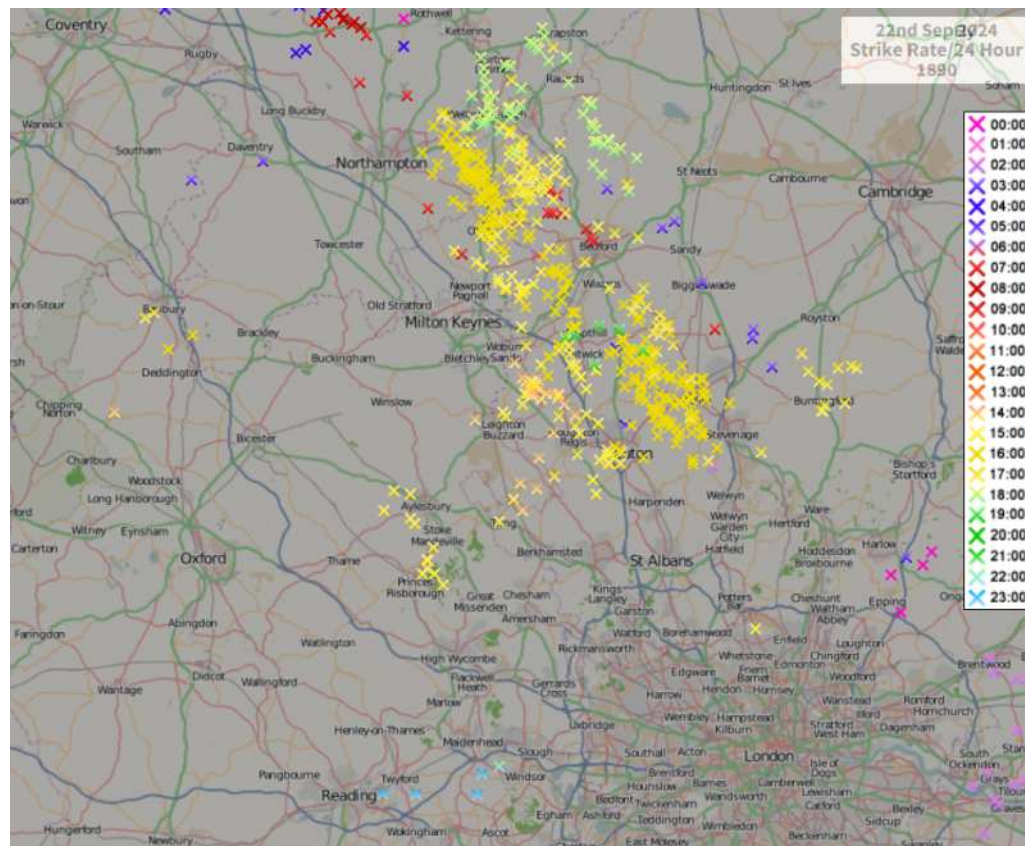


Figure 3: Met Office LEELA lightning strike data for the South East Midlands on 22 September 2024 (midnight to midnight UTC). Crown copyright 2024, courtesy Netweather.

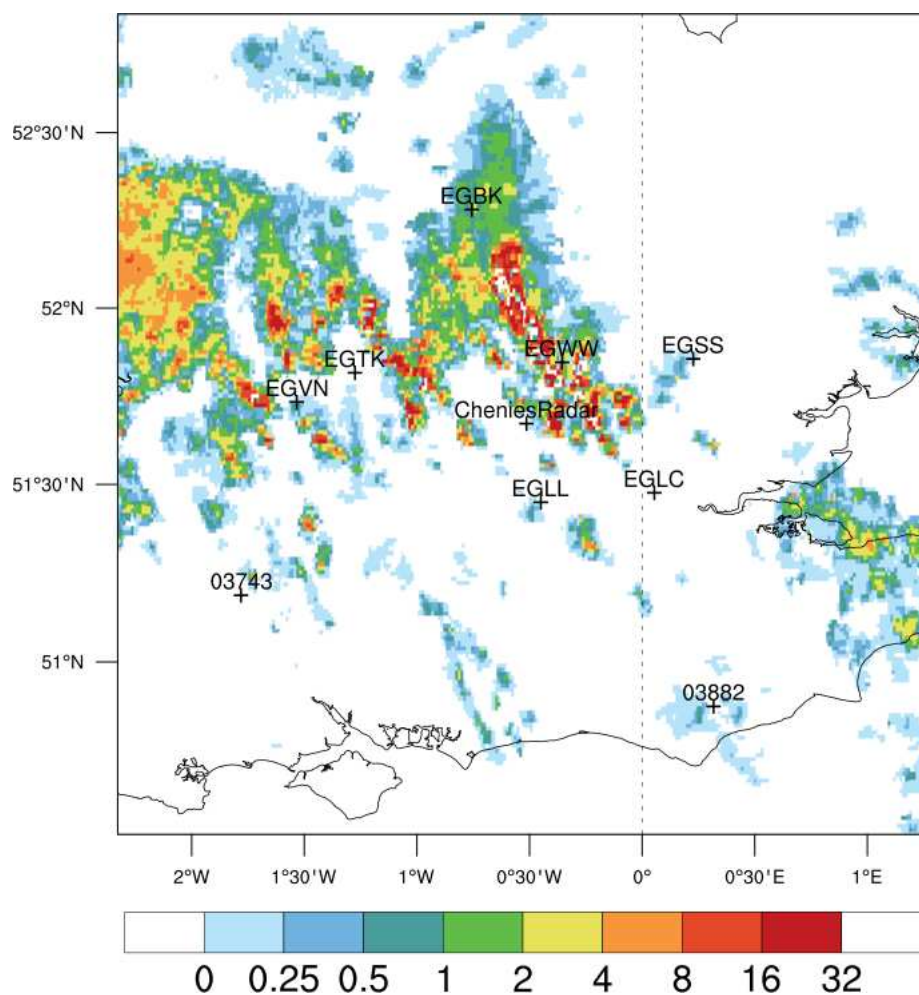


Figure 4: Met Office Nimrod 1-km rain rate centred on the Chenies radar at 1600 UTC on 22 September 2024. EGBK=Northampton/Sywell airport; EGWW=Luton airport; EGTK=Oxford/Kidlington airport; EGVN=RAF Brize Norton. Source: original data from the Met Office via the Centre for Environmental Data Analysis (CEDA) 2024.

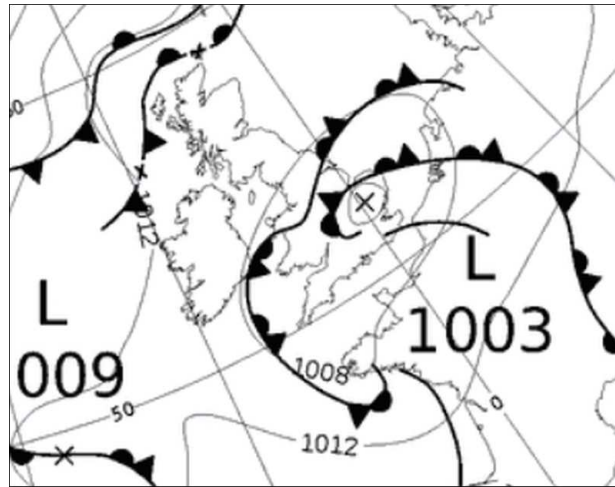


Figure 5: Met Office surface analysis for 23 September 2024, 0600. Crown copyright 2024. Source: <http://www.woksat.info/wwp7.html>

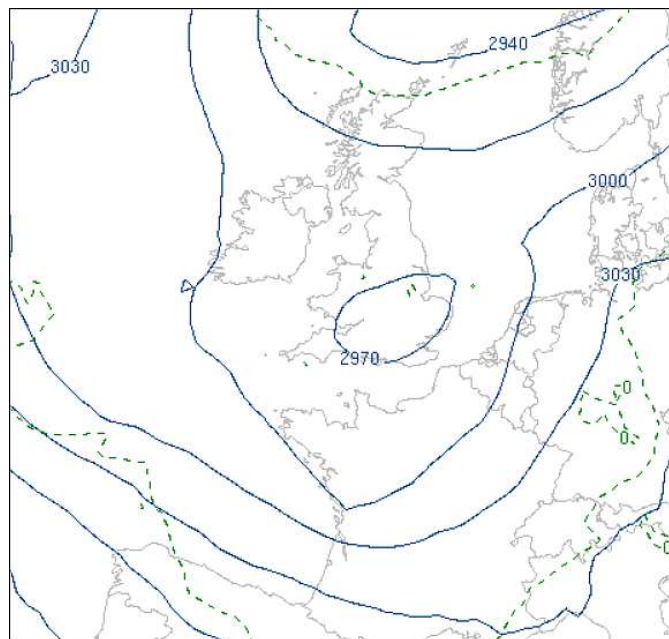


Figure 6: 700hPa analysis at 1200 UTC on 23 September 2024. (Courtesy of Univ. of Wyoming, USA)

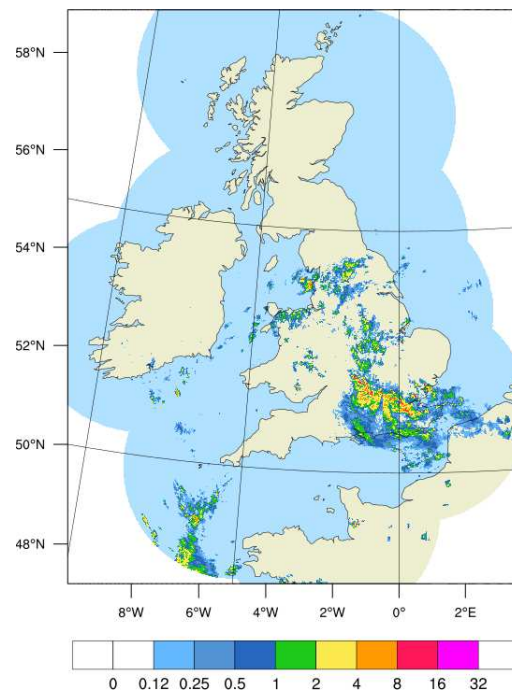


Figure 7: Met Office composite rainfall 23 September 2024 0200 UTC (mm hr^{-1}). Original data from the UK Met Office via CEDA.

extending west-northwestward from London to Oxfordshire which, by 0500 (Figure 8), had become aligned more east-to-west from Hertfordshire and the Chilterns to the Cotswolds and Wiltshire. Composite and single-site radar coverage from 0700-0800 (Figures 9 to 11) highlights this large rain area over the south Midlands and north Wessex, with the heaviest rain across Oxfordshire to the Gloucestershire Cotswolds and down to North Somerset.

By 1000 (on the 23rd) the main rain area had drifted a little west, with the core of heavy rain now across Gloucestershire and north Somerset, looping south to Salisbury Plain (Figure 12). By 1300, radar indicated that the main heavy rain area was now centred over Somerset but had shrunk a little as it rotated west and then southwards. However, a new cluster of moderate/heavy rain was now conspicuous around the Oxfordshire/Warwickshire border (Figure 13). By 1700 this more northward area of moderate/heavy rain had grown and was now the chief feature, merging with the area over east Devon and Somerset to form quite a broad south-west to north-east oriented band which was starting to drift back eastwards with west and north Oxfordshire once again in the core of the heaviest rain. By 2000 this rain band was still drifting slowly east with an axis from Bournemouth north-northeastwards to Northamptonshire (see Figures 14 and 15).

The various phases of the whole event are evident in the graphs for two of the wettest official gauge locations (Figures 16 and 17): Wheatley (just east of Oxford) and South Newington (south-west of Banbury). At Wheatley, only brief showers occurred until the period of continuous rain began around 0100 on the 23rd. There were then nine hours with rainfall of ‘heavy’ intensity ($>4\text{mm}$ per hour) with a peak of 18mm in the hour 0700-0800. Rain then eased off to light between 1000 and 1300 before the resumption of mostly moderate rain through to midnight; over this later 11-hour period, rainfall only exceeded 4mm per hour (‘heavy’) in the hour to 2100. At South Newington, the distribution of rain was rather different. Here, showers between 0900 and 1800 on the 22nd were much more potent, especially between 1500 and 1800 UTC. The main event began just before 0100 and subsequently moderate or heavy rain persisted right through to just before 2300 on the 23rd with the heaviest rain from 1300 to 1900. A few further outbreaks of light rain were evident in the early hours of the 24th.

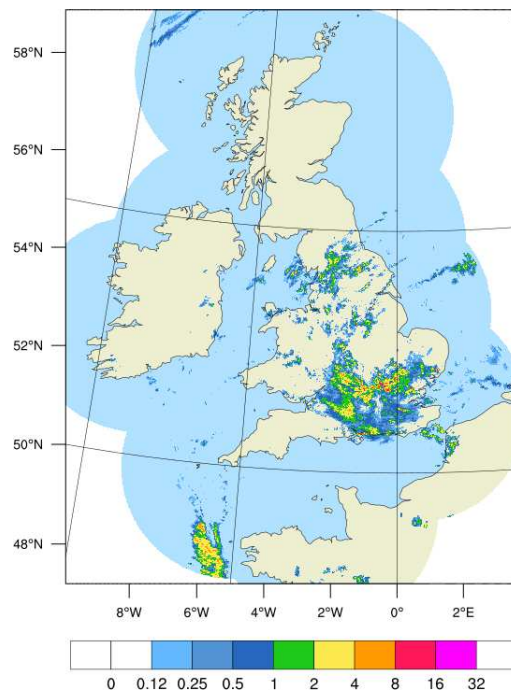


Figure 8: Met Office composite rainfall 23 September 2024 0500 UTC (mm hr^{-1}). Original data from the UK Met Office via CEDa.

The overall 48-hour rainfall distribution for this event is plotted in Figure 18 while the highest one-day and two-day totals for this event are presented in Table 2. It should be noted that, although only two stations recorded $\geq 100\text{mm}$ on one official ‘rainfall day’ (09-09UTC), several others did within a non-standard 24-hour period, e.g. the recording TBR1⁹ gauges at both Wheatley and South Newington recorded over 100mm in periods of less than 18 hours. The 148.8mm at Combe is a new official two-day rainfall record for Oxfordshire. However, the single (09-09 UTC) daily record for the county remains the 128.7mm recorded at Uffington on 25 May 1993 during a severe thunderstorm episode (Pike, 1994). A similar amount (at least) was estimated to have fallen in the localised Wheatley storm on 9 June 1910 (Webb, 2011).

5 Flooding impacts 22–24 September

Late on the September 22nd, in Northamptonshire, considerable flooding affected Grendon, Earls Barton and also the Northampton Road area of Wellingborough. In Bedfordshire, property flooding and road closures were reported in numerous locations on 22-23 September, including Barton-le-Clay, Caddington, Clophill, Flitwick, Dunstable, Cranfield, Houghton Regis, Hockliffe, Lower Shelton, Maulden, Shefford, Silsoe, and Toddington (Central Bedfordshire Council, 2024). During September 23, extensive flooding from surface water and overflowing streams and other smaller watercourses affected Oxfordshire. In Oxford, extensive surface water flooding disrupted rush hour traffic on the morning of the 23rd, especially in the east of the city (This is Oxfordshire, 2024). This relented as rainfall eased off later in the morning before the return of persistent rain from mid-afternoon (it was fortunate there was this lull during the event). In Wheatley (Figure 19) the flooding was described as the most severe since the great thunderstorm of 9 June 1910 (see Webb, 2011). At Tiddington, between Thame and Wheatley, a private weather station reporting to the Met Office WOW site recorded more than 200mm over the 48 hours. Although the station is unofficial, the plotted rainfall ‘footprint’ of official data plus accumulated radar data both indicate peak accumulations near the village and there was spectacular local

⁹Tipping Bucket Rain gauge

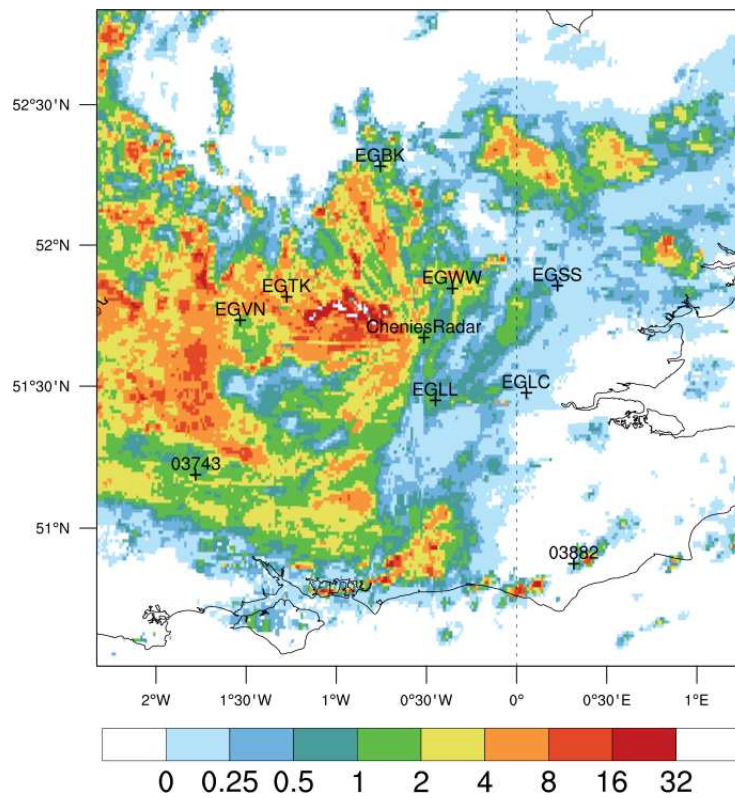


Figure 9: Met Office Nimrod 1-km rain rate centred on the Chenies radar at 0700 UTC on 23 September 2024. EGBK=Northampton/Sywell airport; EGWW=Luton airport; EGTK=Oxford/Kidlington airport; EGVN=RAF Brize Norton. Source: original data from the Met Office via Centre for Environmental Data Analysis (CEDA) 2024.

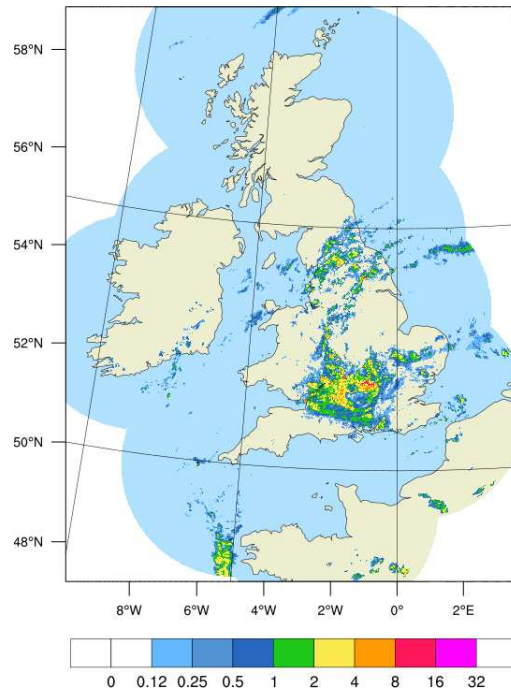


Figure 10: Met Office composite rainfall 23 September 2024 0700 UTC (mm hr⁻¹). Original data from the UK Met Office via CEDA.

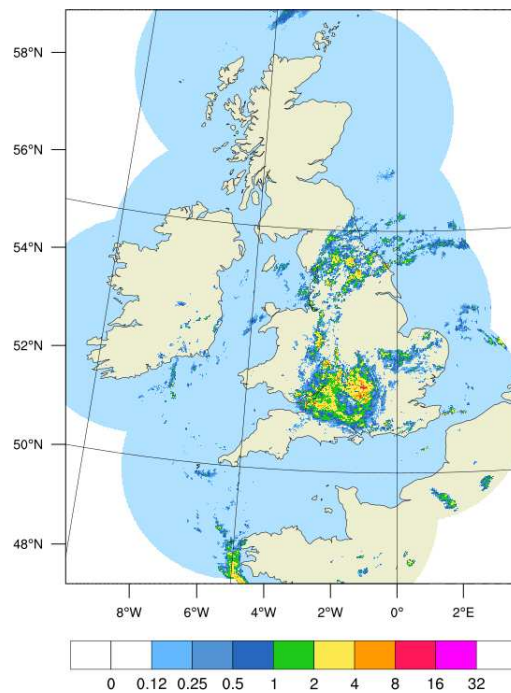


Figure 11: Met Office composite rainfall 23 September 2024 0800 UTC (mm hr⁻¹). Original data from the UK Met Office via CEDA.

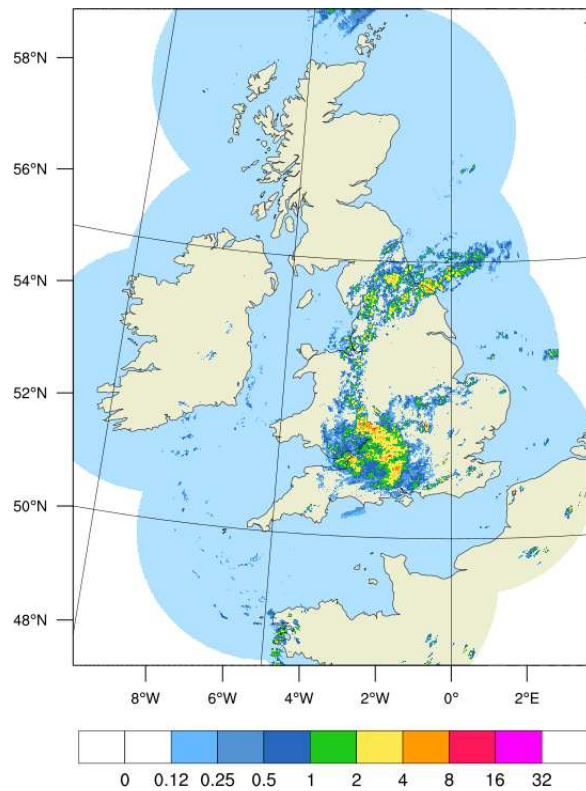


Figure 12: Met Office composite rainfall 23 September 2024 1000 UTC (mm hr^{-1}). Original data from the UK Met Office via CEDA.

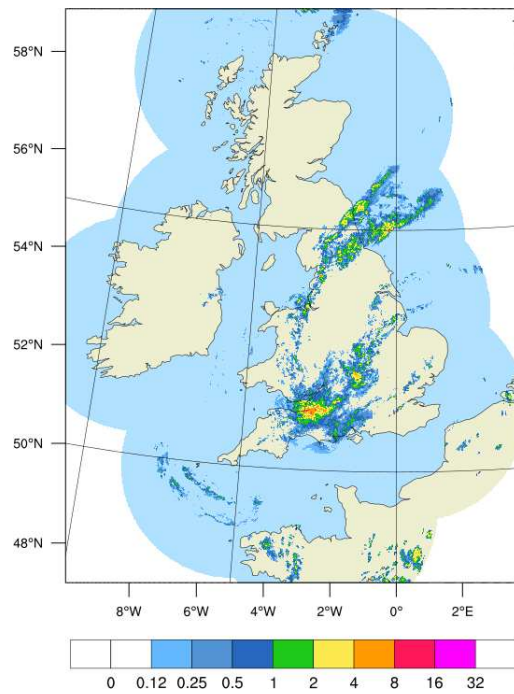


Figure 13: Met Office composite rainfall 23 September 2024 1300 UTC (mm hr^{-1}). Original data from the UK Met Office via CEDA.

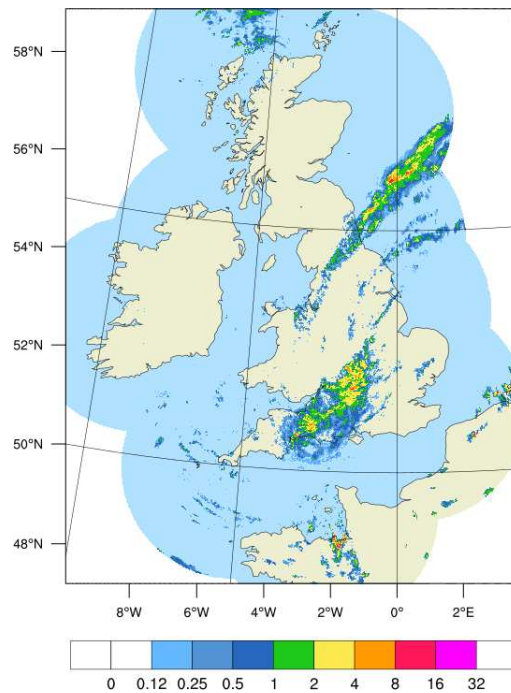


Figure 14: Met Office composite rainfall 23 September 2024 1700 UTC (mm hr⁻¹). Original data from the UK Met Office via CEDA.

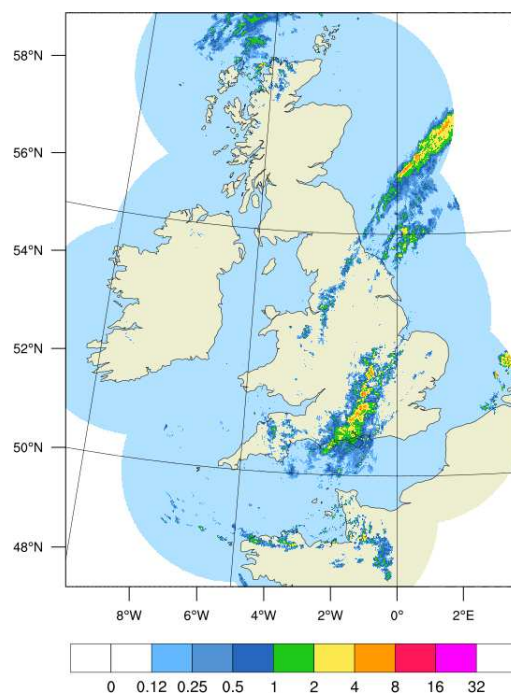


Figure 15: Met Office composite rainfall 23 September 2024 2000 UTC (mm hr⁻¹). Original data from the UK Met Office via CEDA.

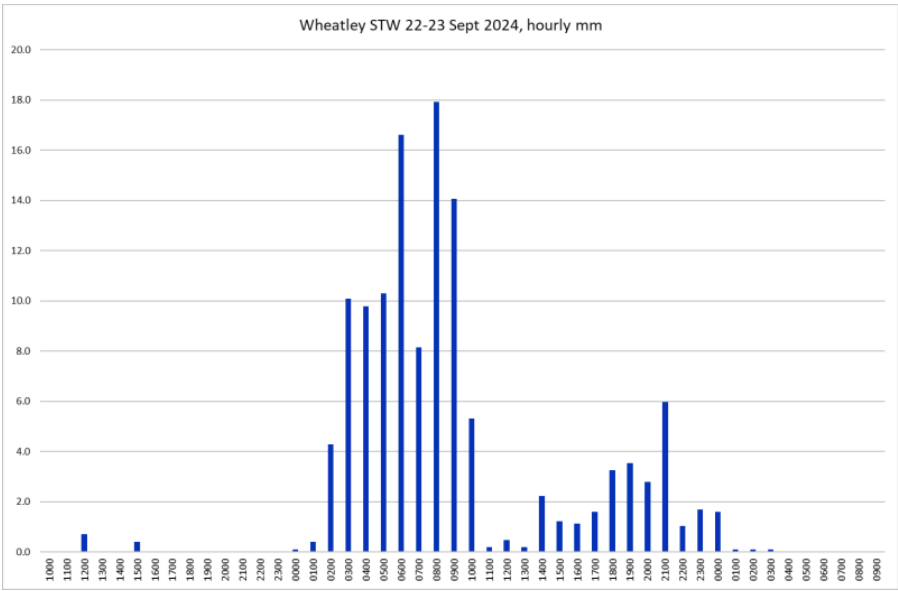


Figure 16: Rainstorm 22-23 September 2024 Wheatley, Oxford (125mm). Sources: EA hourly TBR Gauge data (<https://www.gaugemap.co.uk/>) and Met Office MIDAS daily rainfall via CEDA.

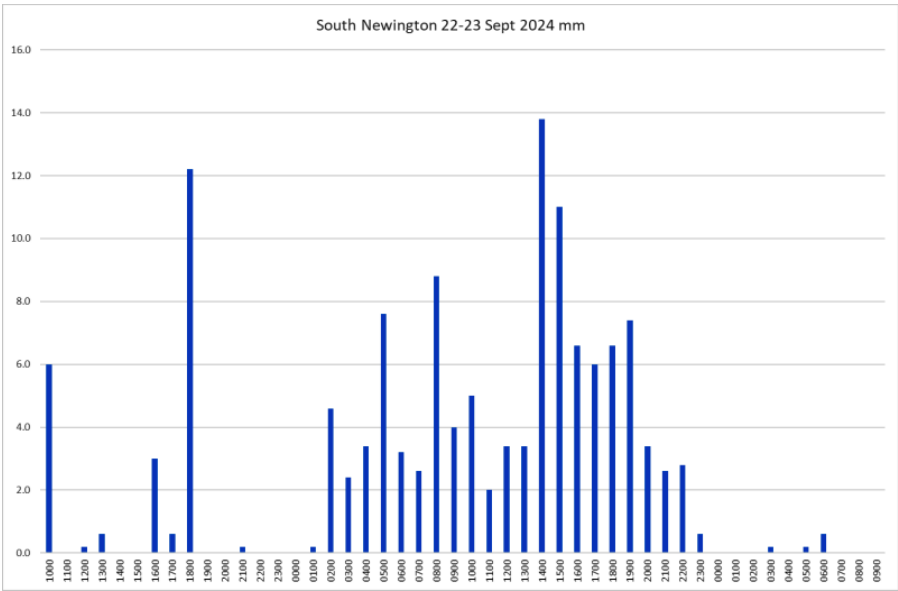


Figure 17: Rainstorm 22-23 September 2024 South Newington, north Oxfordshire (135mm). Hourly rainfall sourced from Met Office MIDAS hourly rainfall via CEDA.

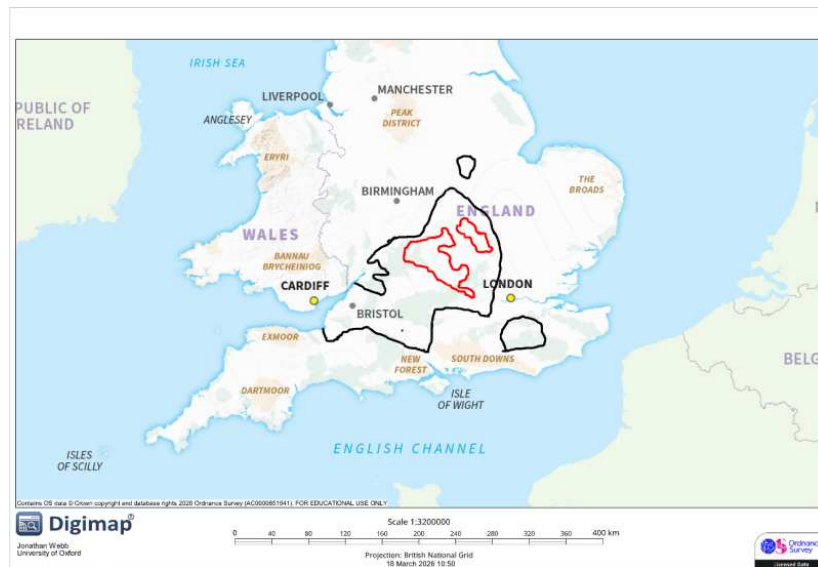


Figure 18: Distribution of heavy rainfall during the 48 hours commencing 0900 UTC on 22 September 2024: >50mm (within black isolines) and >100mm (within red isolines). Rainfalls plotted and isohyets drawn by the author. Basemap Crown copyright and database rights 2024 Ordnance Survey (AC0000851941).

flash flooding (Tiddington Cricket Club, 2024).

6 Two-day rainfalls: historical comparisons

Comparison can be made with 19-20 July 2007 when serious flooding affected the lower Severn (especially) and upper Thames valleys following a large-scale rainfall event with a broad south-east to north-west footprint of two-day rainfalls exceeding 100mm (Prior and Beswick, 2008); also 9-10 July 1968 when two-day falls of over 100mm also occurred across the southern Midlands region within a major rainfall event which extended south-west to north-east across England and southeast Wales (Bleasdale, 1974). Some aspects of the 2024 event were comparable to 19-20 July 2007 and 9-10 July 1968 but with slightly less extreme impacts (and less thundery activity).

Table 3 compares the estimated areas with rainfall accumulations over the 100mm and 50mm thresholds in the three events. The areas have been calculated by plotting actual two-day rainfall readings onto *Digimap*¹⁰ and using their in-house calculation tool. For the July 2007 event, the areas for these thresholds calculated by Prior and Beswick (2008, their Table 6), using the 5-km daily rainfall grids available for 1961 onwards, are also included. The Digimap calculation is very similar for the 50mm+ area but indicates a slightly larger area for 100mm plus¹¹. Regarding the two areal estimates given for the July 1968 event by Prior and Beswick and by Bleasdale in BR 1968, both only referred to the one rainfall day, 10 July, whereas Table 2 refers to the 2-day totals for 9-10 July (since some places affected measured significant falls before 0900 UTC on the 10 July). The July 2007 event encompassed a substantially larger area for the 100mm threshold (Figure 20) with 150mm exceeded around Winchcombe, Glos and Pershore, Worcs. Records from individual stations highlighted that much of the rain fell in one continuous period of heavy rain lasting several hours (Pike and Webb, 2010), rather than in sporadic episodes. Moreover, this was in a single, contiguous large area – one which also covered much of the Upper Thames (e.g. 130mm at Brize Norton Met Office) and Lower Severn catchments resulting in the very severe flooding of both main rivers (some lock measurements indicated the 2007 floods were the worst on the Lower Severn since 1770 and the worst on the Upper Thames since 1894). The number of approved rainfall

¹⁰<https://digimap.edina.ac.uk/>

¹¹The calculation by Prior and Beswick was, itself, an update to the area of 3500 km² quoted by Marsh and Hannaford, 2007

Table 2: Highest rainfall totals (in mm) 22-23 September 2024. MIDAS=Met Office/Environment Agency stations via CEDA Met Office MIDAS database; COL=Climatological Observers Link.

Place	Data source	22 nd	23 rd	22 nd -23 rd
Castle Ashby (Northants)	MIDAS	130.0	30.0	160.0
Combe (Oxon)	MIDAS	100.5	48.3	148.8
South Newington (Oxon)	MIDAS	59.6	75.6	135.2
Chipping Norton SW (Oxon)	MIDAS	77.5	49.2	126.7
Wheatley SW (Oxon)	MIDAS	92.8	32.5	125.3
Charlbury-COL (Oxon)	COL	73.8	48.7	122.5
Banbury Grimsbury (Oxon)	MIDAS	50.4	71.1	121.5
Oxford Radcliffe (Oxon)	MIDAS	77.1	41.8	118.9
Chadlington-Manor Farm (Oxon)	MIDAS	64.1	51.5	115.6
Bicester SW (Oxon)	MIDAS	74.1	38.7	112.8
Woburn (Beds)	MIDAS	90.6	21.6	112.2*
Shipston-on-Stour (Warws)	MIDAS	58.2	53.8	112.0
Stokenchurch Res (Bucks)	MIDAS	93.2	13.2	106.4
Osney Lock (Oxon)	MIDAS	64.3	41.9	106.2
Shirburn (Oxon)	MIDAS	83.2	22.9	106.1
Studham Hall (Beds)	MIDAS	96.8	9.2	106.0
Bourton-on-the-Water (Glos)	MIDAS	60.0	44.8	104.8
Aylesbury SW (Bucks)	MIDAS	73.6	29.3	102.9

*Woburn also had 33.6mm from 0300 to 0900 UTC on the 22nd, and so received 145.8mm in 54 hours.

stations recording ≥ 100 mm in the standard 0900-0900 two-day period was also appreciably higher on 19-20 July 2007 than in September 2024, although it may be noted that a reduction in the numbers of such stations has continued over the past 20 years (Hawkins *et al*, 2025).

On 9-10 July 1968, the event total area with over 100mm was similar to 2024 but consisted of multiple separate areas along the heavy rainfall swath (Figure 21), albeit with a principal ‘footprint’ over Somerset (locally over 150mm in North Somerset), the Bristol area and sections of adjoining counties. However, the July 1968 episode was outstanding for the area of the central and southern UK which received in excess of 50mm, considerably larger than in either 2007 or 2024.

Prior to 2024, the previous highest two-day rainfalls at the Oxford Radcliffe Observatory site were 98.1mm on 9-10 July 1968 and 97.6mm on 2-3 October 2020. In the July 1968 case, another official gauge, 700 metres from the observatory in Norham Road, Oxford recorded 101.4mm over the two-day period with Farmoor Reservoir logging 112.5mm and Swinford Pumping Station 109.5mm. On 3 October 2020, the UK as a whole experienced its wettest day on record (Kendon and McCarthy, 2021). This episode of heavy rain was widespread across Oxfordshire with two-day rainfalls (2-3 October) exceeding 70mm at all Met Office/EA Oxfordshire rainfall stations, albeit with none of the sites quite reaching 100mm. The Radcliffe Observatory total was the second highest in the county for the 48-hour period after Shirburn Model Farm which received 98.2mm.



Figure 19: Flooding in Wheatley, Oxfordshire, 23 September 2024. Courtesy [Wheatley Village Archive](#).

Table 3: Area affected by three heavy south Midlands rainfall events based on Digimap calculations (values in brackets are estimates by Prior and Beswick, 2008).

Event	Approximate area km ² with ≥ 50 mm rain	Approximate area km ² with ≥ 100 mm of rain
9-10 July 1968	35,000*	2,800**
19-20 July 2007	28,000 (28,250)	4,100 (3,800)
22-23 September 2024	20,000	2,720

*32,525 km² for 10 July *per* Prior and Beswick

**1,450 km² *per* Prior and Beswick and 2,250 km² *per* *British Rainfall* 1968 for 10 July

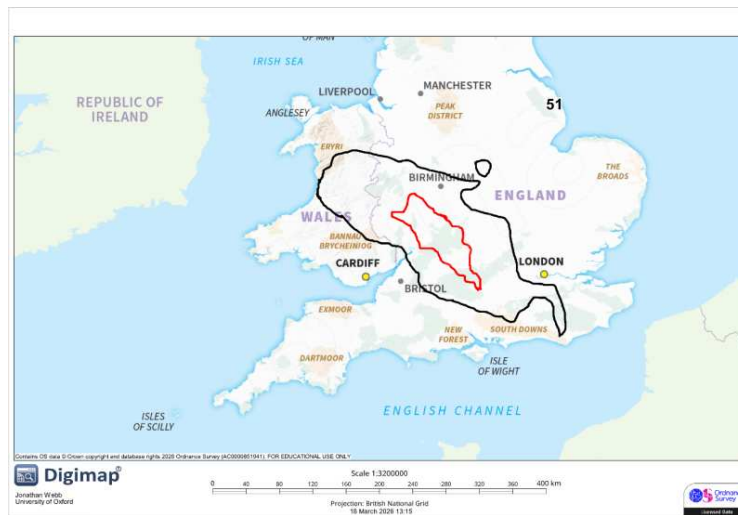


Figure 20: Distribution of heavy rainfall during the 48 hours commencing 0900 UTC on July 2007: >50mm (within black isolines) and >100mm (within red isolines). Rainfalls plotted and isohyets drawn by the author. Basemap Crown copyright and database rights 2024 Ordnance Survey (AC0000851941).

7 Exceptional seven-day rainfall totals and impact on river levels

Further widespread heavy rain occurred on 25–26 September as a large and complex area of low pressure transferred east across Wales and England. Prolonged rain affected central and northern England, while the 26th was a very showery day over central and southern areas. Thunder was quite widespread across the Midlands while an especially potent storm, associated with a small low centre, tracked north-east to the west of London. Tornadoes occurred at Hook and Hartley Wintney in Hampshire, with additional severe squalls and a probable tornado at nearby Yateley (Horton, 2024b).

Previous notable wet spells for Oxford (from 1827 up to 2019) are noted by Burt and Burt (2019, chapter 28). The 5-day (22–26 September) and 7-day (20–26 September) 2024 totals of 148.4mm and 151.5mm were both well above the previous highest. Table 4 lists the highest 7-day rainfall totals for 20–26 September 2024 across the south Midlands region; accumulations exceeded 200mm in the Cheltenham and Northampton areas with over 190mm at stations in west Bedfordshire and north Oxfordshire.

Flows of major rivers increased rapidly across central and southern England in response to the exceptional rainfall in late September 2024 (UKCEH, 2024). The Bedford Ouse recorded its highest peak flow in any month on the 27th (in a series from 1972). On 29 September, the River Ivel at Blunham (Beds) peaked above the previous record in December 2020. New September peak flow records were registered for many other southern and East Midlands rivers over this period, including the Soar and Great Ouse (both in series of 50 years or more), also on the Thames (27th), Hampshire Avon (28th), Itchen (29th), Soar and Don (30th), all in series of at least 30 years. It was fortunate that the first 19 days of September had been relatively dry across the region; this, combined with river flows being at their (on average) seasonal minimum, meant that the large rise in flows of the Thames and tributaries was from a relatively low baseline.

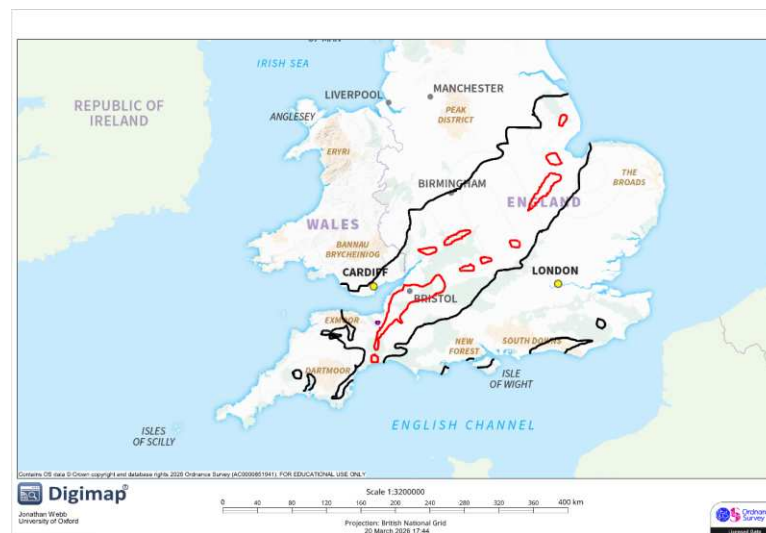


Figure 21: Distribution of heavy rainfall during the 48 hours commencing 0900 UTC on 9 July 1968: >50mm (within black isolines) and >100mm (within red isolines). Rainfalls plotted and Isohyets drawn by the author. Basemap © Crown copyright and database rights 2024 Ordnance Survey (AC0000851941).

Table 4: Highest rainfall totals (in mm) 20–26 September 2024.

Place	Rainfall (mm)
Castle Ashby (Northants)	242.6
Dowdeswell Res (Glos)	206.8
Stowell Park Res (Glos)	197.8
Woburn (Beds)	196.4
South Newington (Oxon)	190.6
Combe (Oxon)	178.7
Banbury, Grimsbury (Oxon)	177.5
Burton-on-the-Wolds (Leics)	177.3
Winchcombe-Sudeley Castle (Glos)	177.0
Shipston-on-Stour (Warws)	174.8
Chipping Norton SW (Oxon)	170.3
Chipping Camden (Glos)	167.6
Maidenhead (Berks)	167.0
Studham Hall (Beds)	165.0
Fleckney (Leics)	164.0
Over Farm (Glos)	162.6
Bourton-on-the-Water (Glos)	161.5

Acknowledgements

Rainfall data was sourced from the Met Office/Environment Agency MIDAS database, courtesy of the Centre for Environmental Data Analysis (CEDA) with additional data from the Climatological Observers Link ‘A’ stations. Special thanks are due to Paul Brown for forwarding his plotted rainfall totals for the 1968, 2007 and 2024 events; also to David Smart (UCL) for kindly plotting Met Office Chenies single-site radar data and Nimrod 1-km data (original data via CEDA).

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Part IV THE INCIDENCE OF THUNDER AT OXFORD, 1983–2025

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Abstract

This author's own full thunderstorm records for the Oxford area begin in January 1983 and this article looks in some detail at the last 43 years (i.e. to 2025), covering aspects such as thunderstorm hours and impacts. Further perspective and discussion of possible longer-term trends are discussed with reference to the historic Radcliffe Observatory records.

1 Introduction

Burt (2021) examined the long-term record of thunder days at Oxford (1828–2019), predominantly using data from the historical Radcliffe Observatory Meteorological Station's climatological record. However, since the Radcliffe station's recording of some non-instrumental elements, including thunder, were discontinued after 1986, the study was supplemented by this author's personal records from 1987–2019 to complete 200 years of data.

This author's own full thunderstorm records for the Oxford area begin in January 1983 and this article looks in more detail at the last 43 years, covering additional aspects such as thunderstorm hours and impacts. Note that the first four years overlap with the Radcliffe record, from 1983 to 1986. The author's observations were made at sites 3–4km from the observatory and so, as expected, there are some small differences in monthly thunder day totals. Interestingly the annual totals for two of the four years (1983 and 1985) are identical.

¹²TORRO, Tornado and Storm Research Organisation.

2 Annual incidence of thunder

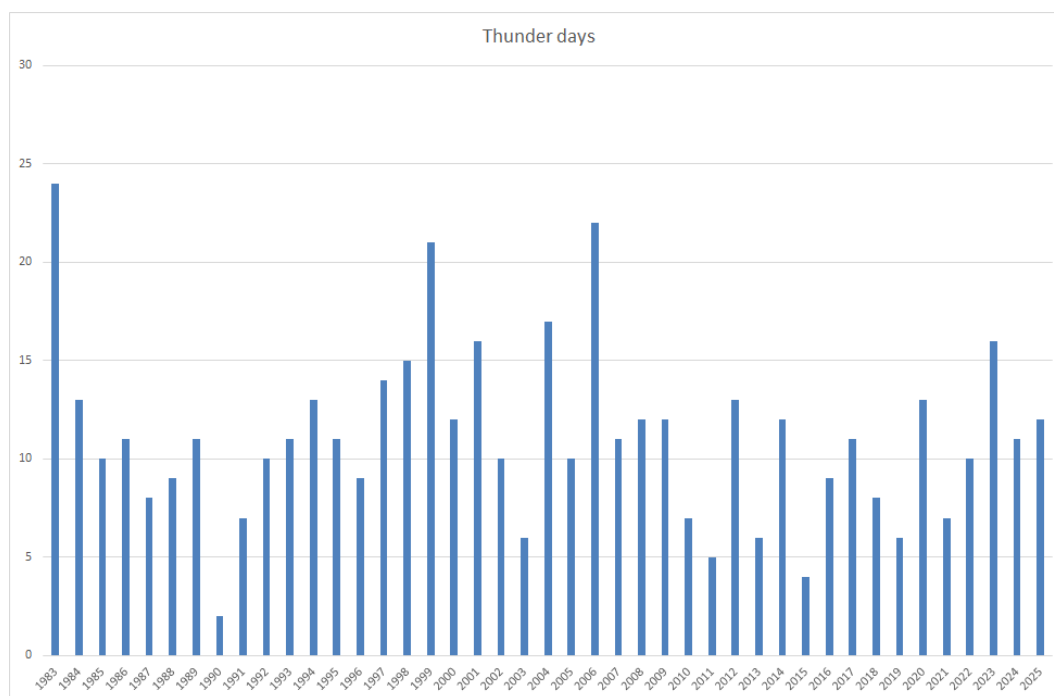


Figure 1: Annual Days with *thunder heard* in Oxford, 1983–2025 (this author’s record).

Figures 1 and 2 present analyses of both thunder days and thunder hours by year. Note that a *thunder day* refers to any 24-hour period between 0000 UTC and midnight on which thunder is heard. A *thunder hour* relates to any 60-minute period, starting on the hour (for example 0000, 0100 UTC etc) during which thunder was heard. Both graphs show a conspicuous ‘quiet’ period since 2007, albeit at a rather ‘flat’ level. Over the 43 years, evidence of a trend is less conclusive, with peaks in 1983 and 2006 and an earlier, but shorter, quiet run of years from 1987 to 1991.

The highest annual thunder days total in the author’s record is 24 in 1983, the same as recorded at the observatory station that year. In the full Radcliffe Observatory record from 1828 to 1986 the highest annual total was 28 days in 1925 (Burt, 2021). Examination of the monthly climate returns (see Met Office Climatological Returns: Oxford Radcliffe, reference [2]) and published Radcliffe Observations for 1925 (reference [4]) indicate that the number of hours with thunder was 47, just above the 45 hours this author recorded in 2006.

3 Monthly distribution of thunder

The monthly distributions of both thunder days and hours (Figures 3 and 4) are very similar and both show August as the peak month for activity with May and July, by an odd coincidence, tying in second place on both parameters.

For interest, the monthly distributions were also analysed for two shorter periods 1983–2003 and 2004–2025 to see if there were any significant changes for the more recent 22-year period as compared with the first 21 years. Annual thunder hours averaged 1.15 hours less in the more recent period; this was mainly due to a fall in mean thunder hours in both May and July, partly offset by a rise in September and October.

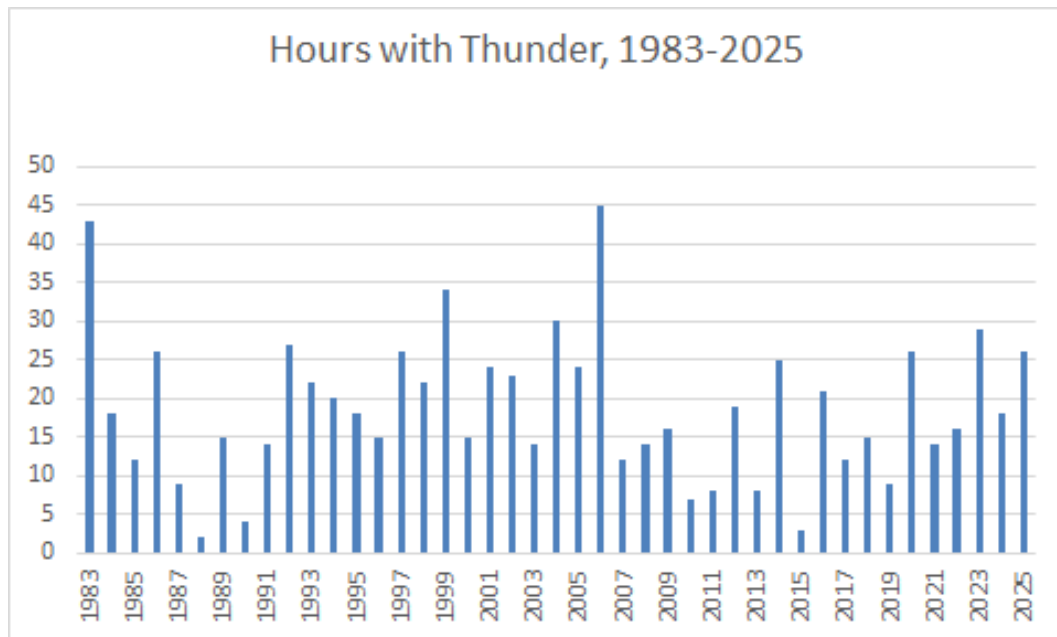


Figure 2: Annual hours with thunder heard at Oxford, 1983-2025 (this author's record).

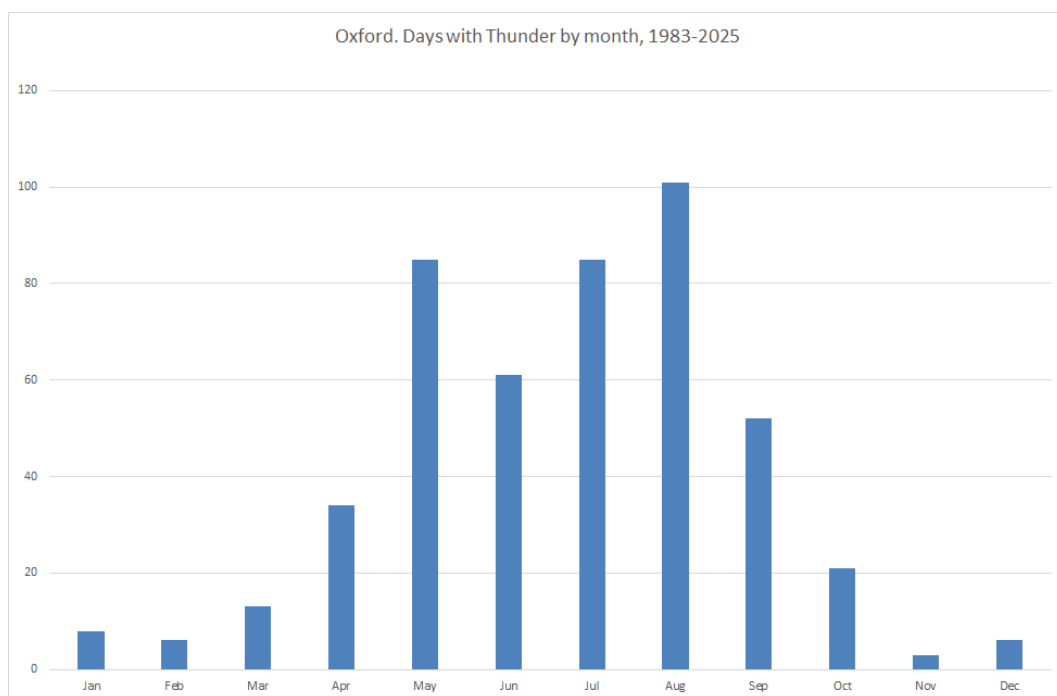


Figure 3: Total days of thunder per month at Oxford, 1983-2025.

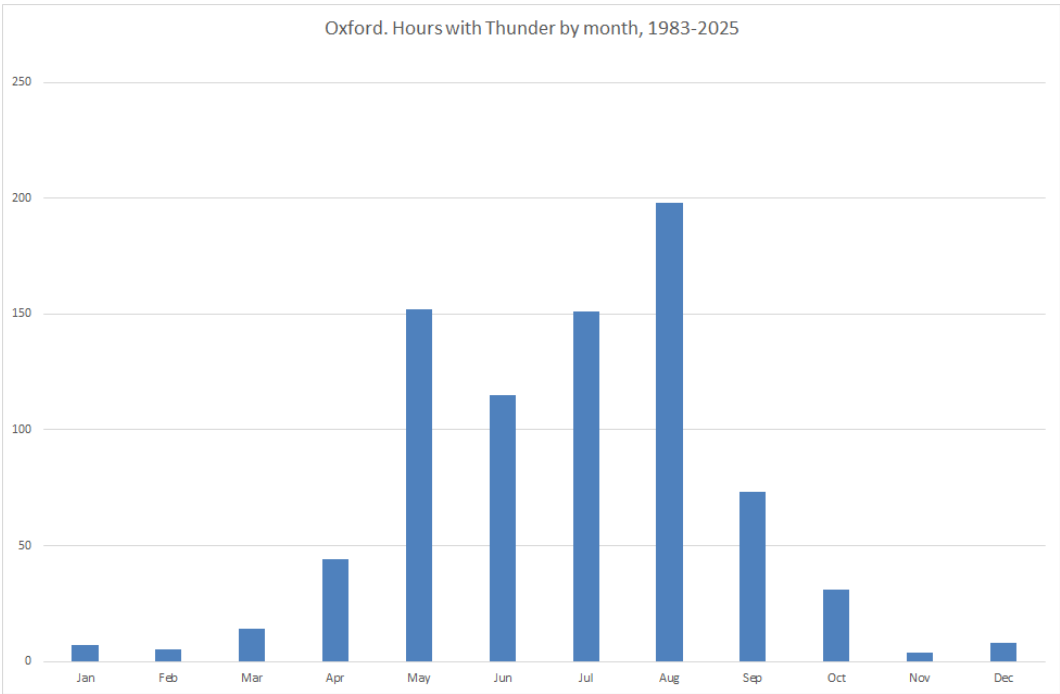


Figure 4: Total hours with thunder at each month at Oxford, 1983–2025

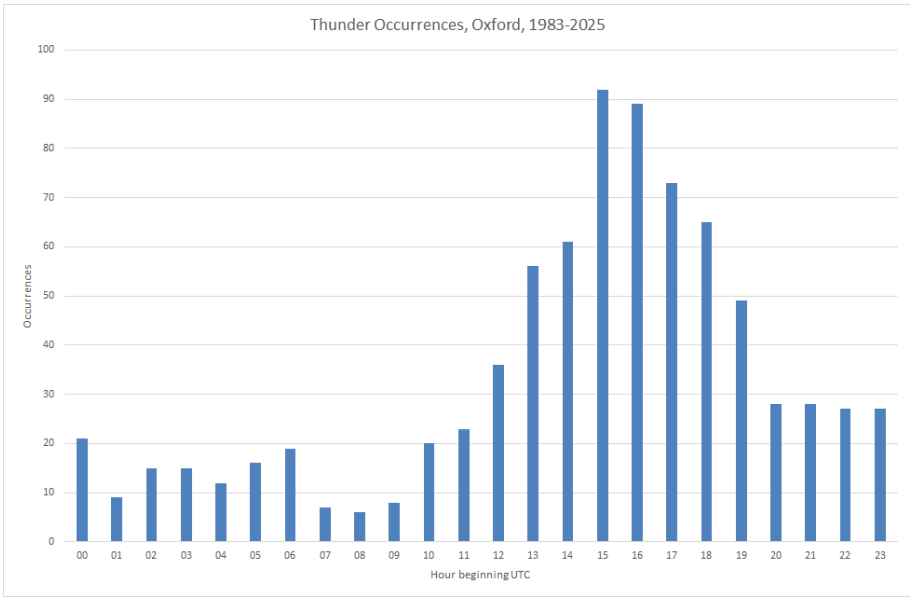


Figure 5: Diurnal distribution of thunder at Oxford, 1983–2025.

4 Diurnal distribution of thunder

There are no great surprises (for a location well inland) with the diurnal distribution of thunder hours (Figure 5) with the clear late afternoon peak and with lowest occurrence in the morning from 0700 to 0900 UTC. It is, however, worth noting, that after a steady decline in frequencies in early evening, there is something of a plateau of relatively high incidences from 2000 UTC to midnight; also note the brief ‘spike’ at around 0600 UTC.

5 Thundery months

Table 1 gives details of the most thundery months over the period 1983–2025, in respect of thunder days but also noting thunder hours and heavy thunderstorms (the latter are discussed below). In the pre-1983 Radcliffe Observatory records, the most thundery months based on thunder days were (hours with thunder in brackets):

- August 1878 with 10 days (16 hours),
- July 1925 with 9 days (20 hours),
- May 1926 with 9 days (11),
- May 1945, also with 9 days (12).

Note that thunder hours for 1878 are taken from the Radcliffe Observations volumes (reference [4]), while those for 1925, 1926 and 1945 are from the Radcliffe Meteorological Station Climatological Returns available via the Met Office Digital Archive.

Table 1: Most-thundery months at Oxford (1983–2025)*

Month Year	Days with thunder	Hours with thunder	Heavy thunderstorms
August 2004	9	18	1
July 1983	8	17	1
May 1983	7	11	2
August 2020	7	16	2

*June 2023 was also noteworthy with 13 thunder hours, although days with thunder totalled 5.

6 Incidence of heavy thunderstorms

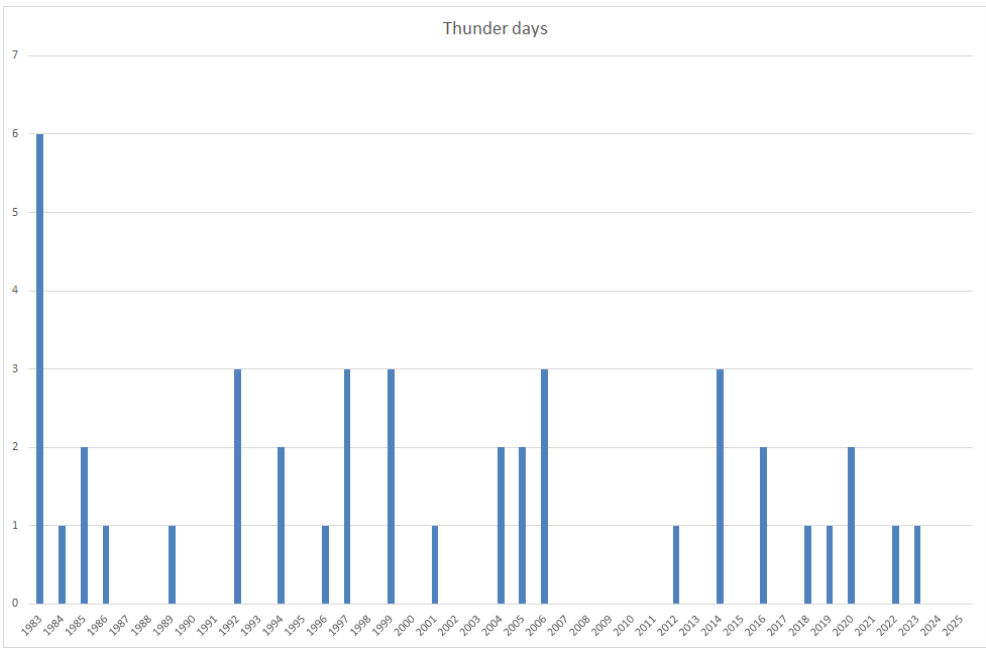


Figure 6: Incidence of heavy thunderstorms at Oxford, 1983–2025.

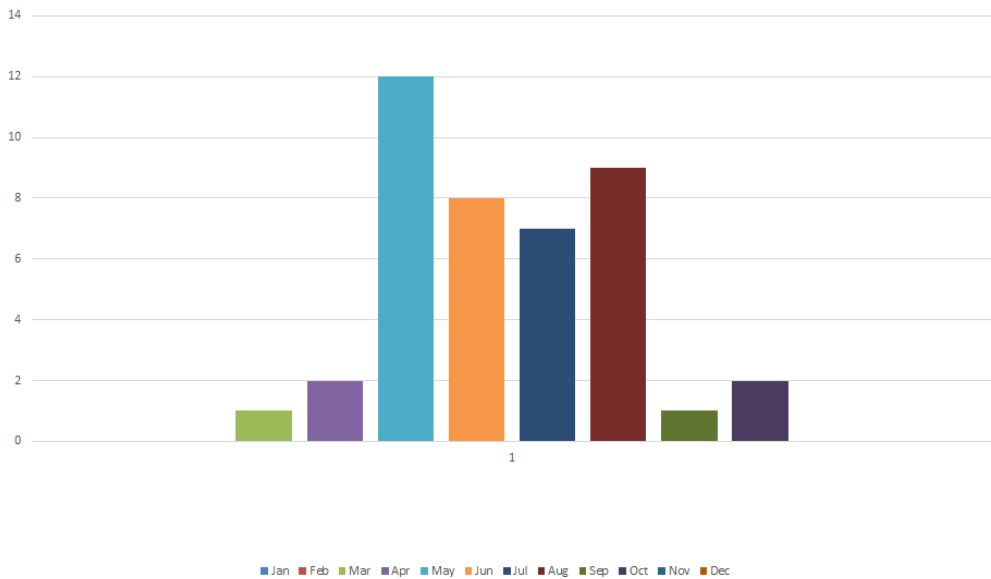


Figure 7: Heavy thunderstorms by month at Oxford, 1983–2025. Note that none were observed in the 4 month November to February period.

This author uses a scale from 1 to 10 to rate thunderstorm severity. It is based on three parameters and associated points: (a) overall electrical activity rated 1–4, (b) close lightning strikes to ground rated 0–4, (c)

precipitation rated 0–2. Storms with a total rating of 5 and above are classed as *heavy thunderstorms*. During the 1983–2025 period, May had the highest number of heavy storms, followed by August (Figure 7). The caveat is that this threshold provides a smaller sample, even over 43 years. It is possible July would rank relatively higher with data over a longer period. The diurnal distribution of these more severe storms does not differ significantly from the overall thunderstorm diurnal profile. The most severe thunderstorms and thunderstorm episodes during the period discussed are noted below.

Oxford's top five thunderstorms, 1983–2025:

7 June 1996
24 May 1989
19 May 1999
8–9 August 1992
15 May 2001

Honorary mentions:

24 July 1994 (not quite overhead at the observer's site), 8 July 2004 and 3 August 2004 (two notable storms within 4 weeks).

Most thundery 24-hour periods and only instances of heavy thunderstorms on consecutive days:

8–9 August 1992, 16–17 May 1997, 28–29 June 2005.

7 Concluding remarks and comparison: 1983–2004 and 2005–2025

Dividing the 43-year record into two periods of 22 years and 21 years respectively, the mean annual number of thunder days shows a numerical decrease from the earlier to later period, albeit with the average still rounding to 11 days. Nine months of the year reflect this decrease, the exceptions (showing an increase) have been March, September and October. Both thunder days and thunder hours show a conspicuous decline after 2006. Also noteworthy is the scarcity of heavy thunderstorms from 2007 to 2013 (note that none were observed in the 4 month November to February period).

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Studies of snowfall and thunderstorms in the four seasons.

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4. Webb J. D. C. : The incidence of thunder at Oxford, 1983–2025.