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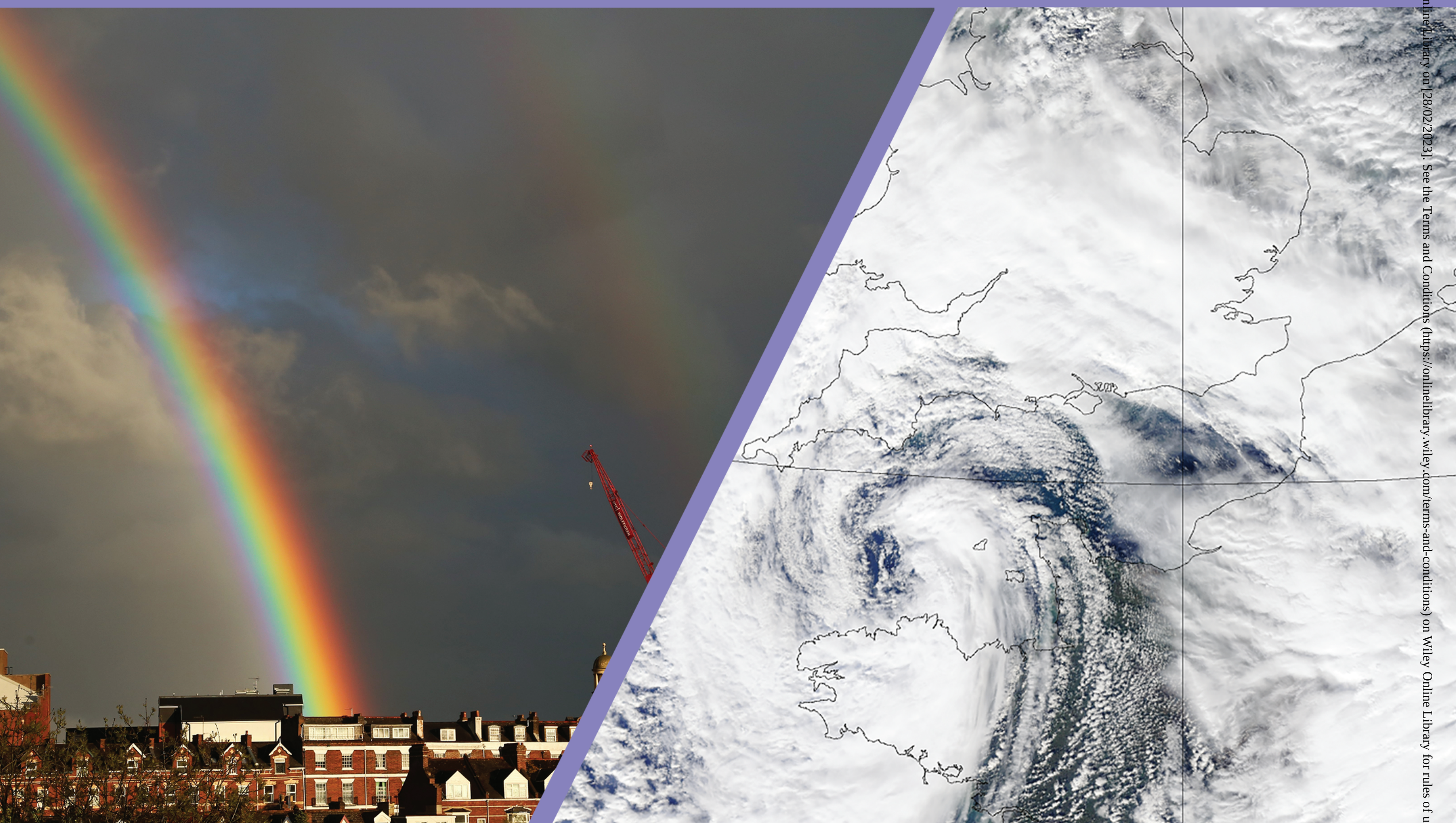

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State of the UK Climate 2020

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(Left) Primary and secondary rainbows appear above Exeter, Devon as a heavy shower clears eastwards on the evening of 30th April 2020. Image by Matt Clark, Met Office (Right) Storm Alex centred near the Channel Islands on 2nd October 2020. Image copyright Met Office / NOAA / NASA.

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SPECIAL ISSUE ARTICLE

International Journal of Climatology RMetS

State of the UK Climate 2020

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INTRODUCTION

This report provides a summary of the UK weather and climate through the calendar year 2020, alongside the historical context for a number of essential climate variables. This is the seventh in a series of annual 'State of the UK climate' publications and an update to the 2019 report (Kendon *et al*., 2020). It provides an accessible, authoritative and up-to-date assessment of UK climate trends, variations and extremes based on the most up to date observational datasets of climate quality.

The majority of this report is based on observations of temperature, precipitation, sunshine and wind speed from the UK land weather station network as managed by the Met Office and a number of key partners and co-operating volunteers. The observations are carefully managed such that they conform to current best practice observational standards as defined by the World Meteorological Organization (WMO). The observations also pass through a range of quality assurance procedures at the Met Office before application for climate monitoring. Time series of near-coast sea-surface temperature and sea-level are also presented and in addition a short section on phenology which provides dates of first leaf and bare tree indicators for four common shrub or tree species.

National and regional statistics in this report are from the HadUK-Grid dataset which is the principal source of data (Hollis *et al*., 2019). Temperature and rainfall series from this dataset extend back to 1884 and 1862, respectively. Details of the datasets used throughout this report and how the various series which are presented are derived are provided in the appendices.

The report presents summary statistics for the most recent year 2020 against the most recent decade 2011–2020, the most recent 30-year reference period (1981–2010) and the climate reference period 1961–1990. The full series provide longer-term context, while a comparison is also made to centennial averages for the Central England Temperature series. The decade 2011–2020 is a non-standard reference period, but it provides a 10-year 'snapshot' of the most recent experience of the UK's climate and how that compares to historical records. This means differences between 2011 and 2020 and 30-year reference periods may reflect shorter-term decadal variations as well as long-term trends.

For this annual publication, the most recent decade (currently 2011–2020) changes every year, while the most recent 30-year reference period (currently 1981–2010) changes every decade. For next year's report, the most recent 30-year reference period will change from 1981–2010 to 1991–2020, while the climate reference period 1961–1990 will be retained. However, this report also includes a brief summary of key differences between preliminary 1991–2020 and 1981–2010 averages for temperature and rainfall.

Throughout the report's text the terms “above normal” and “above average” and so on refer to the 1981–2010 baseline reference period unless otherwise stated. The majority of maps in this report show the year 2020 relative to the 1981–2010 reference period—that is, they are anomaly maps which show the spatial variation in this difference from average. Maps of actual values are in most cases not displayed because these are dominated by the underlying climatology, which for this report is of a lesser interest than the year-to-year variability. These data are presented to show what has happened in recent years, not necessarily what is expected to happen in a changing climate.

Values quoted in tables throughout this report are rounded, but where the difference between two such values is quoted in the text (e.g., comparing the most recent decade with 1981–2010), this difference is calculated from the original unrounded values.

Updates Compared to State of UK Climate 2019

- A chart showing global surface temperature has been added.
- The section on sea level rise has been revised.
- A section summarizing key differences between preliminary 1991–2010 and 1981–2010 averages has been added.

Feedback

We would welcome suggestions or recommendations for future annual publications of this report. Please send any feedback to the Met Office at ncic@metoffice.gov.uk

This State of the UK Climate report was supported by the Met Office Hadley Centre Climate Programme funded by BEIS and Defra.

EXECUTIVE SUMMARY

- The UK's climate is changing. Recent decades have been warmer, wetter and sunnier than the 20th century.
- Year 2020 was third warmest, fifth wettest and eight sunniest on record for the UK. No other year has fallen in the top-10 for all three variables for the UK.
- The UK has warmed at a broadly consistent but slightly higher rate than the observed change in global mean temperature.

Land temperature

- 2020 was the third warmest year for the UK in a series from 1884, and also third warmest for Central England in a series from 1659.
- 2020 included the fifth warmest winter (December 2019–February 2020), eighth warmest spring, sixth warmest January, equal-fourth warmest April and equal-sixth warmest November for the UK in series from 1884.
- All the top 10 warmest years for the UK in the series from 1884 have occurred since 2002.
- The most recent decade (2011–2020) has been on average 0.5°C warmer than the 1981–2010 average and 1.1°C warmer than 1961–1990.
- The Central England Temperature series provides evidence that the 21st century so far has overall been warmer than the previous three centuries.

Air and ground frost

- 2020 was the seventh consecutive year where the number of air and ground frosts was below the 1981–2010 average. The number of air and ground frosts were both fourth lowest in the series from 1960/1961.
- The most recent decade (2011–2020) has had 16% fewer days of air frost and 14% fewer days of ground frost compared to the 1981–2010 average, and 25%/20% fewer compared to 1961–1990.

Energy demand and growing conditions indices

- Heating degree days in 2020 were fifth lowest, and cooling and growing degree days equal-ninth/eighth highest, respectively for the UK in series from 1960.
- The most recent decade (2011–2020) has had 6% fewer heating degree days per year on average compared to 1981–2010 and 12% fewer compared to 1961–1990.
- The most recent decade (2011–2020) has had 7% more growing degree days per year on average compared to 1981–2010 and 17% more compared to 1961–1990.

Near-coast sea-surface temperature

- 2020 was the eighth warmest year for UK near-coastal sea-surface temperature (SST) in a series from 1870.
- The most recent decade (2011–2020) has been on average 0.3°C warmer than the 1981–2010 average and 0.7°C warmer than 1961–1990.
- Nine of the 10 warmest years for near-coast SST for the UK have occurred since 2002.

Precipitation

- 2020 was the UK's fifth wettest year in a series from 1862, with 116% of the 1981–2010 average and 122% of the 1961–1990 average rainfall.
- February 2020 was the UK's wettest February and fourth wettest calendar month on record in a series from 1862. It was the wettest February for England and Wales in a series from 1766.
- 2020 also included the fifth wettest winter, the fifth driest spring and, for England, the driest May on record in a series from 1862.
- 3 October 2020 was one of the UK's wettest days on record in a daily series from 1891, with storms Ciara and Dennis on 8th/15th February and storm Bella on 26th December also in the UK's top 40 wettest days.
- Six of the 10 wettest years for the UK in a series from 1862 have occurred since 1998.
- Since 2009, the UK has had its wettest February, April, June, November, December on record in monthly series from 1862—that is, five of 12 months—as well as the wettest winter on record.
- The most recent decade (2011–2020) has been on average 4% wetter than 1981–2010 and 9% wetter than 1961–1990 for the UK overall.
- For the most recent decade (2011–2020) UK summers have been on average 15% wetter than 1981–2010 and 17% wetter than 1961–1990. UK winters have been 11%/19% wetter.

Snow

- Any snow during 2020 mainly affected upland and northern areas, and there were no major widespread snow events.
- 2020 was one of the least snowy years on record.
- Widespread and substantial snow events have occurred in 2018, 2013, 2010 and 2009, but their number and severity have generally declined since the 1960s.

Sunshine

- 2020 was the eighth sunniest year for the UK in a series from 1919, with 109% of the 1981–2010 average and 113% of 1961–1990 average sunshine hours.

- Spring 2020 was the UK's sunniest spring on record, and also sunnier than most UK summers. It included the sunniest April, and sunniest May, in series from 1919.
- The most recent decade (2011–2020) has had for the UK on average 4% more hours of bright sunshine than the 1981–2010 average and 8% more than the 1961–1990 average.
- For the most recent decade (2011–2020) UK winters have been 5% sunnier than 1981–2010 and 13% sunnier than 1961–1990. UK springs have been 11%/16% sunnier.

Wind

- Ten named storms affected the UK in 2020.
- This was a fairly typical year for storminess compared to recent decades.
- There are no compelling trends in storminess as determined by maximum gust speeds from the UK wind network over the last five decades.

Sea-level rise

- Mean sea level around the UK has risen by approximately 1.5 mm·year^{-1} on average from the start of the 20th century, excluding the effect of vertical land movement, resulting in an overall rise of 16.5 cm over that period.
- For the 20th century the rate of sea level rise around the UK is close to the estimate of the global sea level rise.
- The rate of sea level rise has increased recently, exceeding 3 mm·year^{-1} for the period 1993–2019.

Significant weather

- Severe and widespread flooding in February 2020, at least as severe as that of November 2019, was due to storms Ciara and Dennis, arriving only 1 week apart.
- On 31st July, 37.8°C was recorded in Greater London making this the UK's third warmest day on record.
- In early August, southern England experienced one of the most significant heatwaves of the last 60 years with a succession of days exceeding 34°C and 'tropical' nights exceeding 20°C.
- On 16 August 2020, a rain-gauge in Norfolk recorded a daily total of 239.9 mm; the UK's highest daily total in August on record at an individual station.
- 3 October 2020 and 15 February 2020 were two of the three wettest days on record UK-wide in over 47,000 days from 1891. Remarkably, four of the 41 days in this series with a UK total exceeding 20 mm occurred in 2020
- In terms of wind gusts, Storms Ellen and Francis were two of the most notable August storms to affect the UK in the last 50 years.

Preliminary 1991–2020 long term averages

- For the UK the period 1991–2020 has been on average 0.3°C warmer than 1981–2010 and 0.9°C warmer than 1961–1990, with warming across all months and countries.
- For the UK the period 1991–2020 has been on average 6% wetter than 1961–1990 but only 1% wetter than 1981–2010. Rainfall has increased by 5% in both winter and summer compared to 1981–2010 and 12%/7% compared to 1961–1990.

Phenology

- First leaf dates in 2020 were particularly early (on average 10.4 days earlier than the 1999–2019 baseline) for a range of common shrub/tree species, associated with mild conditions through January and February and some notable warmth and sunshine in April.
- End of season bare tree dates in 2020 were also slightly earlier (on average 4.3 days earlier than the 1999–2019 baseline) for the same species.
- Overall, the 2020 leaf-on season was extended by 6.2 days on average compared with the 1999–2019 baseline.

1 | SYNOPTIC SITUATION

Figure 1 shows seasonal mean sea-level pressure anomalies for the four seasons of 2020 relative to the 1981–2010 average, using the ERA5 reanalysis (Hersbach *et al.*, 2020). This provides an indication of atmospheric circulation patterns for each season overall. Note that pressure anomalies are scaled equally across all four seasons for consistency, however, winter months typically tend to have larger pressure anomalies than summer months

A deep low pressure anomaly extended across the northern half of the UK during the winter, with a high pressure anomaly across southern Europe. December 2019 and February 2020 were dominated by a mild westerly weather type, with low pressure predominant. The weather was frequently wet and windy with a succession of Atlantic low pressure systems and associated fronts—including five named storms—and only very brief settled interludes. In January, the low pressure anomaly was further north and the pressure generally higher over the

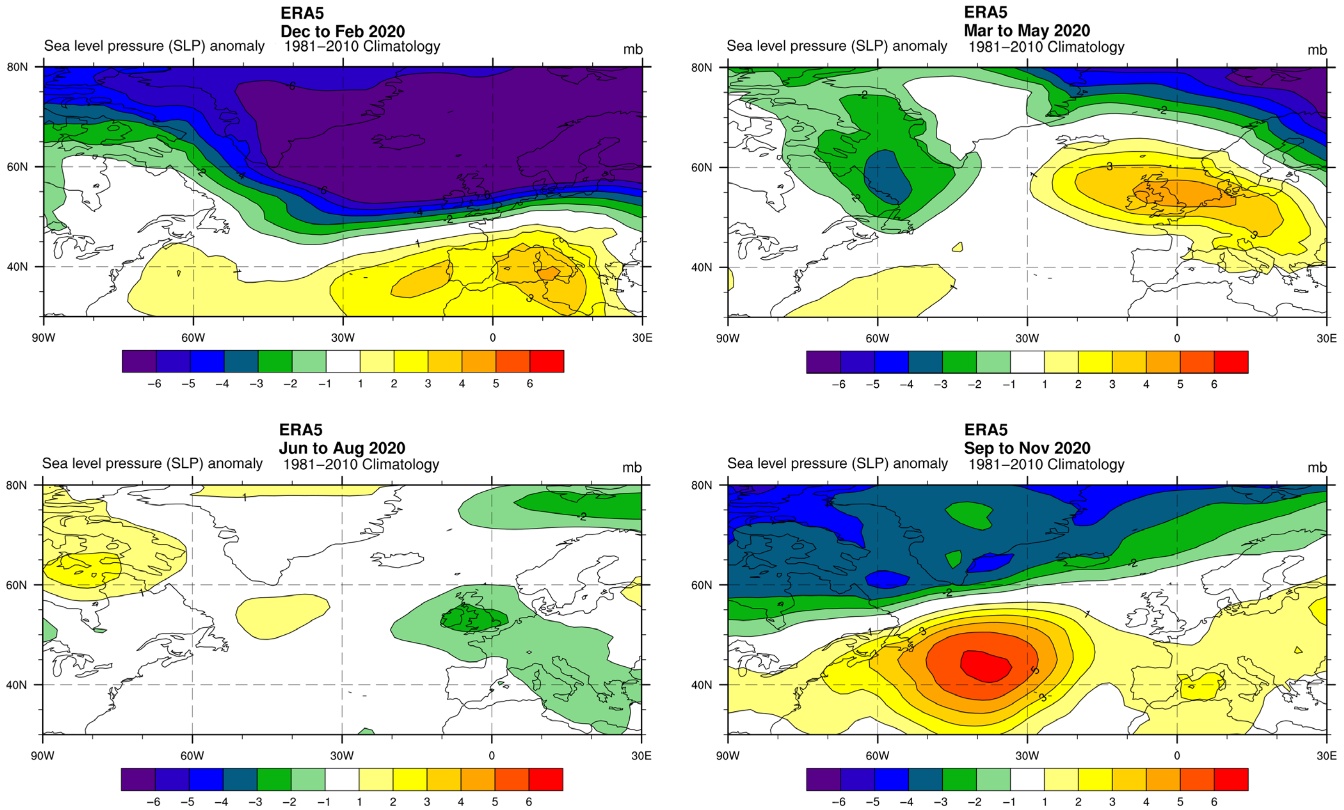


FIGURE 1 2020 seasonal mean sea-level pressure anomalies (hPa, relative to 1981–2010 average). Winter refers to the period December 2019–February 2020. Note that winter 2021 (December 2020–February 2021) will appear in State of the UK Climate 2021. Images provided by the NOAA-ESRL Physical Sciences Division, Boulder, CO from their web site at http://www.esrl.noaa.gov/ using the ERA5 reanalysis (Hersbach *et al.*, 2020)

UK, and there was a week of more settled weather with high pressure just after mid-month. Other than at the start of December, the weather was often mild, occasionally exceptionally so.

A high pressure anomaly was located across the UK during the spring. The first half of March was unsettled, but from mid-month high pressure slowly built across the British Isles and any unsettled spells were otherwise relatively brief, so the season was of opposite character to the preceding winter. The high pressure anomaly was centred across the north-east during April, with easterly winds a regular feature, resulting in low minimum temperatures but high maximum temperatures in plenty of sunshine. The high pressure anomaly was firmly established across the UK during May, bringing plenty of fine, dry, settled weather, although northerly winds brought a cold snap before mid-month. The highest ever March reading of mean-sea-level pressure was recorded in north-west Scotland on the 29th (Burt, 2021).

A shallow low pressure anomaly was located over the UK during the summer. The season comprised a mixture of weather types. All three summer months saw some fine, settled weather, including spells of hot weather, but it was often rather unsettled and changeable, particularly in June and August, although southern areas were generally nearer the influence of high pressure across the near-continent. An area of low pressure brought some very wet weather to the north and west from 27th to 28th June, and the second half of August was generally wet and windy with depressions heading in from the west, including named storms Ellen and Francis.

Mean sea level pressure was near normal over the UK for autumn overall; slightly higher than normal during September and November, but lower in October. There was some fine, dry settled weather in the middle of September but it was much colder and unsettled towards the end of the month with low pressure to the east drawing a cool north-easterly flow with some very wet and windy weather across East Anglia. October began and ended unsettled with turbulent weather from storms Alex and Aiden, but a brief spell of easterly winds from mid-month. November was fairly quiet but often rather mild and unsettled. A deep low pressure anomaly dominated the UK in December, and for much of the month the weather was mild and very wet including storm Bella on 26th December, after which conditions turned colder.

1.1 | NAO index

Figure 2 Shows the winter North Atlantic oscillation (WNAO) index from 1850 to 2020 inclusive (Annex 1 provides details of the WNAO index). (Note here and throughout the report winter refers to the year in which January and February fall.) This index is a measure of the large-scale surface pressure gradient in the North Atlantic between the Azores and Iceland, which determines the strength of westerly winds across the Atlantic, and is the principal mode of spatial variability of atmospheric patterns in this region. When the pressure difference is large, the WNAO is positive and westerly winds dominate with stronger and more frequent storms. When the pressure difference is small, the WNAO is negative with an increased tendency for blocked weather patterns, reducing the influence of Atlantic weather systems

The WNAO index for 2020 was positive; the most positive WNAO since winter 1995 and sixth most positive in a series from 1850. The winter overall was mild and wet—for the UK it was fifth warmest in a series from 1884 and also fifth wettest in a series from 1862. February in particular was exceptionally wet (wettest for the UK in a series from 1862) and the NAO was very strongly positive—comparable with the NAO for February 1990 (second wettest) and February 1997 (fourth wettest). The NAO was also strongly positive in January. Winter 2020 (WNAO +1.8) was frequently dominated by mild, wet, westerly weather patterns and, based on the combination of both mild and wet characteristics, may be compared against other winters such as the exceptionally wet winters of 2016 (+1.4) and 2014 (+1.2), and other mild, wet winters including 2007 (+0.9), 1995(+1.8), and 1990(+1.2). In contrast, a WNAO negative winter would be dominated by cold, dry, blocked weather patterns such as 2010 (WNAO −3.1). However, inevitably over this 3-month duration many if not most winters have a mixture of weather types and fall somewhere between these mild and wet versus cold and dry extremes.

Overall, the WNAO index shows a large annual variability but also decadal variability with periods of mainly positive phase (e.g., 1910–1920s and 1990s) and negative phases (e.g., 1960s). Hanna *et al.* (2015) discusses changes in the NAO index and notes an increase in variability of WNAO since 1990. Since 2012 the WNAO has generally been in a positive phase (Figure 2).

Figure 3 shows the summer North Atlantic Oscillation (SNAO) index from 1850 to 2020 inclusive (Annex 1 provides details of the SNAO index). Similar to the WNAO index, this is a measure of large-scale climate variability in the North Atlantic based on the surface pressure gradient, but based on a more northerly location and smaller spatial scale than the winter counterpart, reflecting the more northerly location of the Atlantic storm track in summer.

The 2020 SNAO index was slightly negative. The summer was slightly warmer and wetter than average, although not exceptional. For the UK, a negative SNAO

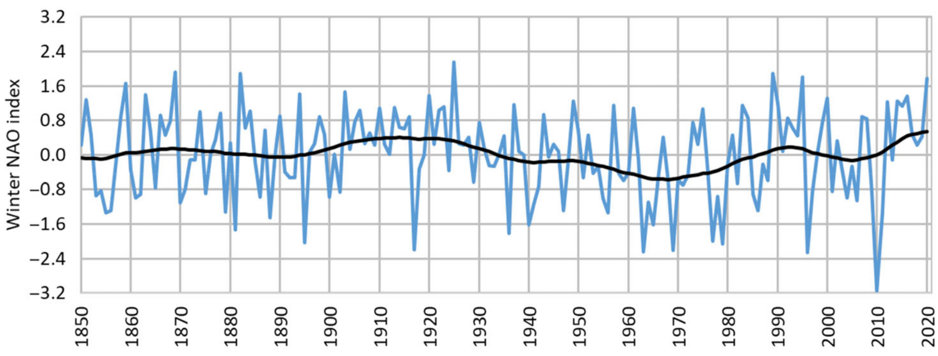


FIGURE 2 Winter NAO index based on standardized monthly mean pressure difference between stations in Gibraltar and south-west Iceland (see Annex 1 for details). Winter 2020 refers to the period December 2019–February 2020. Note that winter 2021 (December 2020–February 2021) will appear in State of the UK Climate 2021

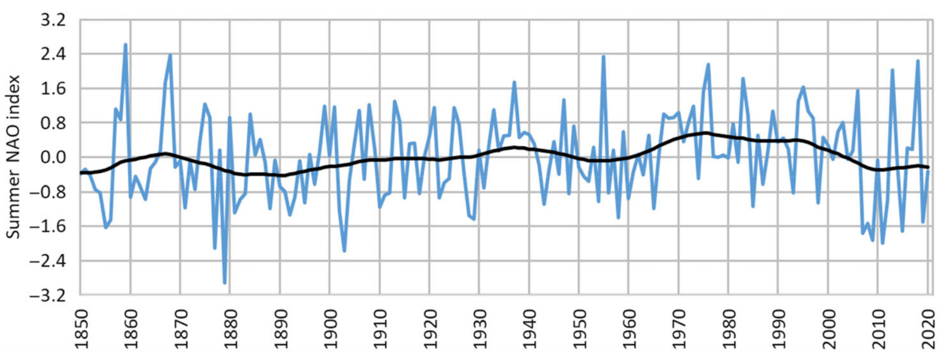


FIGURE 3 Summer NAO index based on standardized monthly mean pressure difference using HadSLP2 dataset (see Annex 1 for details). Summer 2020 refers to the period June to August 2020

index tends to be associated with cool, wet summers, although with a fairly weak correlation. Recent summers with a low SNAO index include 2007, 2008, 2009, 2011, 2012, 2015 and 2019 and these were all generally wetter than average (especially 2007, 2008, 2009 and 2012) with temperatures mostly near or below average (especially 2011, 2012 and 2015).

As with its winter counterpart, the SNAO shows periods of mainly positive phase (e.g., 1970–1990s) and negative phase (e.g., 1880s and 1890s), with Hanna *et al*. (2015) noting a decrease in SNAO since the 1990s, which includes the run of recent wet summers from 2007 to 2012. The summers of 2013 and 2018 were in marked contrast to this recent sequence.

2 | TEMPERATURE

The UK mean temperature (T_{mean}) for 2020 was 9.6°C, which is 0.8°C above the 1981–2010 long-term average, making this the third warmest year in the UK series from 1884, marginally warmer than 2011, and with only 2014 and 2006 warmer. 2020 was also the third warmest year in the Central England Temperature (CET) series from 1659. The annual mean temperature was around 0.5–1.0°C above average across most of the UK, but more than 1.0°C across south-east England and East Anglia, whereas Northern Ireland was less than 0.5°C above normal (Figure 4, Table 1).

The UK annual mean daily maximum temperature (daily maximum temperature is hereafter referred to as T_{max}) for 2020 was 13.4°C, which is 0.9°C above average. T_{max} anomalies were around 0.5–1.0°C across much of the UK but over 1.0°C across most of southern England. The UK annual mean daily minimum temperature (daily minimum temperature is hereafter referred to as T_{min}) for 2020 was 5.9°C, which is 0.7°C above average. T_{min} anomalies were around 0.5–1.0°C across most of the UK. Both T_{max} and T_{min} anomalies were generally lowest across Northern Ireland (Figure 4, Table 1).

The UK seasonal Tmean for winter 2020 (December 2019–February 2020) was 5.3°C, which is 1.6°C above the 1981–2010 average. This was the fifth warmest winter for the UK in the series from 1884. Temperatures were well above normal in all 3 months—December 2019 (anomaly +1.3°C), January (+2.0°C, the UK's sixth warmest January), and February (+1.4°C) The winter was generally mild throughout, with temperatures mostly above normal, with an absence of frosts, and any cold spells and snowfalls limited in severity. It was particularly mild across northern Scotland in late December 2019, when a new UK December daily maximum temperature record was set (18.7°C at Achfary, Sutherland), covered in State of UK Climate 2019 (Kendon *et al*., 2020).

The UK seasonal Tmean for spring was 8.7°C, which is 0.9°C above the 1981–2010 average. This was the UK's eighth warmest spring in a series from 1884. Temperature anomalies were near normal in March (anomaly +0.1°C) but above in April (+1.7°C) and May (+1.0°C). During a spell of particularly fine, warm and sunny weather in early April, Treknow (Cornwall) recorded 26.0°C on the 10th—around 15°C above average for the time of year—and it was the UK's equal-fourth warmest April in a series from 1884. There was a notable cold snap in mid-May with daily maximum temperatures of only 6–7°C across much of Scotland and north-east England on the 10th, followed by some unusually sharp and widespread frosts; −0.7°C at Sheffield on the 14th was the equal-lowest May temperature on record for the city in a 137-year record. In contrast, there was some fine, warm, settled weather in the second half of the month with temperatures reaching 26–27°C across central and eastern England on the 20th—in places an increase of almost 20°C in daily maximum temperature in just 10 days.

The UK seasonal Tmean for summer was 14.8°C, 0.4°C above average. June and August were both warmer than average (each with anomaly +1.0°C) but July cool (−0.8°C). In contrast to the generally fine spring, the three summer months were mostly unsettled. Each month did see some hot weather: a brief spell in late June (33.4°C at Heathrow on the 25th and 30°C was reached as far north as Carlisle and Ayrshire); a single hot day at the end of an otherwise cool July (37.8°C on the 31st—the UK's third hottest day on record)—and a more sustained heatwave across southern England in early August in which daily maximum temperatures reached 34°C on six consecutive days with five "tropical nights" when temperatures did not drop below 20°C. This was one of the most significant heatwaves to affect southern England in the last six decades (for more details see Section 8). East Anglia had its second warmest August in a series from 1884. However, temperatures were otherwise often rather below average, particularly during July.

The UK seasonal Tmean for autumn was 10.0°C, 0.5°C above normal. Temperatures were near average in September (+0.2°C) and October (−0.1°C) but above in November (+1.5°C). September saw both notably warm and cold spells with temperatures reaching 30°C in the south-east on the 15th, but a cold snap with some frosts late in the month. There were no extremes of temperature in October and very little frost, while much of November was mild, again with few frosts. It was the UK's equal sixth-warmest November in a series from 1884. December, which is included in Figure 6 but not Figure 5, was also mostly a mild month (anomaly

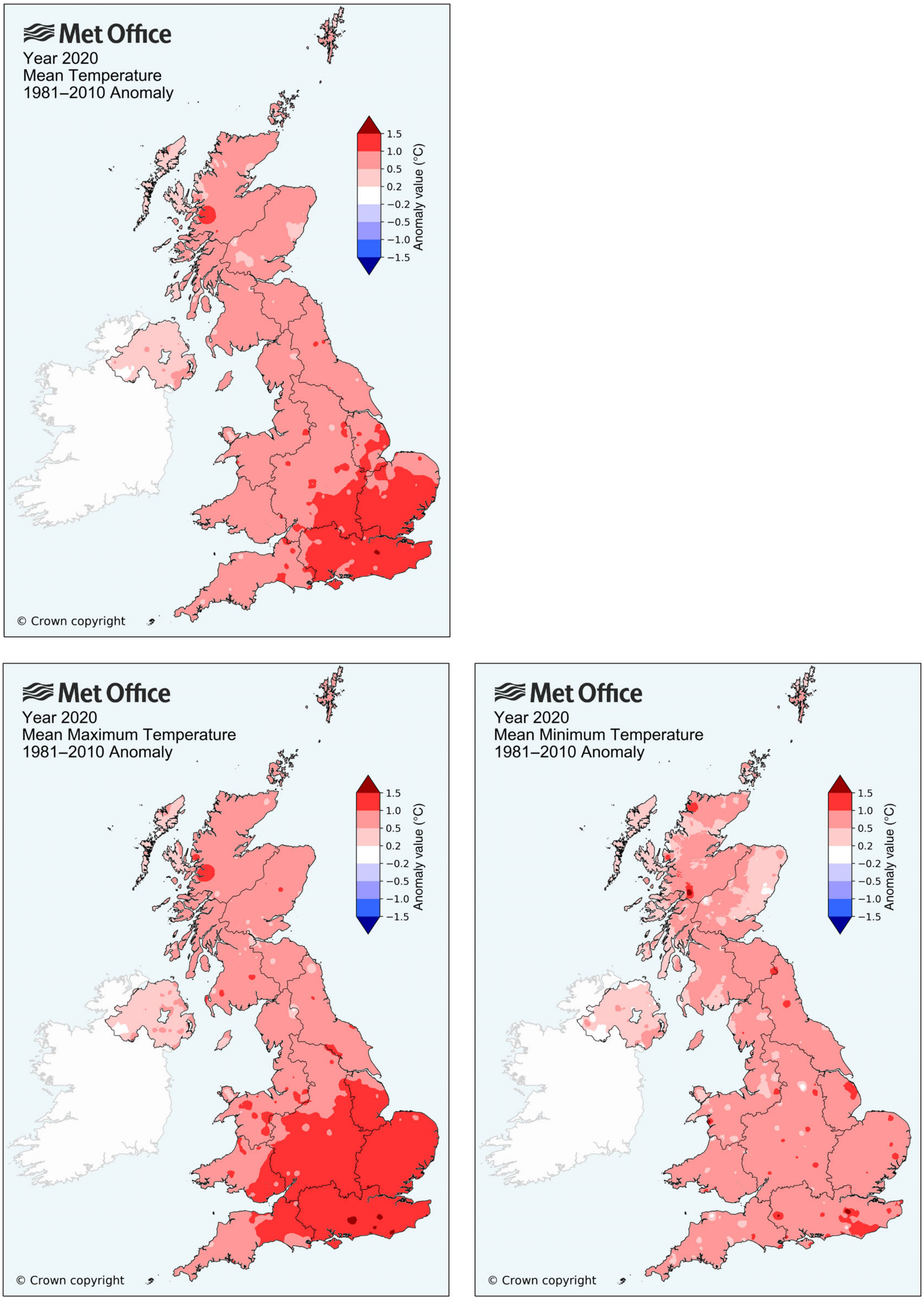


FIGURE 4 2020 annual average temperature anomalies (°C) relative to 1981–2010 average for mean, maximum and minimum temperature. The gridding process aims to strike a balance between a spatially smoothed field and the local characteristics of individual stations. Bulls-eye features present in the T_{min} map are likely to be due to localized micro-climate features, such as frost hollow effects, at individual weather stations, which the gridding process is unable to fully represent

+0.5°C) but with a colder spell from Christmas to New Year. In summary, for year 2020 overall, temperatures were above average in January, February, April to June, August and November, near average in March, September, October and December, and below average in July (Figure 6, Table 1).

Figure 7 shows time series of annual Tmean anomalies for the UK and countries from 1884 to 2020 inclusive, and Figure 8 the seasonal UK Tmean anomaly series. There has been an increase in temperature from the 1970s to the 2000s with the most recent decade (2011–2020) being on average 1.1°C warmer than the 1961–1990 average and 0.5°C above 1981–2010. All the top 10 warmest years in the UK Tmean series (including 2020) have

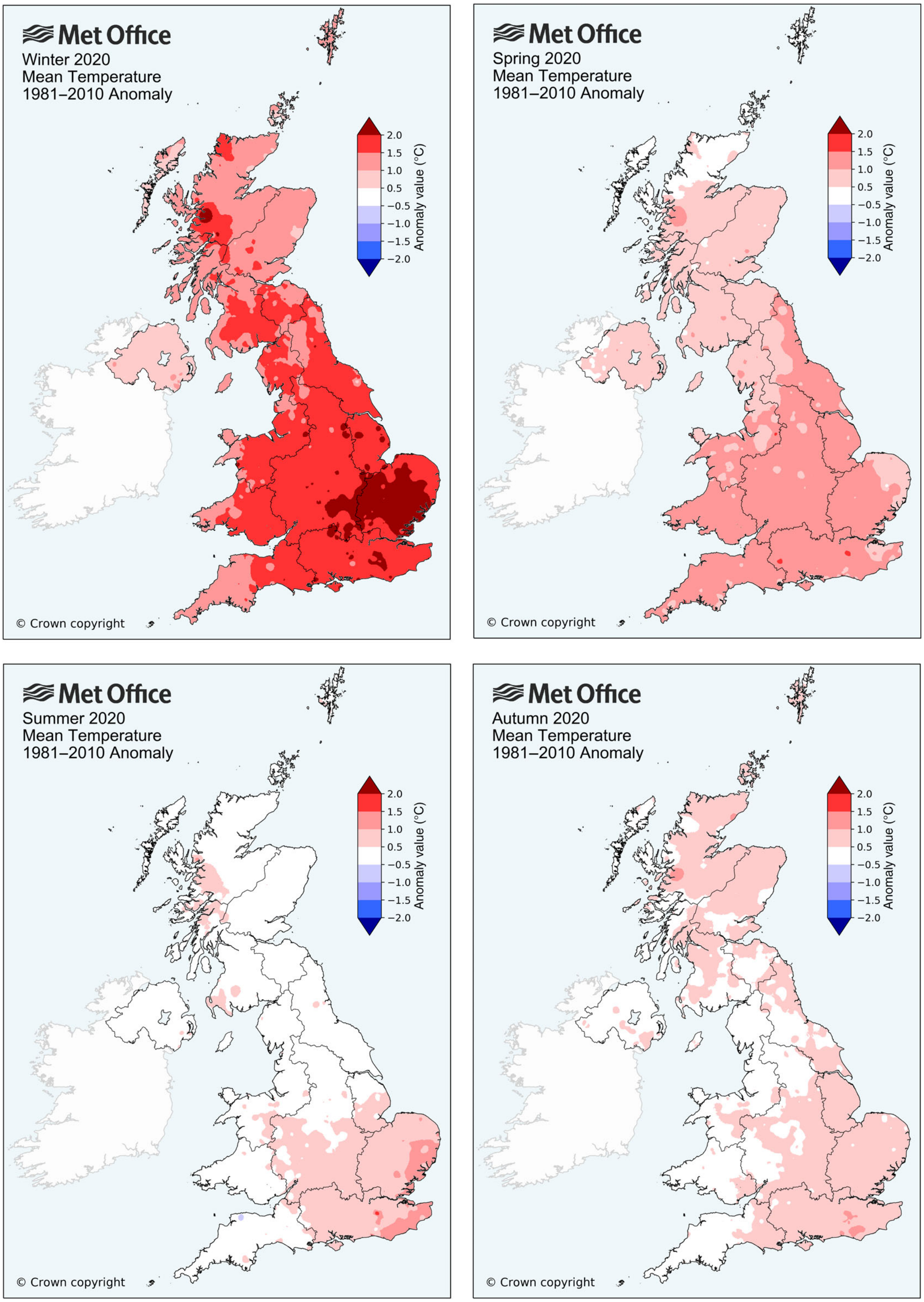


FIGURE 5 2020 seasonal average temperature anomalies (°C relative to 1981–2010 average). Winter refers to the period December 2019–February 2020. Note that winter 2021 (December 2020–February 2021) will appear in State of the UK Climate 2021

occurred since 2002 (Figure 7). While all top 10 warmest years have occurred this century, none of the top 10 coldest years have occurred this century. The coldest year this century (2010) is ranked 22nd coldest in the UK series; every other year this century falls in the top third warmest years in the series.

All four seasons have seen 2011–2020 warmer than 1961–1990, with the largest changes for winter and spring at 1.1 and 1.2°C, and summer and autumn at 0.9°C above the 1961–1990 average (Figure 8). As with the annual series, the seasonal series show large inter-annual variability and some decadal variability, with a marked

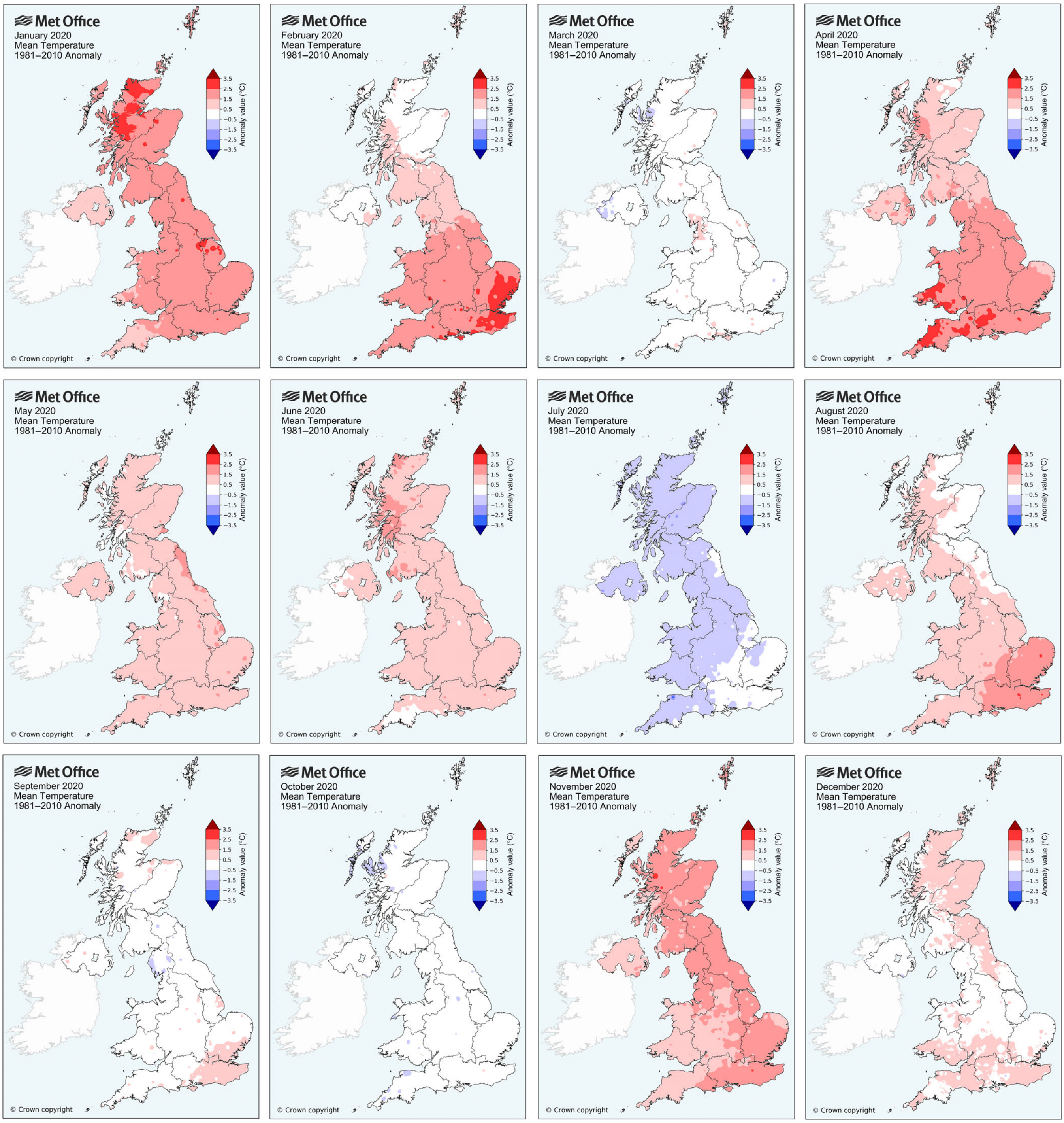


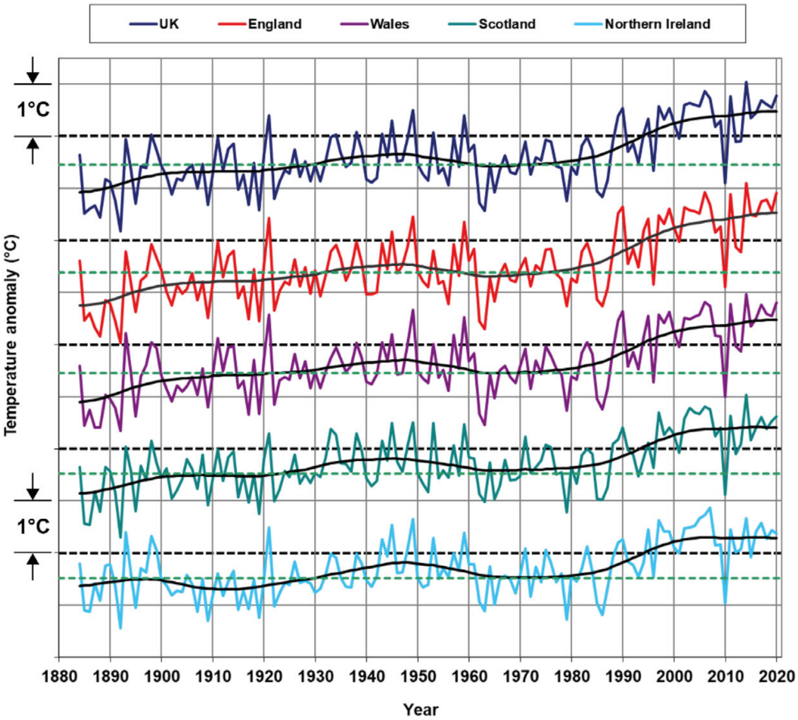
FIGURE 6 2020 monthly average temperature anomalies (°C) relative to 1981–2010 average

TABLE 1 Monthly, seasonal and annual mean temperature and anomaly values (°C) relative to 1981–2010 average for the UK, countries and CET for year 2020

	UK		England		Wales		Scotland		Northern Ireland		CET	
	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly
January	5.6	2.0	6.2	2.1	5.8	1.7	4.8	2.2	5.3	1.1	6.4	2.0
February	5.1	1.4	6.2	2.0	5.8	1.9	3.1	0.4	4.6	0.3	6.3	1.9
March	5.6	0.1	6.4	0.2	5.9	0.1	4.2	0.0	5.6	−0.2	6.7	0.1
April	9.1	1.7	10.2	2.0	9.9	2.3	7.1	1.0	9.0	1.4	10.4	1.9
May	11.3	1.0	12.4	1.1	11.6	1.0	9.7	0.8	11.1	0.9	12.5	0.8
June	14.0	1.0	15.0	0.9	14.0	0.9	12.6	1.3	13.5	0.7	15.3	0.8
July	14.3	−0.8	15.7	−0.6	14.3	−0.9	12.3	−1.0	13.6	−1.0	15.7	−1.0
August	15.9	1.0	17.4	1.3	16.0	1.1	13.5	0.5	14.9	0.6	17.6	1.2
September	12.8	0.2	13.9	0.2	13.0	0.2	11.0	0.1	12.5	0.1	13.9	−0.1
October	9.4	−0.1	10.3	−0.1	9.7	−0.2	7.9	−0.1	9.2	−0.2	10.5	−0.2
November	7.7	1.5	8.4	1.5	7.9	1.2	6.6	1.7	7.6	1.2	8.5	1.4
December	4.3	0.5	4.8	0.4	4.9	0.5	3.4	0.6	4.4	−0.1	5.0	0.4
Winter	5.3	1.6	6.0	1.8	5.7	1.6	4.0	1.4	5.1	0.8	6.2	1.6
Spring	8.7	0.9	9.6	1.1	9.1	1.1	7.0	0.6	8.5	0.7	9.9	0.9
Summer	14.8	0.4	16.0	0.5	14.8	0.4	12.8	0.2	14.0	0.1	16.2	0.3
Autumn	10.0	0.5	10.9	0.6	10.2	0.4	8.5	0.6	9.8	0.4	11.0	0.3
Annual	9.6	0.8	10.6	0.9	9.9	0.8	8.0	0.6	9.3	0.4	10.8	0.8

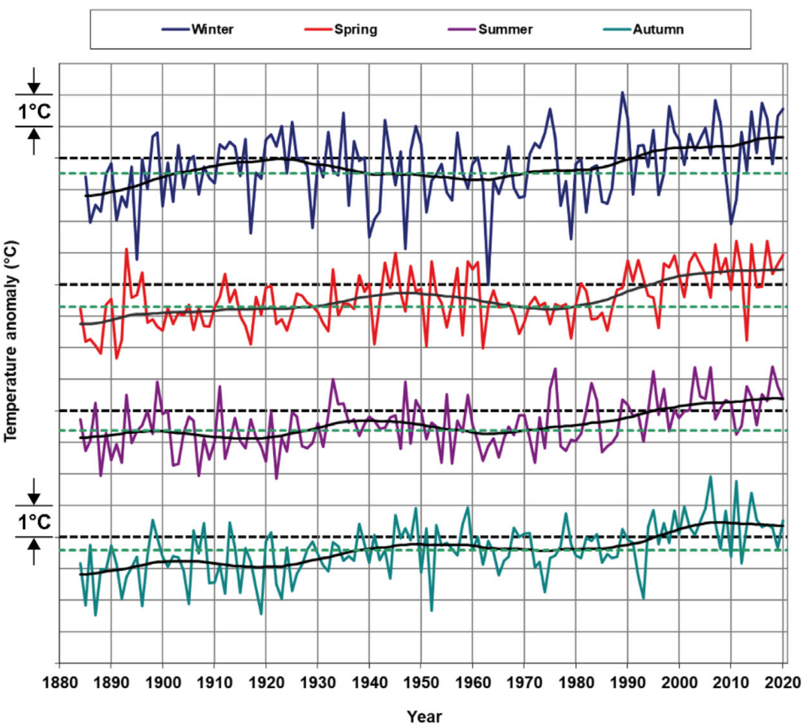
Key						
Warmest on record	Top 10 warm	Warm: ranked in upper third of all years	Middle: ranked in middle third of all years	Cool: ranked in lower third of all years	Top 10 cold	Coldest on record

Note: Colour coding relates to the relative ranking in the full series which spans 1884–2020 for all series except CET which is 1659–2020.



Area	1961–1990 average	1981–2010 average	2011–2020 average	2020
UK	8.3	8.8	9.3	9.6
England	9.0	9.7	10.2	10.6
Wales	8.6	9.1	9.6	9.9
Scotland	6.9	7.4	7.8	8.0
Northern Ireland	8.4	8.9	9.2	9.3

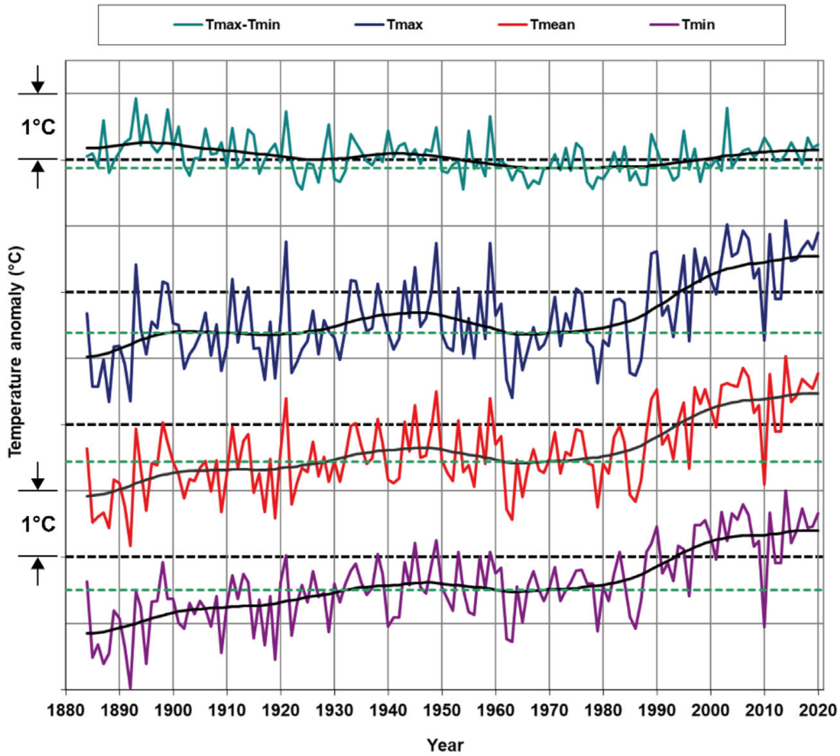
FIGURE 7 Annual Tmean (°C) for the UK and countries, 1884–2020, expressed as anomalies relative to the 1981–2010 average. The hatched black line is the 1981–2010 long-term average. The lower hatched green line is the 1961–1990 long-term average. Light grey grid-lines represent anomalies of ±1°C. The table provides average annual Tmean values (°C). Smoothed trend lines used here and throughout the report are described in Annex 2



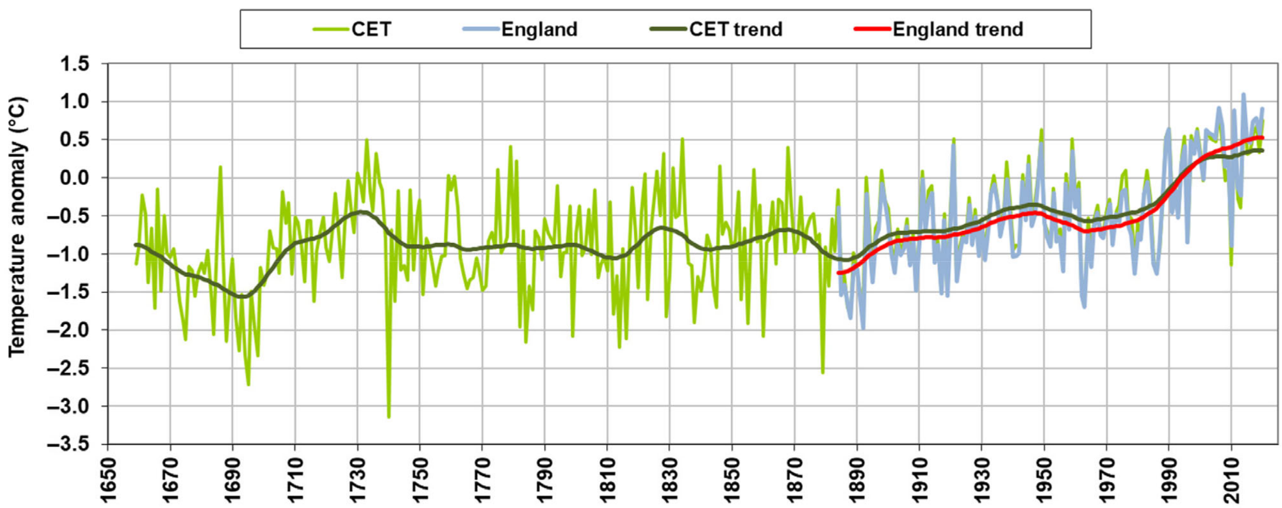
Season	1961–1990 average	1981–2010 average	2011–2020 average	2020
Winter	3.2	3.7	4.4	5.3
Spring	7.0	7.7	8.2	8.7
Summer	13.8	14.4	14.7	14.8
Autumn	9.0	9.4	9.9	10.0

FIGURE 8 Seasonal Tmean (°C) for the UK, 1884–2020 (note winter from 1885 to 2020; year is that in which January and February fall. Winter 2021—which includes December 2020—will appear in next year's publication). The hatched black line is the 1981–2010 long-term average. The lower hatched green line is the 1961–1990 long-term average. Light grey grid-lines represent anomalies of ±1°C. The table provides average seasonal T_{mean} values (°C)

FIGURE 9 Annual T_{max}, Tmean and T_{min} (°C) for the UK, and T_{max} minus T_{min}, 1884–2020, expressed as anomalies relative to the 1981–2010 average. The hatched black line is the 1981–2010 long-term average. The lower hatched green line is the 1961–1990 long-term average. Light grey grid-lines represent anomalies of ±1°C. The table provides average absolute values (°C)



Variable	1961–1990 average	1981–2010 average	2011–2020 average	2020
T_{max}	11.8	12.5	13.0	13.4
T_{mean}	8.3	8.8	9.3	9.6
T_{min}	4.8	5.3	5.7	5.9
Tmax minus T_{min}	7.1	7.2	7.3	7.4



Variable	1961–1990 average	1981–2010 average	2011–2020 average	2020
CET	9.5	10.0	10.4	10.8
England	9.0	9.7	10.2	10.6

FIGURE 10 Annual T_{mean} (°C) for CET series, 1659–2020, and England temperature series, 1884–2020, expressed as anomalies relative to the 1981–2010 average. The table provides average annual T_{mean} values (°C)

increase in temperature across all four seasons from the 1970s to the 2000s. Warming has been slightly greater for T_{max} than T_{min} in recent decades (Figure 9) resulting in a small increase in the average diurnal temperature range (DTR, T_{max} minus T_{min}) but to levels similar to those observed prior to the mid-20th century.

The uncertainty in these statistics is principally a function of the number and distribution of stations in the observing network which varies through time. For monthly, seasonal and annual averages the standard error is less than 0.1°C and consequently the uncertainty is much smaller than the year-to-year variability. For simplicity of presentation all the temperature data are presented in the tables to the nearest 0.1°C. More information relating to the uncertainties and how they are estimated is provided in Annex 2.

Figure 10 shows annual Tmean for England from 1884 to 2020 and CET series from 1659. The series are highly correlated for the period of overlap (R^2 value .98) and have a root-mean-square difference of 0.1°C which is comparable to the estimated series uncertainty as described in Annex 2. The CET series could effectively be considered a proxy for an England series from 1659, although because these are different datasets produced

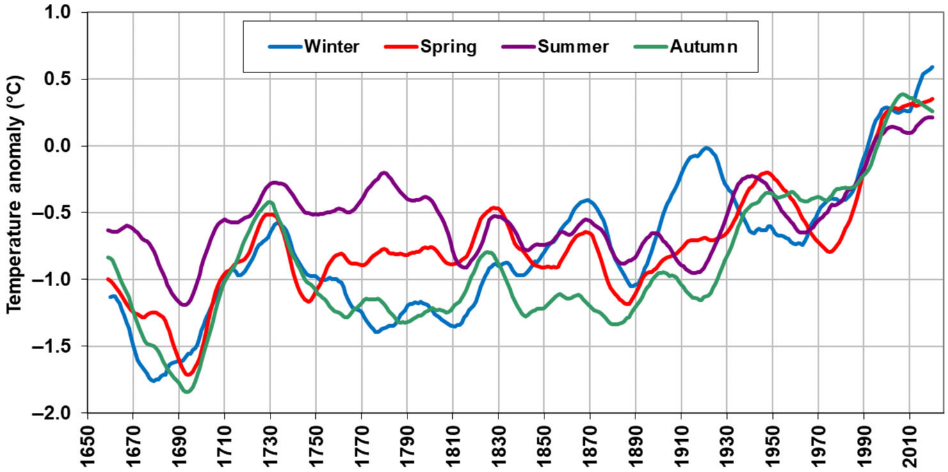


FIGURE 11 Seasonal CET series (°C), 1659–2020, expressed as anomalies relative to 1981–2010 average. The figure shows a smoothed trend for each series using a weighted kernel filter described in Annex 2

TABLE 2 Centennial averages for CET series (°C) 1659–2020 (winter from 1660 to 2020)

Season	1659–1700	1701–1800	1801–1900	1901–2000	2001–2020
Year	8.7	9.2	9.1	9.5	10.3
Winter	3.0	3.5	3.7	4.2	4.9
Spring	7.5	8.1	8.1	8.4	9.2
Summer	14.9	15.5	15.2	15.4	16.0
Autumn	9.1	9.6	9.5	10.1	11.0

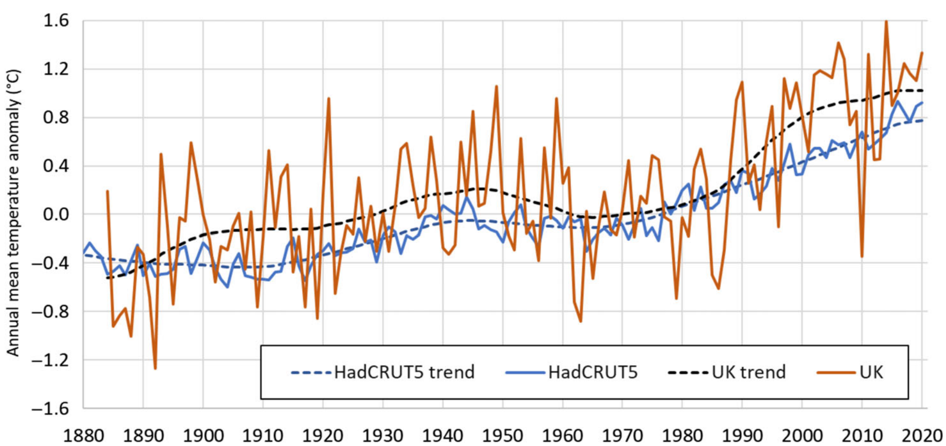


FIGURE 12 Annual T_{mean} (°C) for the UK, 1884–2020, plotted alongside global annual T_{mean} (°C) based on HadCRUT5 dataset. Both series are expressed as anomalies relative to the 1961–1990 average

in different ways, some differences are inevitable. The CET series provides evidence that the 21st century so far has overall been warmer than any period of equivalent length in the previous three centuries, and that all seasons are also warmer (Figures 10 and 11). When comparing the early 21st century (2001–2020) to previous centennial averages, the difference is typically 0.5–1.0°C compared to 1901–2000 and 0.5–1.5°C compared to 1801–1900 and 1701–1800, with some seasonal variations (Table 2).

Figure 12 plots annual Tmean for the UK from 1884 to 2020 alongside global mean surface temperature based on the 'best estimate' time-series from the HadCRUT5 dataset (Morice *et al.*, 2021). Both series are plotted as anomalies relative to the 1961–1990 average. The most recent decade 2011–2020 for the UK has been 1.1°C warmer than the 1961–1990 average, compared to 0.8°C for global surface temperature. Overall the warming trend for the UK is broadly consistent with, but slightly greater than, that observed globally, although since the UK covers only approximately 1/2,000 of the Earth's surface, and comprises land surface, rather than a combination of land and sea, the annual variability in UK Tmean is very much larger.

2.1 | Days of air and ground frost

The UK sees a very large spatial variation in the average number of days or air and ground frost. The 1981–2010 annual average days of air frost ranges from more than 100 days across much of the high ground of Scotland to less than 10 days across parts of west Cornwall.

The average number of days of air frost for the UK for 2020 was 38 days, 20 days below average and the fourth lowest in a series from 1960. This was the seventh consecutive year with fewer air frosts than average. The number of days of ground frost for 2020 was 88 days, 22 days below the 1981–2010 average and also fourth lowest in a series from 1961. Some locations recorded at least 40 fewer days of ground frost for the year overall compared to normal but with considerable spatial variation across the UK (Figure 13). The number of air and ground frosts was well below average in January and February—and to a lesser extent in April and October to December, but near or slightly above average in March, May and September. Note that air frosts are derived from daily minimum temperature grids which extend back to 1960 and ground frosts are derived from monthly ground frost grids which extend back to 1961, so both of these series

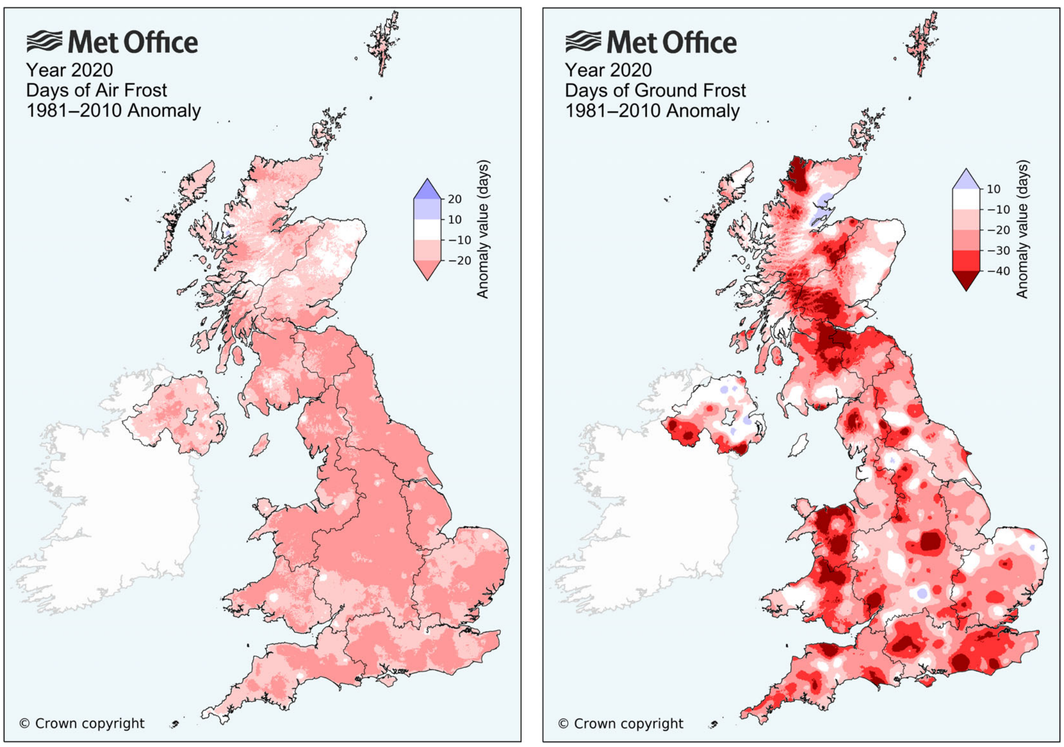
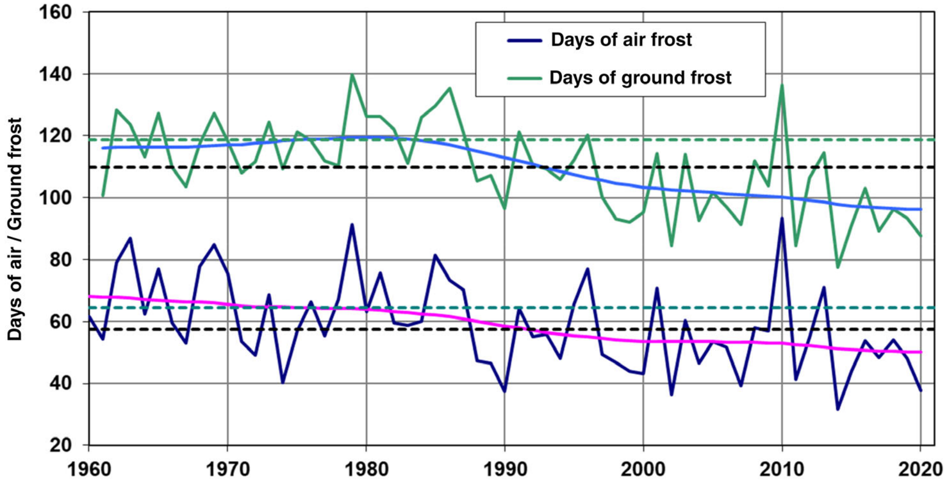


FIGURE 13 Days of air frost and days of ground frost anomaly for year 2020 relative to 1981–2010. See Annex 1 for definitions. Bullseye features in these and the $T_{\min}$ maps are likely to be due to localized factors such as frost hollow effects at individual weather stations (present in either the actual or long-term average grids) which the gridding process is unable to fully represent, particularly for ground frost



Variable	1961–1990 average	1981–2010 average	2011–2020 average	2020
Days of air frost	64	58	48	38
Days of ground frost	119	110	94	88

FIGURE 14 Annual number of days of air frost and ground frost for the UK, 1961–2020. The hatched black line is the 1981–2010 long-term average. The hatched green line is the 1961–1990 long-term average. The table provides average annual values (days)

are less than half the length of the UK and regional monthly, seasonal and annual temperature series which are derived from monthly temperature grids from 1884.

The annual numbers of days of air and ground frost for the UK overall for 2020 were well below average for the most recent decade, with the series showing a reduction through the 1980s and 1990s. The most recent decade, 2011–2020, has recorded 25%/20% fewer annual days of air frost and ground frost per year than the average for 1961–1990, and 16%/14% fewer, respectively than 1981–2010 (Figure 14). The most recent years with above average days of air and ground frosts were 2013 and 2010. Annex 1 explains how these areal-series are calculated.

2.2 | Degree days

A degree day is an integration of temperature over time and is commonly used to relate temperature to particular impacts. It is typically estimated as the sum of degrees above or below a defined threshold each day over a fixed period of time. The standard degree days monitored by the Met Office are heating, cooling and growing degree days which relate to the requirement for heating or cooling of buildings to maintain comfortable temperatures, or the conditions suitable for plant growth, respectively. These indices are useful metrics, but as they are derived from temperature only, users should be aware that other relevant factors such as solar gain, day length, wind and rain will also influence the actual responses of, for example, plant growth. The thresholds used for heating degree days (HDDs), cooling degree days (CDDs) and growing degree days (GDD) are 15.5, 22 and 5.5°C, respectively and the formulae used described in Annex 1. Note that degree days are derived from daily temperature grids which extend back to 1960, so the degree day series are less than half the length of the UK and regional monthly, seasonal and annual temperature series which are derived from monthly temperature grids from 1884.

HDD for 2020 were less than 90% of average across much of England but nearer average across northern England, Wales, Scotland and Northern Ireland (Figure 15). Averaged across the UK, HDD for 2020 were 91% of the 1981–2010 average and fifth lowest in a series from 1960. The lowest 10 HDD years for the UK in this series from 1960 have all occurred since 1999 (Figure 16). For the UK, the most recent decade 2011–2020 has had an annual average HDD 12% lower than 1961–1990 and 6% lower than 1981–2010. Nevertheless, recent years such as 2010 and 2013 demonstrate it is still possible for UK climate to experience well above average HDD values. Note that HDD relate to heating requirements of buildings so will be greatest in the winter months, but since HDD presented here are for the calendar year these are split across two winters.

The UK experienced a brief spell of hot weather in late June, a single very hot day at the end of July and a longer hot spell in early August 2020: temperatures exceeded 28°C fairly widely on 24–26th June, 31st July and 7–12th August—mainly across England. CDD for 2020 (22) were well above the 1981–2010 average (13), and equal-ninth highest in a series from 1960—although

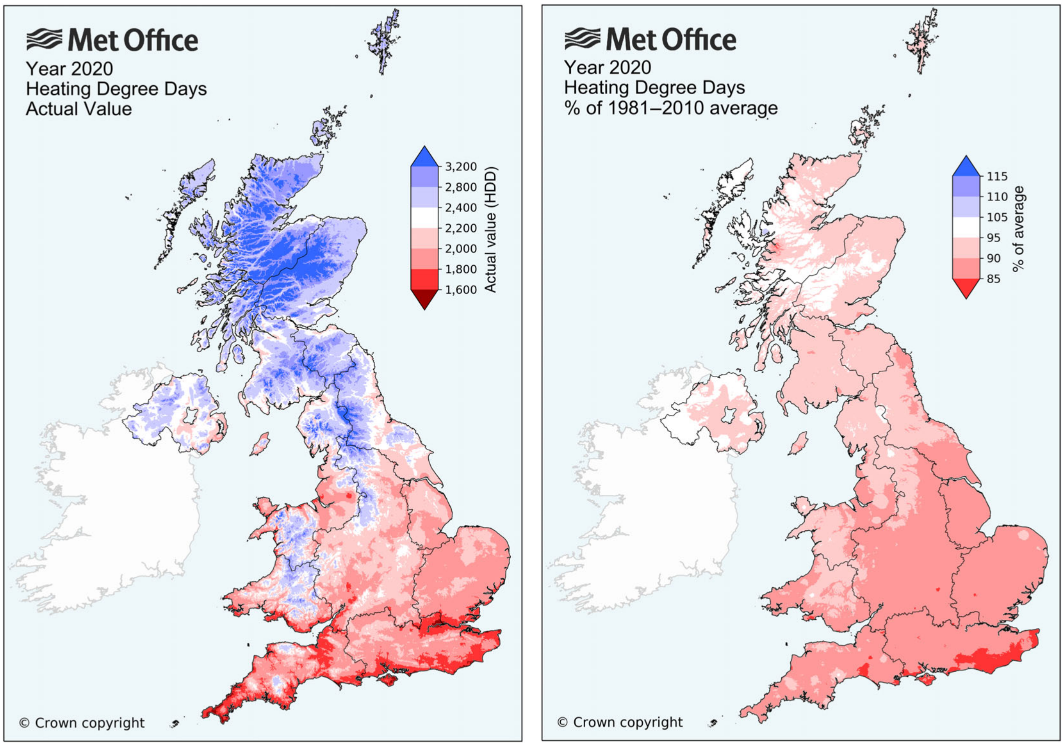
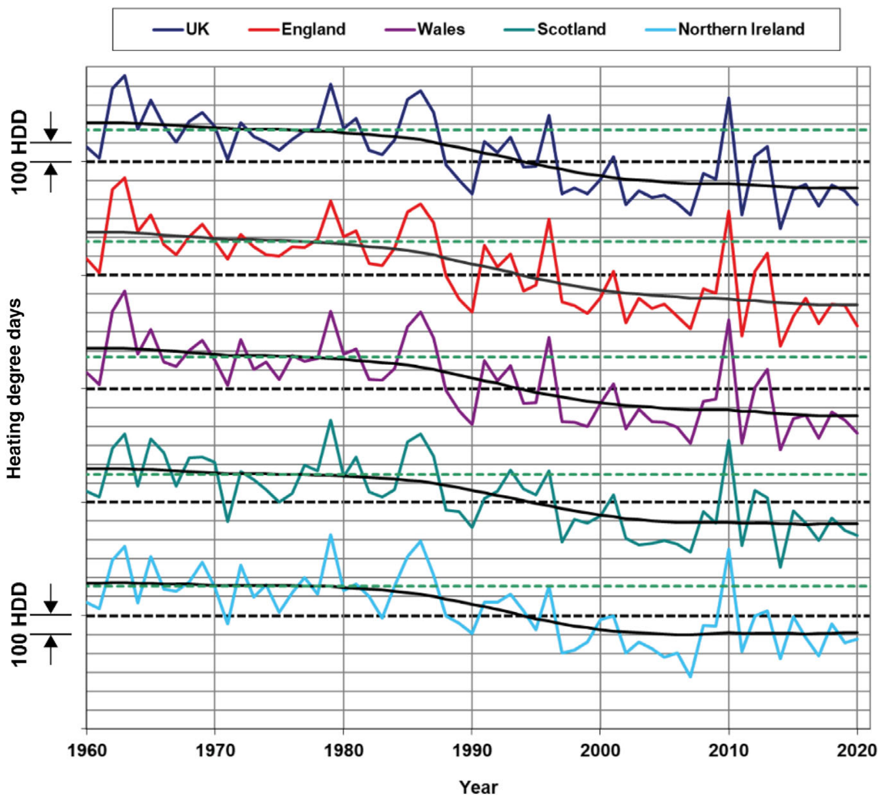


FIGURE 15 Heating degree days for 2020 (left) actual and (right) % of 1981–2010 average

FIGURE 16 Heating degree days for the UK and countries, 1960–2020, expressed as anomalies relative to the 1981–2010 average. The hatched black line is the 1981–2010 long-term average. The hatched green line is the 1961–1990 long-term average. Light grey grid-lines represent anomalies of ±100 HDD. The table provides average annual values (HDD)



Area	1961–1990 average	1981–2010 average	2011–2020 average	2020
UK	2,739	2,572	2,419	2,345
England	2,521	2,343	2,170	2,076
Wales	2,620	2,452	2,293	2,218
Scotland	3,149	3,001	2,876	2,825
Northern Ireland	2,655	2,499	2,395	2,377

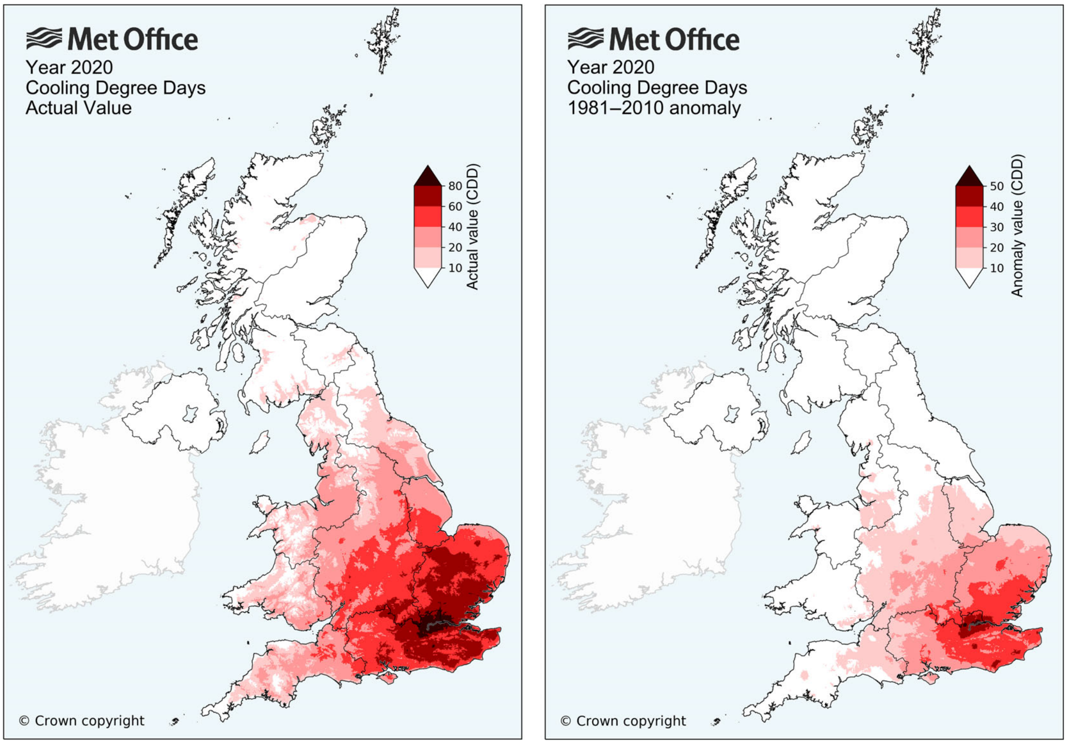
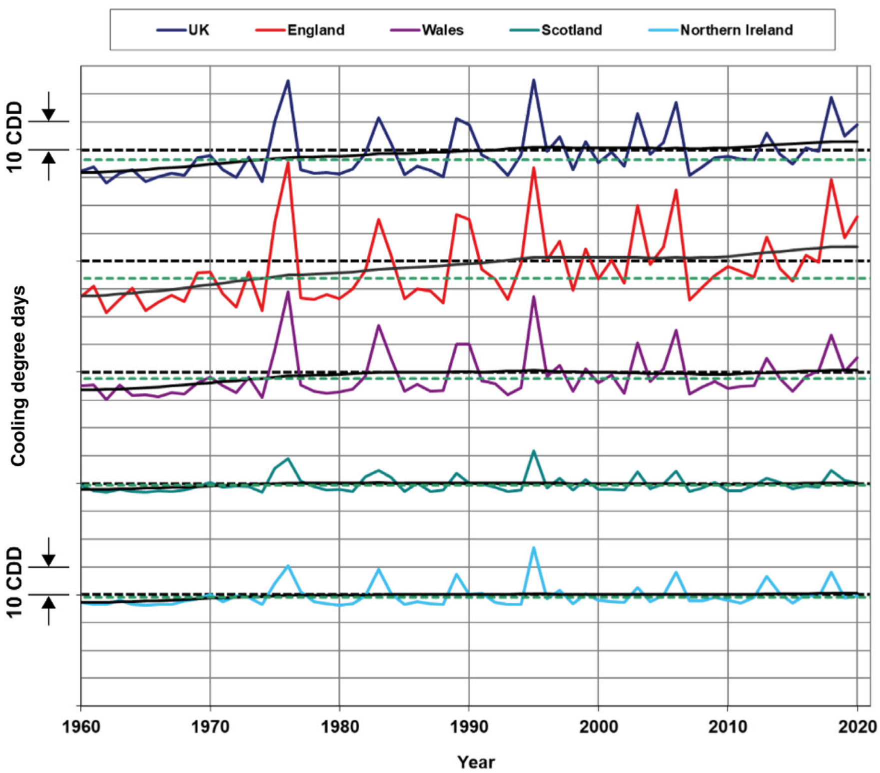


FIGURE 17 Cooling degree days for 2020, (left) actual and (right) anomaly. The anomaly is presented as a difference from, rather than percentage of, average. This is because CDD are close to zero over much of Highland Scotland



Area	1961–1990 average	1981–2010 average	2011–2020 average	2020
UK	9	13	16	22
England	14	21	25	36
Wales	8	10	11	15
Scotland	3	3	3	3
Northern Ireland	3	4	4	3

FIGURE 18 Cooling degree days for the UK and countries, 1960–2020, expressed as anomalies relative to the 1981–2010 average. The hatched black line is the 1981–2010 long-term average. The hatched green line is the 1961–1990 long-term average. Light grey grid-lines represent anomalies of ±10 CDD. The table provides average annual values (CDD)

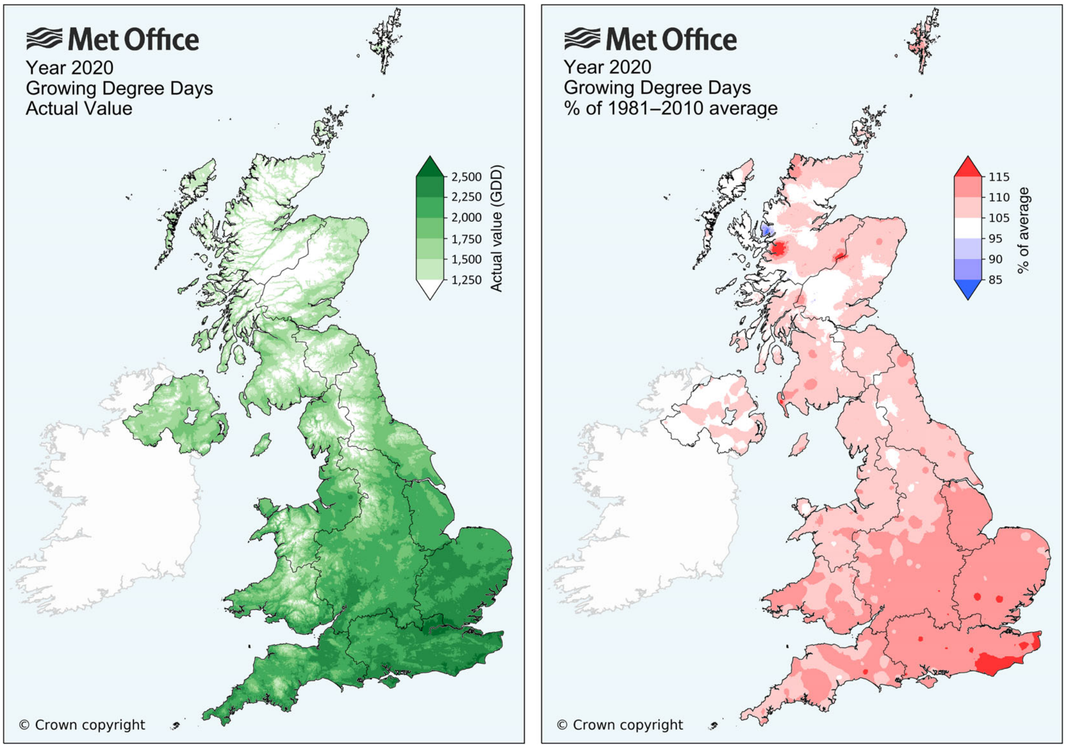
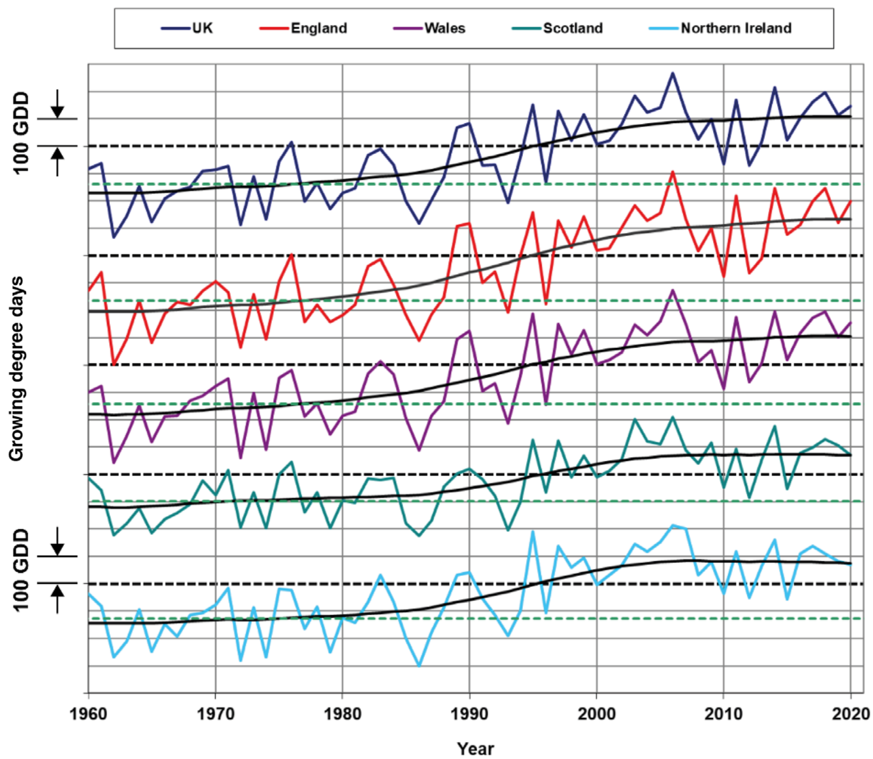


FIGURE 19 Growing degree days for 2020 (left) actual and (right) % of 1981–2010 average

FIGURE 20 Growing degree days for the UK and countries, 1960–2020, expressed as anomalies relative to the 1981–2010 average. The hatched black line is the 1981–2010 long-term average. The hatched green line is the 1961–1990 long-term average. Light grey grid-lines represent anomalies of ±100 GDD. The table provides average annual values (GDD)



Area	1961–1990 average	1981–2010 average	2011–2020 average	2020
UK	1,471	1,610	1,717	1,758
England	1,677	1,841	1,976	2,041
Wales	1,517	1,660	1,767	1,814
Scotland	1,124	1,222	1,290	1,294
Northern Ireland	1,424	1,550	1,625	1,621

not as high as 2018 (32). As is typically the case, the spells of hot weather during 2020 were mainly located across central and south-east England, with 40–60 CDD fairly widely and more than 80 CDD across Greater London, here almost twice the long-term average (Figure 17).

Across England and Wales the significant peaks in CDD coincide with significant heat-waves (including 1976, 1995, 2003, 2006 and 2018). Although these time-series are dominated by annual variability, there is an underlying rising trend. For England, the most recent decade 2011–2020 CDD value of 25 compares to 21 for 1981–2010 and 14 for 1961–1990. The cooler climate of Scotland and Northern Ireland means that CDD are much lower, each with long-term averages of less than 5 CDD (Figure 18).

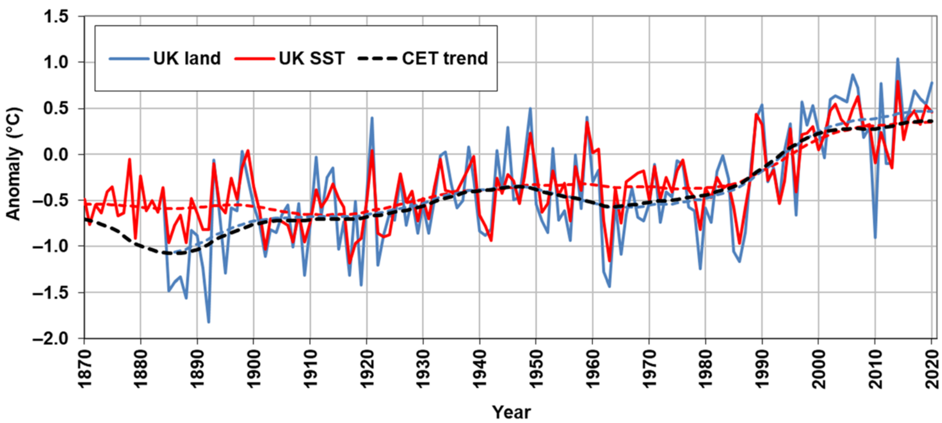
GDD for 2020 were between 105 and 110% of average across much of the UK, but more than 110% across southern England (Figure 19). UK GDD overall were 109% of the 1981–2010 average and eighth highest in a series from 1960. The highest 10 GDD years for the UK in this series from 1960 have all occurred since 1995. The most recent decade has had an annual GDD 17% higher than 1961–1990 and 7% higher than 1981–2010, and the similar (downwards) trend in HDD and (upwards) trend in GDD from 1960 to date each reflect the underlying warming of the UK's climate (Figure 20), coupled with fewer frosts resulting in an extended growing season. 1993 was the last year with GDD below the 1961–1990 average for the UK overall. Phenology data for first leaf and bare tree dates of four common shrub or tree species are presented in Section 10.

2.3 | Coastal waters

The annual mean sea-surface temperature (SST) for 2020 for near-coast waters around the UK was 11.9°C, 0.5°C above the 1981–2010 long-term average. This was the eighth-warmest year for UK near-coast SST in a series from 1870 (Figure 21). For UK near-coast SST, the most recent decade, 2011–2020, is 0.7°C warmer than the 1961–1990 average and 0.3°C above 1981–2010. Nine of the ten warmest years in the series have occurred since 2002, and all ten since 1989. Every year this century has fallen within the warmest third of the series.

Over the past 30 years, warming has been most pronounced in the north of Scotland and the North Sea, with SSTs increasing by up to 0.24°C per decade. However, shorter-term variations are superimposed on the longer-term trend, for example, a period of cooler SSTs from 2010 to 2013. Recent years have seen warmer conditions return (Tinker and Howes, 2020).

Near-coast SST data are highly correlated with the land observations (R^2 value .82, see Annex 2) with a root mean square difference of less than 0.3°C. Some differences between historical trends in these series are apparent, notably the 1960s and 1970s and the period pre-1900. However, these differences are also apparent in the CET series, also shown in Figure 21, which closely follows the UK series. Uncertainties in the SST dataset will generally be larger at smaller scales (such as UK near-coast) and can include uncertainty in the bias adjustments applied to minimize the effect of instrumentation changes.



Area	1961–1990 average	1981–2010 average	2011–2020 average	2020
UK land	8.3	8.8	9.3	9.6
UK near-coast SST	11.1	11.5	11.8	11.9

FIGURE 21 UK annual mean temperature over land 1884–2020, Central England temperature trend and UK annual mean sea surface temperature across near-coastal waters around the UK 1870–2020 (°C), expressed as anomalies relative to the 1981–2010 long-term average. Hatched blue and red lines are the UK land and SST trends. The table provides average annual values (°C)

3 | PRECIPITATION

The UK rainfall total for 2020 was 1,336 mm, 116% of the 1981–2010 average. This was the fifth wettest year for UK in a series from 1862, and the wettest year since 2000. It was also ranked 18th wettest in the England and Wales precipitation series from 1766. Most of the UK received above average rainfall, especially in the west, but rainfall totals were below average across parts of eastern and north-east England and the far north-east of Scotland. It was a particularly wet year across parts of north-west England and south-west Scotland which received more than 125% of average fairly widely, and some locations recorded more than 135% of average (Figure 22). The wettest location was Ennerdale, Black Sail in the Lake District with 5,281 mm, 148% of average—while the driest locations in Essex, Kent and Lincolnshire recorded around 500 mm.

Figures 23 and 24 and Table 3 show seasonal and monthly rainfall anomalies across the UK for 2020. As is always the case, there were very large variations in monthly and seasonal rainfall patterns over the course of the year.

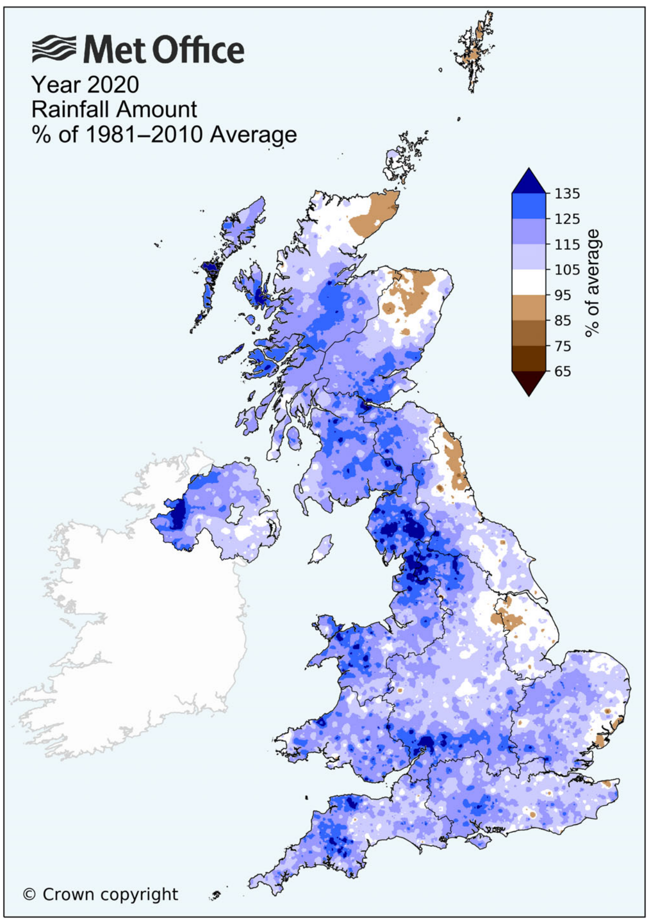


FIGURE 22 Rainfall anomalies (%) for year 2020

The UK rainfall total for winter was 474 mm, 144% of the 1981–2010 long-term average, and this was the UK's fifth wettest winter in a series from 1863. Totals exceeded 150% quite widely across the UK, with only parts of Northumberland and the far north-east of Scotland drier than average. December 2019 rainfall totals were near or slightly above average across much of the UK. January 2020 was near average for the UK overall but with less than 50% across parts of Northern Ireland and north-east Scotland. February was an exceptionally wet month with between two and three times the normal rainfall amount across almost the entire UK—and more than 300% across Cumbria, West and North Yorkshire, Lancashire, Nottinghamshire, Greater Manchester and Shropshire. The UK recorded 214 mm, 242% of the 1981–2010 long-term average making this the UK's wettest February on record in a series from 1862 and, despite only 29 days in the month, the fourth wettest calendar month on record. It was also the wettest February in the England and Wales series from 1766. Several rain-gauges in the English Lake District recorded more than 900 mm of rainfall – on average over 30 mm per day through the month, including a monthly rain-gauge at Styhead with 1,138 mm. Parts of West Yorkshire recorded more than four times the month average; monthly rainfall anomalies as high as this in the UK being exceptionally unusual (Davies *et al*., 2021).

The very wet and unsettled weather continued to mid-March, but, in contrast, after this the weather turned abruptly very much drier and more settled. The UK recorded, on average, 395 mm in the 75-days from 1 January to 15 March 2020—followed by only 82 mm in the 76-days from 16th March to 31st May—a remarkable near-five-fold reduction. March overall was generally drier than average—particularly in the east—although not exceptionally so. April was very dry (ranked 11th driest for the UK), especially so across north-east England and eastern Scotland, with less than 5 mm falling quite widely—and 10% of normal or less across East Lothian, Northumberland and County Durham. May was also very dry with less than 20% of average falling across the southern half of the UK; for England this was the driest May in a series from 1862, and it was the second-driest May in the England and Wales Precipitation series (EWP) from 1766. Less than 5 mm fell widely across southern England and a few locations recorded below 1 mm for the whole month (for more details, see Section 8). The UK rainfall total for spring was 142 mm, 60% of average and this was the UK's fifth driest spring in a series from 1862.

Each month of summer was mostly wetter than average, and the UK rainfall total for summer was 326 mm, 135% of the 1981–2010 average—wet, although not

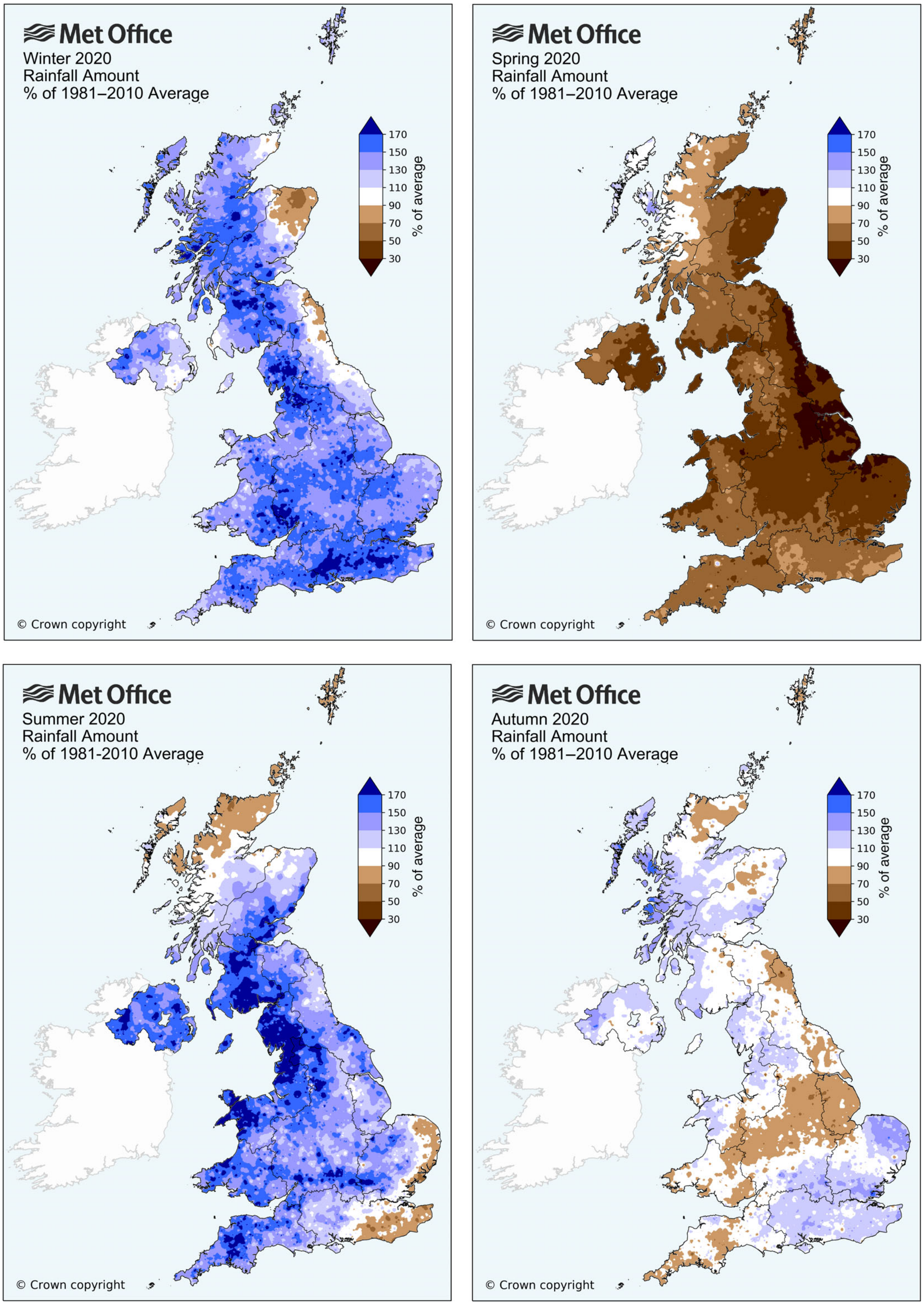


FIGURE 23 Rainfall anomalies (%) for seasons of 2020. Winter refers to the period December 2019 to February 2020. Note that winter 2021 (December 2020 to February 2021) will appear in State of the UK Climate 2021

exceptional, and broadly comparable with summer 2019. The wettest areas relative to average were across north-west England, south-west Scotland and Northern Ireland which widely received 150% of average or more. June rainfall totals were variable but some locations were very wet (Cornwall, for example). July was also rather wet across the north-west and August wetter again more widely—although dry across the far north-west of Scotland. For Northern Ireland this was the seventh wettest summer in a series from 1862.

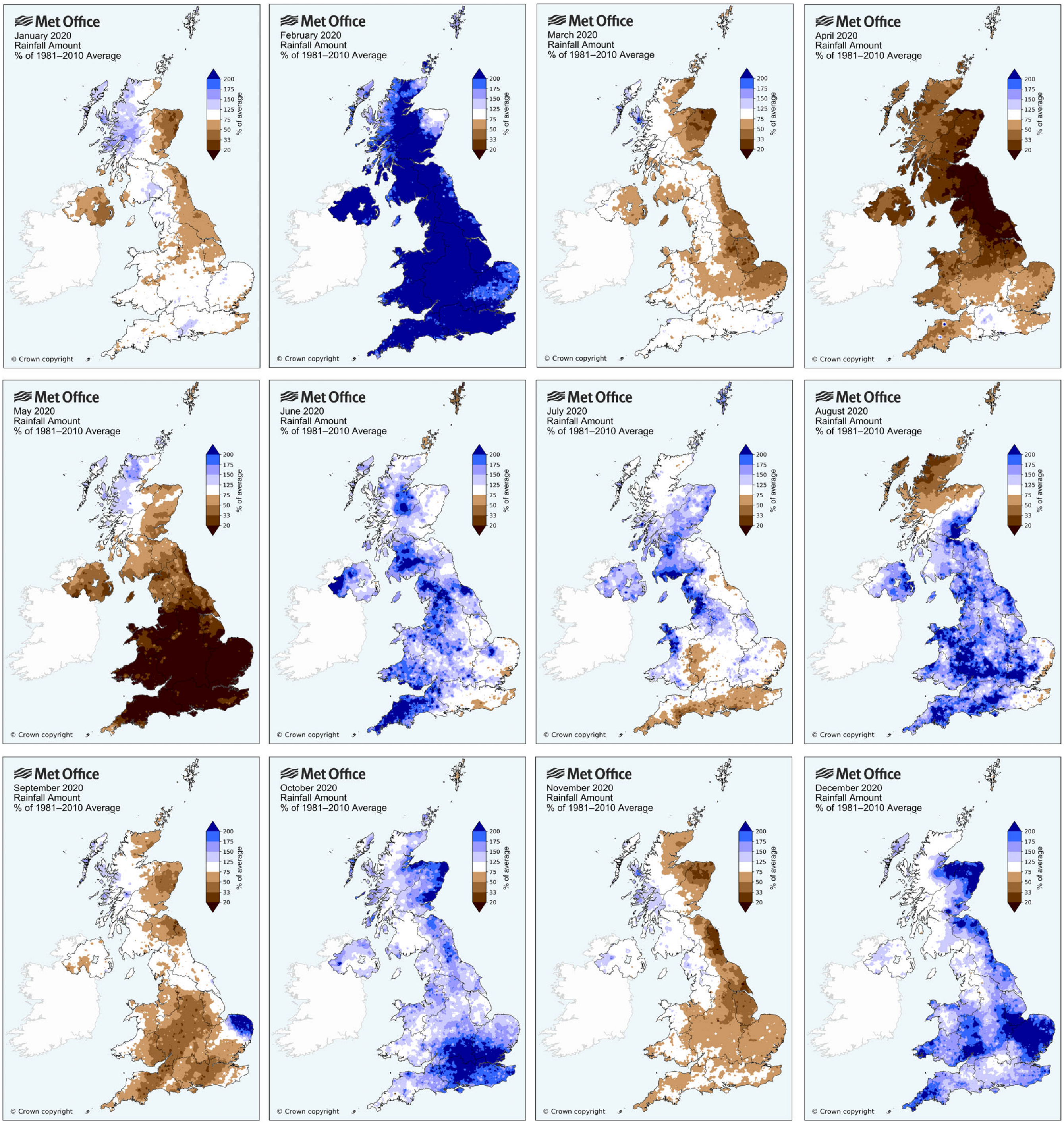


FIGURE 24 Rainfall anomalies (%) for months of 2020

From August to December monthly rainfall anomalies alternated wet then dry: August (137%), September (81%), October (144%), November (87%) and December (142%). As a result, UK autumn rainfall overall was unremarkable—365 mm, 106% of the 1981–2010 average—with below average rainfall across most of the UK during September and November offset by a wet October. Parts of north-east Scotland, and central southern England received more than twice the average monthly rainfall and for the UK this was the fifth wettest October on record, while at Oxford it was the wettest calendar month since October 1875. December was also a wet month across East Anglia and north-east Scotland. In summary, year 2020 comprised a very wet winter followed by a very dry spring, a rather wet summer and a variable autumn.

TABLE 3 Monthly, seasonal and annual rainfall actual (mm) and anomaly values (%) relative to 1981–2010 for the UK, countries and England and Wales precipitation series (EWP) for year 2020

	UK		England		Wales		Scotland		Northern Ireland		EWP	
	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly	Actual	Anomaly
January	121	100	74	90	146	93	203	115	70	60	83	89
February	214	242	161	268	295	266	277	214	232	277	170	255
March	79	83	51	79	103	88	120	86	70	73	58	81
April	30	42	29	50	41	46	30	33	24	32	37	57
May	33	47	10	16	15	17	77	91	31	43	10	16
June	108	147	91	148	141	164	123	139	123	162	98	148
July	96	123	66	106	121	131	134	136	121	149	69	103
August	122	137	114	165	184	171	112	97	154	158	125	166
September	77	81	48	69	81	69	125	93	78	85	56	73
October	182	144	144	157	220	129	240	137	163	136	164	158
November	105	87	64	73	137	84	162	98	122	109	68	68
December	169	142	137	157	263	158	205	126	136	119	159	164
Winter	474	144	341	148	626	144	669	143	412	131	373	145
Spring	142	60	89	49	158	54	228	72	125	51	105	53
Summer	326	135	272	140	447	156	370	122	398	156	293	140
Autumn	365	106	256	103	438	98	527	111	363	112	288	102
Annual	1,336	116	989	116	1747	119	1810	116	1,324	117	1,097	116

Key: Wettest on record | Top 10 wettest | Wet: ranked in upper third of all years | Middle: ranked in middle third of all years | Dry: ranked in lower third of all years | Top 10 driest | Driest on record

Note: Colour coding relates to the relative ranking in the full series which spans 1862–2020 for all series except EWP which is 1766–2020.

As with every year in the UK, numerous widespread flood events of varying severity occurred during 2020; at a national scale, by far the most significant flooding of the year occurred in February (see Figure 67 for UK area-average daily rainfall through 2020).

There was some very wet weather across western Scotland on 10th January, while Storm Brendan on 13–14th January also brought some very wet weather more widely across the UK, with widespread but mostly relatively minor transport disruption due to flooding.

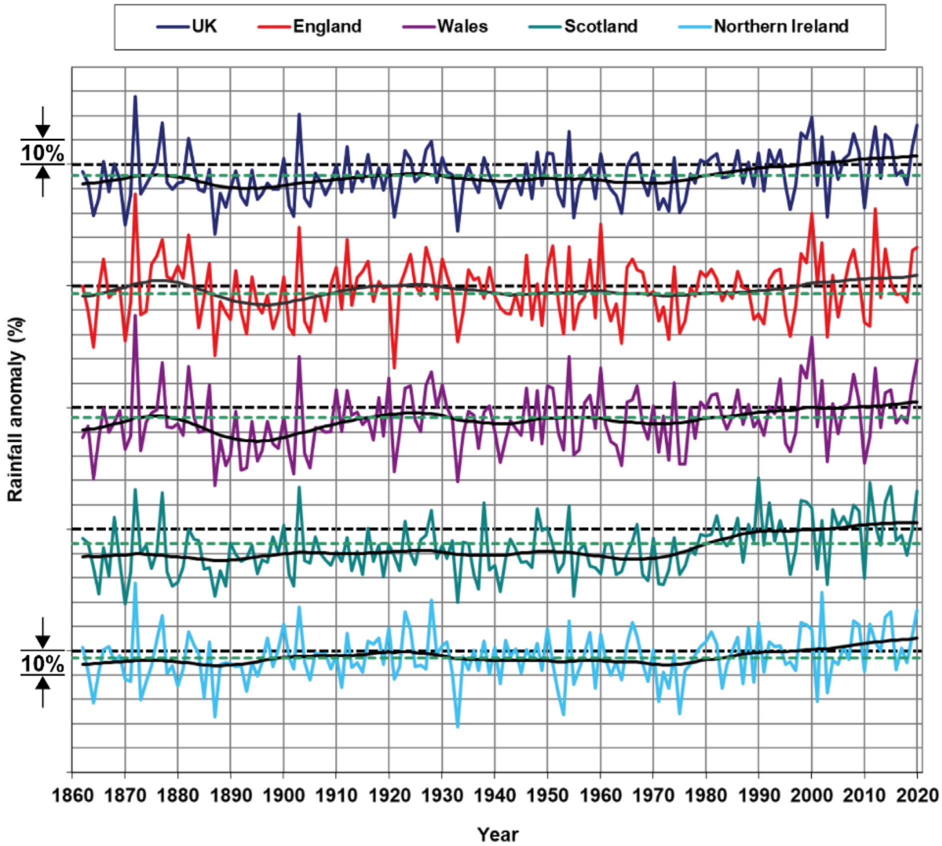
The persistent and very wet weather during February caused significant, severe and widespread flooding problems. 8th February was an exceptionally wet day across North Wales, north-west England, south-west Scotland and Northern Ireland, due to storm Ciara, with totals widely exceeding 50 mm, over 100 mm across parts of Snowdonia and 150 mm in parts of the Lake District. There was significant flooding in North Wales at Llanrwst in the Conwy valley. However, the worst affected areas were across the Pennines, where flooding affected several 100 homes. In West Yorkshire, properties were flooded in the Calder valley including Mytholmroyd and Hebden Bridge, which was previously severely flooded in December 2015. Flooding affected the Yorkshire Dales and Cumbria, with Appleby badly affected from the River Eden.

Ciara was followed only a week later on 15–16th February by storm Dennis, one of the deepest Atlantic depressions on record. Dennis brought a further 50–100 mm or more of rain to western upland parts of the UK, falling on already saturated ground. The Met Office issued a red warning for rain across parts of south Wales and there was more major and widespread flooding. South Wales, Herefordshire, Worcestershire and Shropshire were worst affected by flooding and major incidents declared. The River Wye and River Severn were reported to have reached their highest-ever levels (Sefton *et al*., 2021). Areas of several towns including Hereford and Pontypridd were inundated. Tragically a woman was swept away by floodwater in Worcestershire and over 1,400 homes and businesses were flooded across several counties. The flooding also caused major travel disruption with roads blocked, damaged railway lines and hundreds of flights cancelled. Large areas of farmland were also underwater. For more details of storms Ciara and Dennis see Section 8. Ongoing problems from flooding persisted into early March, with further rain falling on already saturated ground, including storm Jorge on 28th February to 1st March, and local flooding in parts of Wales, north-west England and Northern Ireland.

In complete contrast, there were a few wild fires in late April as a result of the dry weather, and further grass and heathland fires in May. In Scotland there was a large fire along the Errol River in Tayside in the first week of May, and on 31st May, a large grass and gorse fire at Belfast docks brought smoke and reduced visibility across the city and airport.

The often unsettled conditions through the summer led to various flood impacts. A period of thunderstorms and torrential downpours in mid-June led to some flash-flooding affecting many parts of England and Wales, causing blocked roads and transport disruption, and on 17th June, around 100 properties in Pentre, Rhonda Valley were flooded during a torrential thunderstorm. There were also scattered reports of lightning damage. There was a further very wet spell from 27 to 28th June across the north-west; on the 28th, Honister Pass, Cumbria recorded 212.8 mm, while on 4th August, a landslip closed the A83 at Rest and Be Thankful in Argyll. On 11–12th August, torrential downpours caused widespread flash-flooding and disruption to the road and rail networks across eastern Scotland, with Falkirk, Fife, Perth, Edinburgh and the Aberdeenshire area all affected. Several rain-gauges recorded 50–100 mm of rain, which would have fallen in only a few hours, contributing to a landslip that caused a train derailment on 12 August near Stonehaven, tragically leading to three fatalities. The thunderstorms were associated with hot, humid air further south with temperatures across parts of southern England reaching 34–35°C. A few days later on 16 August, there were thunderstorms and some very intense downpours across East Anglia causing some localized flash-flooding with a rain-gauge at East Wretham, Norfolk recording a daily total of 239.9 mm. Storms Ellen and Francis on 20–21 and 25 August also caused various flooding problems (for more detail of both of these events see Section 8).

There were various flood impacts through the remainder of the year. 3 October—the day after storm Alex—was exceptionally wet across the UK, and in terms of average rainfall this was one of the UK's wettest days on record (for more details, see Section 8). However, flood impacts were generally fairly limited, both due to below average rain in September and a lack of intense convective bands (Kendon and McCarthy, 2021). In contrast, Alex itself caused severe flooding to parts of south-east France and north-west Italy, with dozens of houses destroyed, roads washed away, and several fatalities reported. As much as 500 mm of rain fell in the worst affected parts of the Alpes-Maritimes department, equivalent to 3 months rainfall. There was some further flooding in late October from storm Aiden, and ongoing widespread flood impacts through December. Flooding affected Suffolk on the 4th, Wales and the south-west around mid-month and the Midlands just before



Area	1961–1990 average	1981–2010 average	2011–2020 average	2020
UK	1,099	1,150	1,197	1,336
England	827	853	891	989
Wales	1,405	1,463	1,496	1,747
Scotland	1,471	1,563	1,627	1,810
Northern Ireland	1,102	1,136	1,199	1,324

FIGURE 25 Annual rainfall, 1862–2020, expressed as a percentage of 1981–2010 average. The hatched black line is the 1981–2010 long-term average. The lower hatched green line is the 1961–1990 long-term average. Light grey grid-lines represent anomalies of ±10%. The table provides average annual rainfall values (mm)

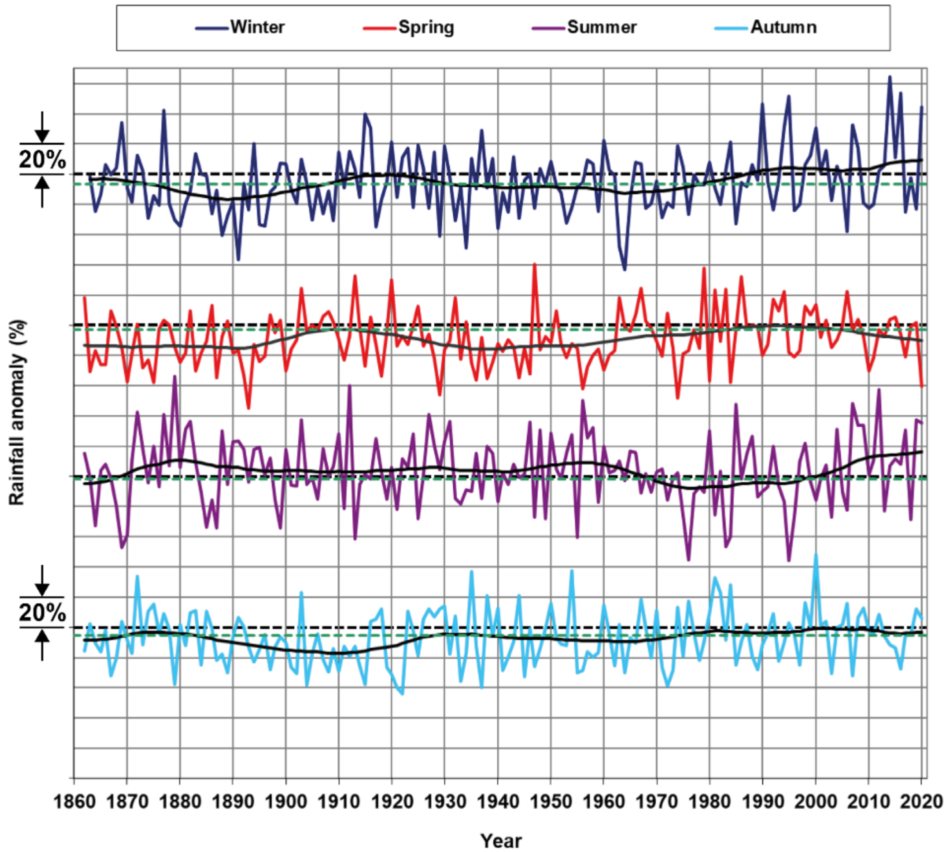
Christmas, with the M1 closed and widespread flooding in Gloucestershire. Storm Bella exacerbated conditions on 26–27th December, and a number of properties flooded in Oxfordshire, Gloucestershire, Northamptonshire and Bedfordshire. Fortunately, after this a period of dry weather extended into early January 2021 offering some respite.

The precipitation data show large annual variability, with a slight increase from the 1970s onwards (Figure 25). The most recent decade (2011–2020) has been on average 9% wetter than 1961–1990 and 4% wetter than 1981–2010; this increase is most pronounced for Scotland and Northern Ireland, being 11%/9% wetter than 1961–1990. The wettest year for the UK overall is 1872 (128% of average) and the driest 1887 (71%). Six of the ten wettest years in the UK series from 1862 have occurred since 1998 (2000, 2020, 2012, 1998, 2008 and 2014).

Figure 26 shows seasonal rainfall series for the UK from 1862 to 2020 (for winter 1863–2020). Similar to the annual series, the seasonal series are dominated by large annual variability with some decadal variability about a relatively stable long-term mean. Nevertheless, there has been a marked increase in winter rainfall in the most recent decade with 2014, 2016 and 2020 all in the top-five wettest. There has also been an increase in summer rainfall with below average rainfall in only two of the last 10 summers (2013 and 2018). For the most recent decade (2011–2020) UK winters have been on average 11% wetter than 1981–2010 and 19% wetter than 1961–1990, and UK summers 15%/17% wetter. In contrast, spring rainfall has decreased but with little change in autumn rainfall

There has been a notably high number of UK records set for wet months and seasons in recent decades. Since 2000, eight seasons have been in the top-ten wettest in UK seasonal series (winter 2014, 2016, 2020 and 2007, spring 2006, summer 2012 and 2007, and autumn 2000) while three have been in the top-10 driest (winter 2006, spring 2020 and autumn 2007). Since 2009, the UK has recorded its wettest February (2020), April (2012), June

FIGURE 26 Seasonal rainfall for the UK, 1862–2020 (note winter from 1863 to 2020; year is that in which January and February fall. Winter 2021—which includes December 2020—will appear in State of the UK Climate 2021). The hatched black line is the 1981–2010 long-term average. The lower hatched green line is the 1961–1990 long-term average. Light grey grid-lines represent anomalies of ±20%. The table provides average seasonal rainfall values (mm)

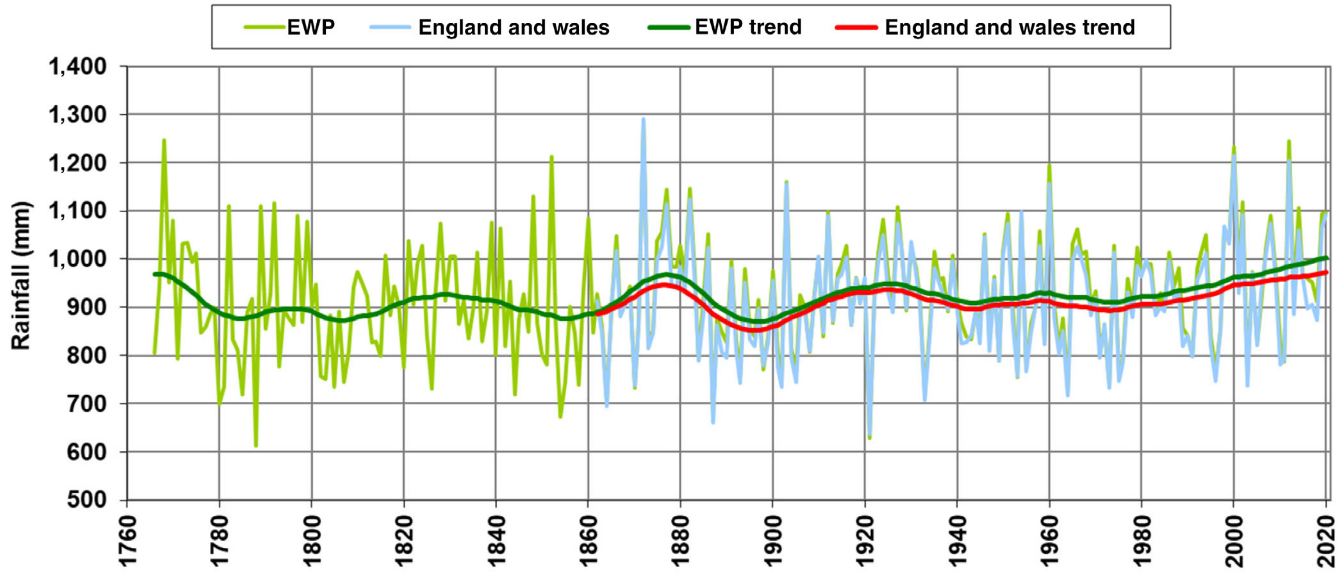


Season	1961–1990 average	1981–2010 average	2011–2020 average	2020
Winter	307	329	365	474
Spring	231	237	216	142
Summer	236	240	276	326
Autumn	326	343	328	365

(2012), November (2009) and December (2015)—five out of 12 months—in monthly series from 1862; and the wettest and second-wettest winters (2014 and 2016), and the driest September (2014).

The annual rainfall total for 2020 in the long running England and Wales Precipitation (EWP) series was 1,097 mm (Figure 27), which is 116% of the 1981–2010 average and ranked 18th wettest in the series from 1766 (recent wetter years including 2014, 2012, 2002 and 2000), and marginally wetter than 2019 (ranked 19th wettest). Figure 27 shows there are some notable decadal fluctuations in the series such as a wet period through the 1870s, and the "Long Drought" from 1890 to 1910 (Marsh *et al*., 2007) highlighting the value of rainfall series before the 20th Century for understanding the full historical context of UK rainfall. The most recent decade is a relatively wet decade in this series, being 6% wetter than 1981–2010 and 10% wetter than 1961–1990. The England and Wales areal rainfall series based on 1 km resolution gridded data is highly correlated to EWP for the period of overlap, with an R^2 value of .98 and root mean square difference of 1.6%. Minor differences between the series are inevitable due to the more limited sampling of stations used for the EWP series and the gridding method used for the England and Wales areal series.

Figure 28 shows trends in seasonal EWP rainfall amounts from 1766 to date. While there is little change in the long-term mean for the annual EWP series, this is certainly not the case for the seasonal series. EWP shows a marked increase in winter rainfall (winter 2014 is the wettest winter in this series and 2016 ranked eighth wettest). Before 1900, EWP winter rainfall was substantially lower than autumn rainfall, but the increase in winter rainfall has meant that during the 20th century autumn and winter rainfall were roughly equal on average. However, there are potential issues with the estimation of early winter rainfall in the series relating to the treatment of snow before systematic meteorological observing networks were established which could be associated with an underestimation of early winter rainfall (Murphy *et al*., 2020). The lower number of rain-gauges earlier in



Area	1961–1990 average	1981–2010 average	2011–2020 average	2020
EWP	915	948	1004	1097
England and Wales	906	936	974	1093

FIGURE 27 Annual rainfall for EWP series, 1766–2020, and England and Wales areal series, 1862–2020 (mm). The table provides average annual rainfall values (mm)

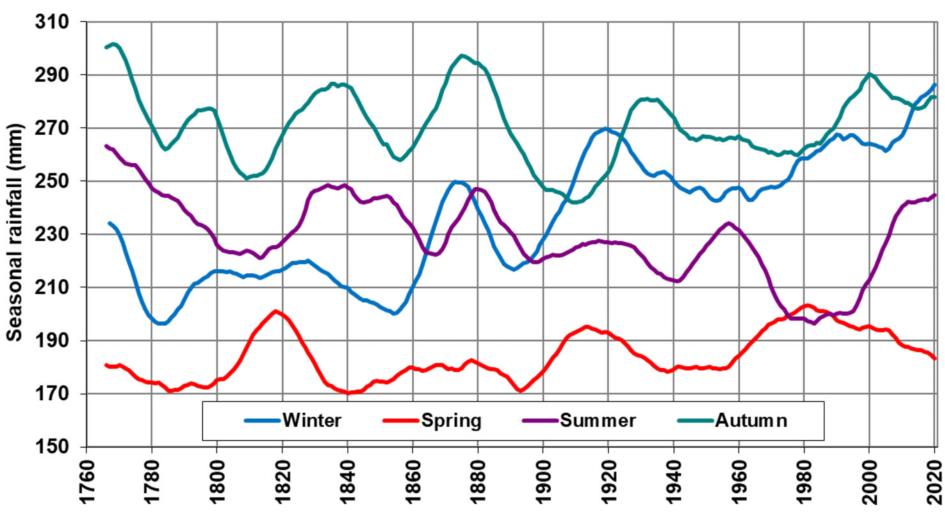


FIGURE 28 Seasonal rainfall trends for EWP series in mm, 1766–2020 (note winter from 1767). The figure shows a smoothing trend for each series using a weighted filter (see Annex 2)

the series used to construct EWP and how well they represent the wetter upland parts of western Britain (where winter rainfall is likely to be higher) could also be a factor.

The increasing winter rainfall has been offset by a slightly smaller reduction in summer rainfall, although a run of recent wet summers from 2007 demonstrates that these trends are very sensitive to the choice of start and end dates, and summer rainfall trends in the 18th and early 19th Century are also subject to some uncertainty and possibly over estimated (Murphy *et al*., 2020). Spring/autumn rainfall have each remained fairly steady with only a slight increase/decrease, respectively.

The rainfall statistics throughout are presented to the nearest whole mm, but the uncertainties of the areal statistics relating to changes in the observing network change over time. The standard error can approach 1–4% depending on region in early decades, but less than 1– 2%

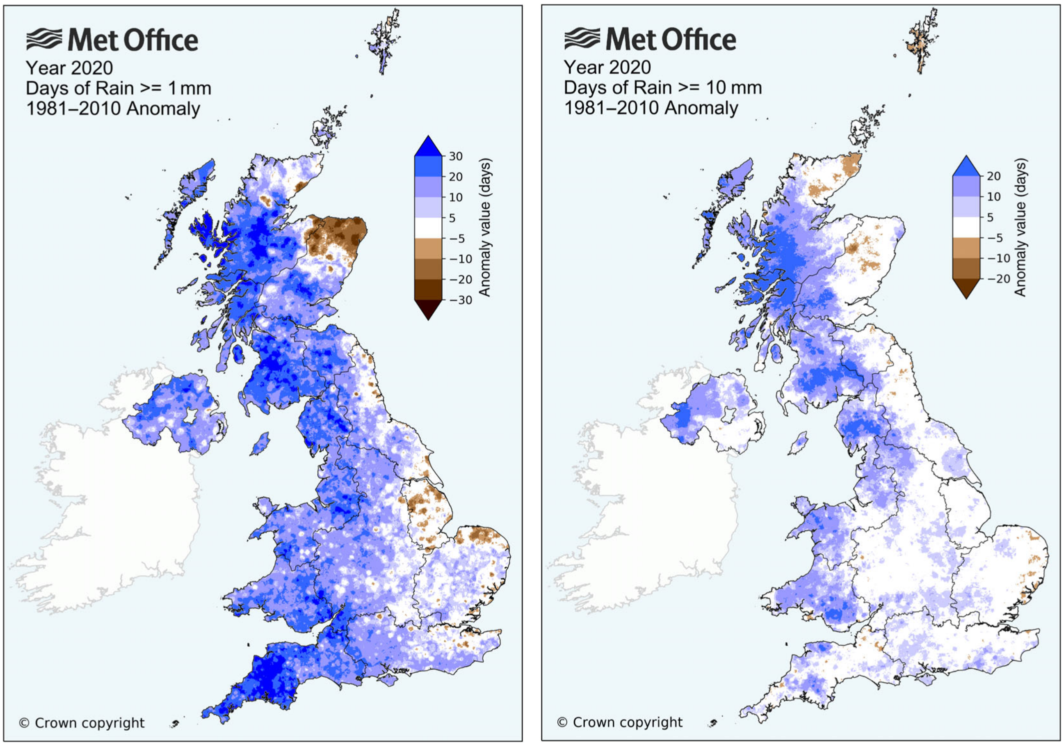
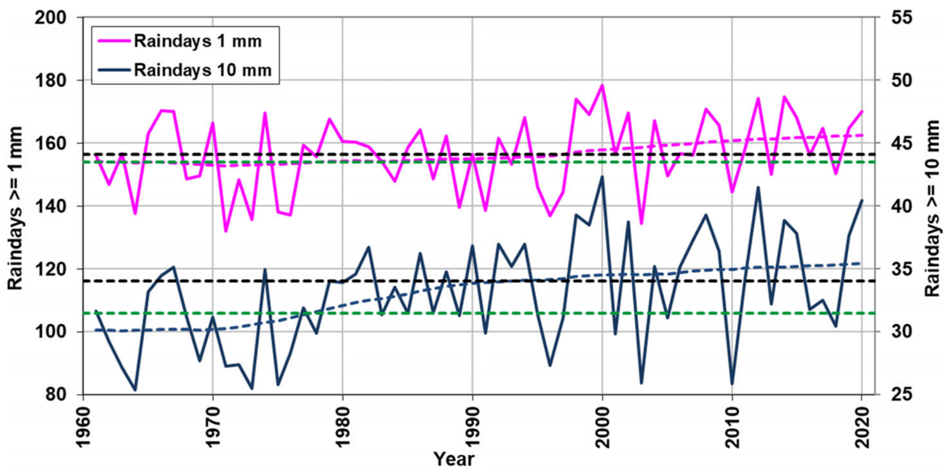


FIGURE 29 Days of rain ≥1 mm (RR1) and 10 mm (RR10) for 2020, difference from 1981 to 2010 average

FIGURE 30 Annual average number of days of rain ≥1 and 10 mm for the UK, 1961–2020. The hatched black line is the 1981–2010 long-term average. The hatched green line is the 1961–1990 long-term average. The table provides average annual values (days)

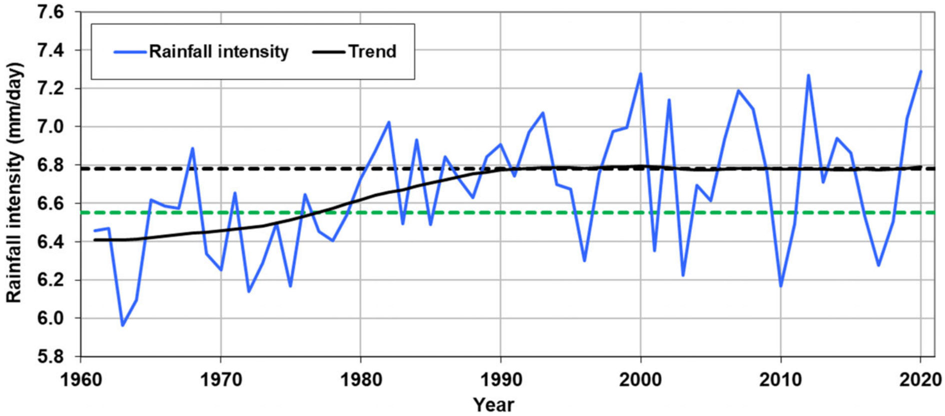


Climate variable	1961–1990 average	1981–2010 average		2011–2020 average	2020
Raindays >= 1 mm	154	156		163	170
Raindays >= 10 mm	31	34		36	40

for the comprehensive network of rain gauges in the years since 1960. The uncertainties are therefore much smaller than the year to year variability and more detail on this can be found in Annex 2. However, it is non-trivial to determine the robustness or significance of observed trends in rainfall as they are quite sensitive to region, season and choice of start and end dates.

3.1 | Days of rain and rainfall intensity

The number of days of rain greater than or equal to 1 mm (RR1) for the UK during 2020 was 170 days, 14 days more than the 1981–2010 long term average. There were 20–30 days more than average, or more, across some western areas, notably south-west England and western Scotland,



	1961–1990 average	1981–2010 average	2011–2020 average	2020
UK rainfall intensity	6.6	6.8	6.8	7.3

FIGURE 31 Annual average rainfall intensity for the UK on days of rain ≥1 mm, 1961–2020. The hatched black line is the 1981–2010 long-term average. The hatched green line is the 1961–1990 long-term average. The table provides average annual values (mm/day)

whereas the number of days was near average in the east and below average in a few locations, such as Aberdeenshire (Figure 29). In general, the monthly variation was comparable to the rainfall anomaly pattern (Figure 24), with more days of rain than average in February, October and December and, with some regional variation, during the summer months, but fewer days of rain in spring. The number of days of rain greater than or equal to 10 mm (RR10) was near average across most of the UK but above average in western Scotland, north-west England, Wales and Northern Ireland. Anomalies were especially high in February and some locations in western Scotland recorded more than 20 days with 10 mm or more (Figure 29).

Figure 30 shows the annual area-average RR1 and RR10 for the UK for 1961–2020. Overall, 2020 was well above the 1981–2010 average for RR1 and third highest for RR10. For both RR1 and RR10 the year with the most days was 2000, and this year was also the third-wettest in the UK series from 1862, with only 1872 and 1903 wetter. The RR1 series shows a slight increase in the last two decades, and the RR10 series an increase of around 10% from 31 days for 1961–1990 to 34 days for the period 1981–2010. This suggests an increase in the number of days of widespread heavy rain across the UK in the last few decades, although caution is needed because both time-series are relatively short and with large annual variability.

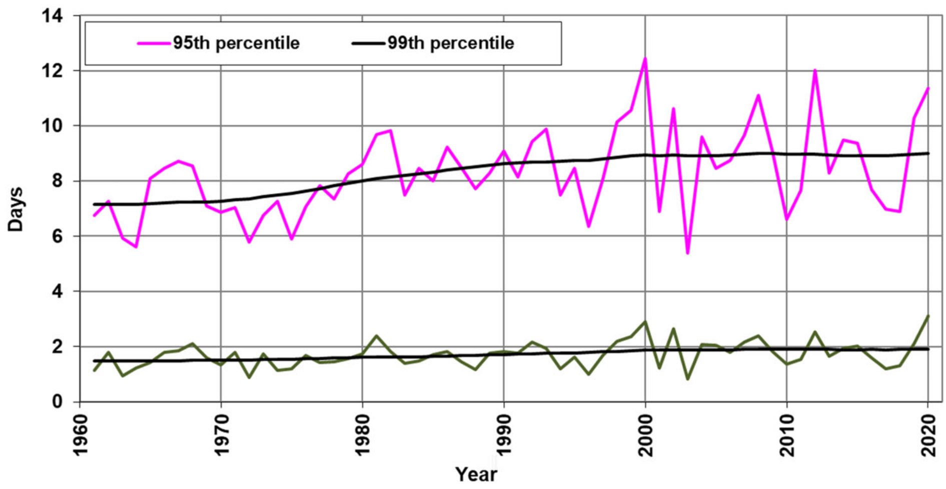
Figure 31 shows an estimate of the areal-average rainfall intensity (see Annex 1 for definition) across the UK for each year from 1961 to 2020. The figure is indicative of trends in rainfall intensity across the UK on wet days although, as with RR1 and RR10, it neither provides a seasonal break-down, nor distinguishes between upland and lowland areas, overall, 2020 was the highest in the series for this metric, consistent with RR10 being above average. The 3 years with highest rainfall intensity in the series (2000, 2012 and 2020) also correspond to the wettest years in the UK series since 1961. There is a slight upwards increase of 0.2 mm (approximately 3%) when comparing the 1961–1990 and 1981–2010 averages, although the series is fairly flat from 1981 onwards. Again, this is a short time-series dominated by year-to-year variability. The rainfall intensity series is fairly well correlated with the RR10 series (R^2 value .72), as would be expected because in years with a large number of very wet days the average rainfall intensity on wet days is higher. In contrast, there is low correlation between the rainfall intensity series and the RR1 series (R^2 value .23) because in years with a large number of days exceeding 1 mm (a much lower threshold) we would not necessarily expect the rainfall intensity on wet days to be higher.

3.2 | Heavy rainfall

Alternative metrics for heavy rain are presented here. Heavy rainfall is a complex variable to monitor due to its potential to be highly localized. These metrics adopt two different methods: a percentile approach and an absolute threshold. The ranking of individual years is quite sensitive to the choice of definition used and the series are relatively short given the variability of rainfall. However, there are some consistent features across these different metrics—most notably, more heavy rain events have been recorded in the most recent decade than in earlier decades in the series.

Figure 32 shows the number of days each year where the rainfall total has exceeded the 95th and 99th percentiles for wet days. The 95th and 99th percentiles are calculated based on the period 1961–1990 for 'wet days'—exceeding 1 mm; the UK value is the areal-average of the number of days calculated at each grid

FIGURE 32 The number of days each year for which rainfall totals have exceeded the 95 and 99th percentile. The table provides average annual values (days)



Percentile	1961–1990 average	1981–2010 average	2011–2020 average	2020
95th	7.7	8.8	9.0	11.4
99th	1.6	1.8	1.9	3.1

point. (Based on Figure 30 we would therefore expect about 154/20 = 7.7 days per year for the 95th percentile for the period 1961–1990—which is indeed the case). The percentiles and daycounts are calculated for each grid point with the UK value as the areal-average of the day-count values across all grid points. As with rainfall intensity, this neither includes a seasonal breakdown, nor does it distinguish between orographically enhanced frontal rain and convective rain. This metric is based on a percentile approach with thresholds that vary geographically so that all parts of the UK will have an equal influence (since the climatologically wetter parts of the UK in the north and west will have higher percentile values than the drier parts of the south and east).

Both series show large annual variability with some decadal variability, but with a rising trend for the 99th/95th percentiles from 1.6/7.7 days for the period 1961–1990 to 1.8/8.8 days for the period 1981–2010. The 2020 values for both percentiles were well above the 1981–2010 and 1961–1990 long term averages which is likely to be influenced by the relatively large number of flood events—particularly during February.

Figure 33 provides a count of the number of times each year any rain gauge in the observing network below 500 m elevation has recorded a daily rainfall total greater than or equal to 50 mm. We refer to this type of metric as a count of station-days. This metric cannot distinguish between a small number of widespread events recorded at many stations, or more frequent but localized events, but is a useful gauge of the occurrence of extreme heavy rainfall overall. This series has been adjusted to take into account the changing size of the UK rain-gauge network which reached over 5,000 gauges in the 1970s and has reduced to fewer than 3,000 in the 2010s (Appendix Figure A1.2a)

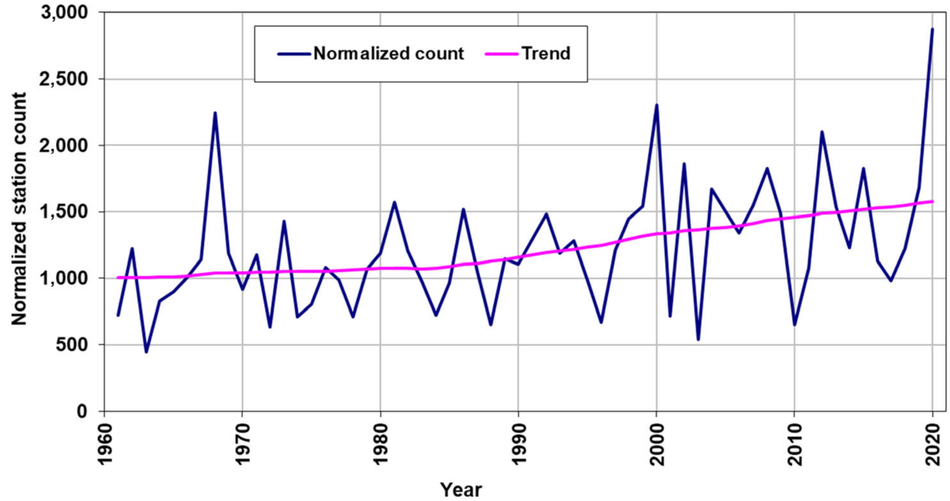
The dense network of several thousand rain gauges across the UK means that widespread heavy rain events will tend to be well captured, although highly localized convective events may still be missed. The adjustment is made by applying a scaling factor to the station-day counts for each year, so that earlier years are scaled down and later years scaled up and the apparent number of stations in the network remains constant throughout. However, note that this adjustment does not take into account the fact that the relative proportion of rain-gauges within different parts of the UK also changes with time. Therefore we cannot rule out the possibility that the present day network while having fewer stations overall may provide better sampling of regions that experience higher frequency of heavy rain days such as western Scotland. By this metric, 2020 had, by some margin, the highest count in this series—indicative of the number of widespread heavy rainfall events which occurred during the year. February 2020 accounted for over a third of the station counts during the year.

3.3 | Snow

Snow and ice caused some impacts across Scotland in the last week of January, and drivers were stranded for several hours on the M74 overnight. Snow also caused some problems from 10 to 14 February as storm Ciara cleared, and there was further snow across upland areas in the north in the last week of February, with a depth of 23 cm at Copley, County Durham on the 24th. However, any disruption from snow during February was not unusual for the time of year and much less significant than flooding impacts associated with storms Ciara and Dennis.

There was a brief spell of snow at the start of December 2020 with travel disruption in the far north of Scotland from 2nd to 5th. Snow also caused some disruption and school closures across Yorkshire and the East Midlands on the 4th. A spell of more significant snow caused further disruption across the north from Boxing Day to the New Year, with some roads blocked, accidents and abandoned cars. A depth of 9 cm was recorded at Buxton, Derbyshire on the 29th. However, overall there were no major snow events affecting the UK during 2020 and snow impacts were mostly limited and unremarkable.

The last spells of significant and widespread lying snow across lowland parts of the UK were in February to March 2018, January and March 2013 and January and December 2010. 2010 was the snowiest year by far for the UK in the last two decades, and was comparable to several snowy years in the 1970s and 1980s. Figure 34 shows the count of station-days where snow depth sensors recorded greater than or equal to 10 or 20 cm of lying snow. The series has not been adjusted for network size, consequently it is indicative but not homogeneous (with the 2020 network size



	1961–1990 average	1981–2010 average	2011–2020 average	2020
Number of station-days	1,043	1,248	1,566	2,877

FIGURE 33 Annual count of the number of UK station-days which have recorded daily rainfall totals greater than or equal to 50 mm from 1961 to 2020, adjusted for station network size and excluding stations above 500 m above sea level. The table provides average annual values (station-days). Note that the number of station-days for the 1961–1990 and 1981–2010 averages has changed slightly from last year's report (1,050, 1,256). This is because the adjustment for station network size has altered as a result of inclusion of year 2020. However, historical observations held within the climatological database also change over time as more digitized data are added or as a result of quality control; data for the full series have been re-extracted from this live database

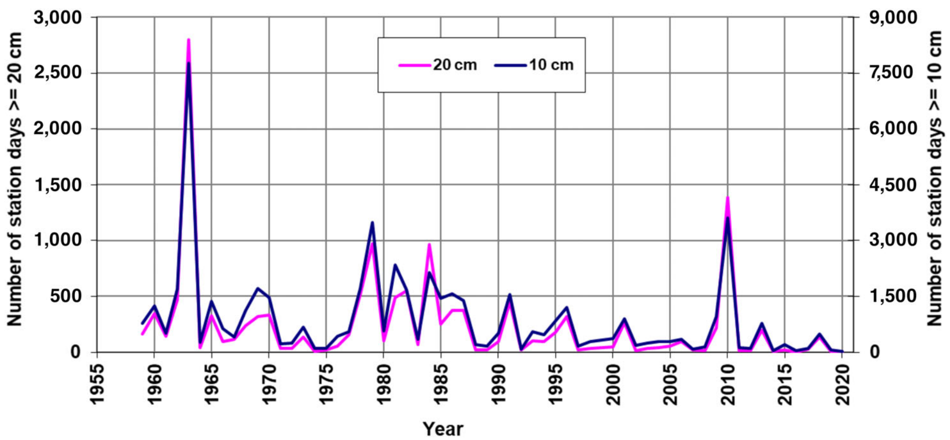


FIGURE 34 Count of number of station-days per year in the UK with recorded snow depths exceeding 20 cm (left hand axis) and 10 cm (right hand axis), excluding stations above 500 m above sea level. This series has not been adjusted for network size. The 2020 values are 23 (10 cm) and 1 (20 cm)

roughly half that of the 1960–1990s, see Annex 1). 2020 was one of the least snowy years in the series—comparable with 2019, 2016 and 2014. The absence of any major widespread snow events during the year would not be considered unusual in the context of the last two decades, but would be more notable if compared to the period 1960–2000. The 1960s had a greater frequency of snowfalls and blizzards than any decade since the 1860s and 1870s (Wild *et al*., 2000) and there were also some very substantial snow events through the 1970s and 1980s.

4 | SUNSHINE

The UK sunshine total for 2020 was 1,497 hr, 109% of the 1981–2010 average. This was the eighth sunniest year for the UK in a series from 1919. Sunshine totals were above average across much of England, and especially parts of the south-east, with more than 120% in parts of Essex and Kent, and it was relatively sunny too across northern Scotland. Totals were nearer normal across most of Wales, Northern Ireland, central and southern Scotland (Figure 35). The sunniest station were Preston Cove House, Dorset and Shoeburyness, Essex, both of which recorded over 2,200 hr–around 120% of average and in total 17 stations recorded over 1,800 hr—around 110–120% of average at these locations. The lowest total was 1,022 hr at Loch Glascarnoch, Highland, this also being the dullest station in 2019 and 2018.

A westerly airstream dominated the weather patterns during winter 2020 (December 2019–February 2020), so there was a marked west/east contrast in sunshine anomalies overall. Western areas received less than 75% of normal sunshine quite widely, whereas eastern areas were generally sunnier than average. This sunshine anomaly pattern persisted through all 3 months of the winter. Sunshine was in very short supply in north-west Scotland in particular, with Poolewe, Wester Ross and Loch Glascarnoch each recording 10 hr or less in December 2019, and only 5 hr each in January—around 15 hr across 2 months or only 15 min per day, on average.

With plenty of fine, settled weather, particularly during April and May, this was an exceptionally sunny spring, especially across the southern half of the UK with over 150% of normal sunshine across England and Wales. The UK recorded 626 hr, 144% of the 1981–2010 long-term average; almost four times as much sunshine as the preceding winter. This was the UK's sunniest spring on record by a very wide margin of 71 hr, and remarkably also sunnier than all but three summers in the UK sunshine series from 1919. All three spring months were sunnier than average; March (134% for the UK) April (150% for the UK) and May (144%); the UK had both its sunniest

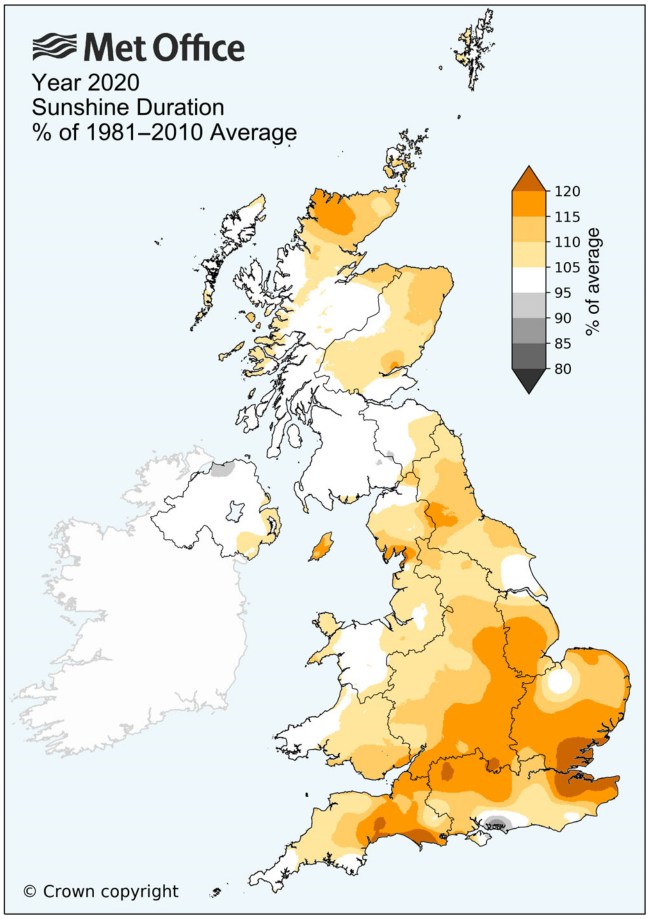


FIGURE 35 Sunshine anomalies (%) for year 2020 relative to 1981–2010

April, and sunniest May, on record, again by wide margins. With 267 hr (an average of 8.6 hr per day), May 2020 was, by a narrow margin, the UK's sunniest month on record. Sunshine totals across much of southern England and west Wales reached 300–350 hr. Three hundred thirty-two hours was recorded At Oxford, 332 hours were recorded, 172% of the 1981–2010 average, making this the sunniest calendar month on record here in a series from 1880, by a margin of over 20 hr from July 1911.

After the exceptional spring, the often unsettled conditions during summer resulted in inevitably disappointing sunshine totals in comparison. The UK recorded 451 hr, 89% of the 1981–2010 summer average—less than three-quarters of the spring sunshine total - and this was the UK's dullest summer since 2012. Although it is not especially unusual for the UK sunshine total for summer to be less than that for spring, such a large difference (175 hr) is exceptional. The summer saw below average sunshine across almost all of the UK, and across all three summer months, but especially July and August; Northern Ireland recording its second dullest July on record. However, the far north-west of Scotland, the Northern

Isles, and some parts of south-east England were sunnier than average.

Autumn sunshine totals were slightly below average overall, with fine, sunny weather in September followed by a dull October (the UK's fifth dullest October on record); England and Wales recorded around only two-thirds of the normal sunshine amount. Sunshine totals in November and December were variable, but below average for the UK overall (Figures 36 and 37).

Figures 38 and 39 show annual sunshine anomalies for the UK and countries, and seasonal sunshine anomalies for the UK, from 1919 to 2020 inclusive. The

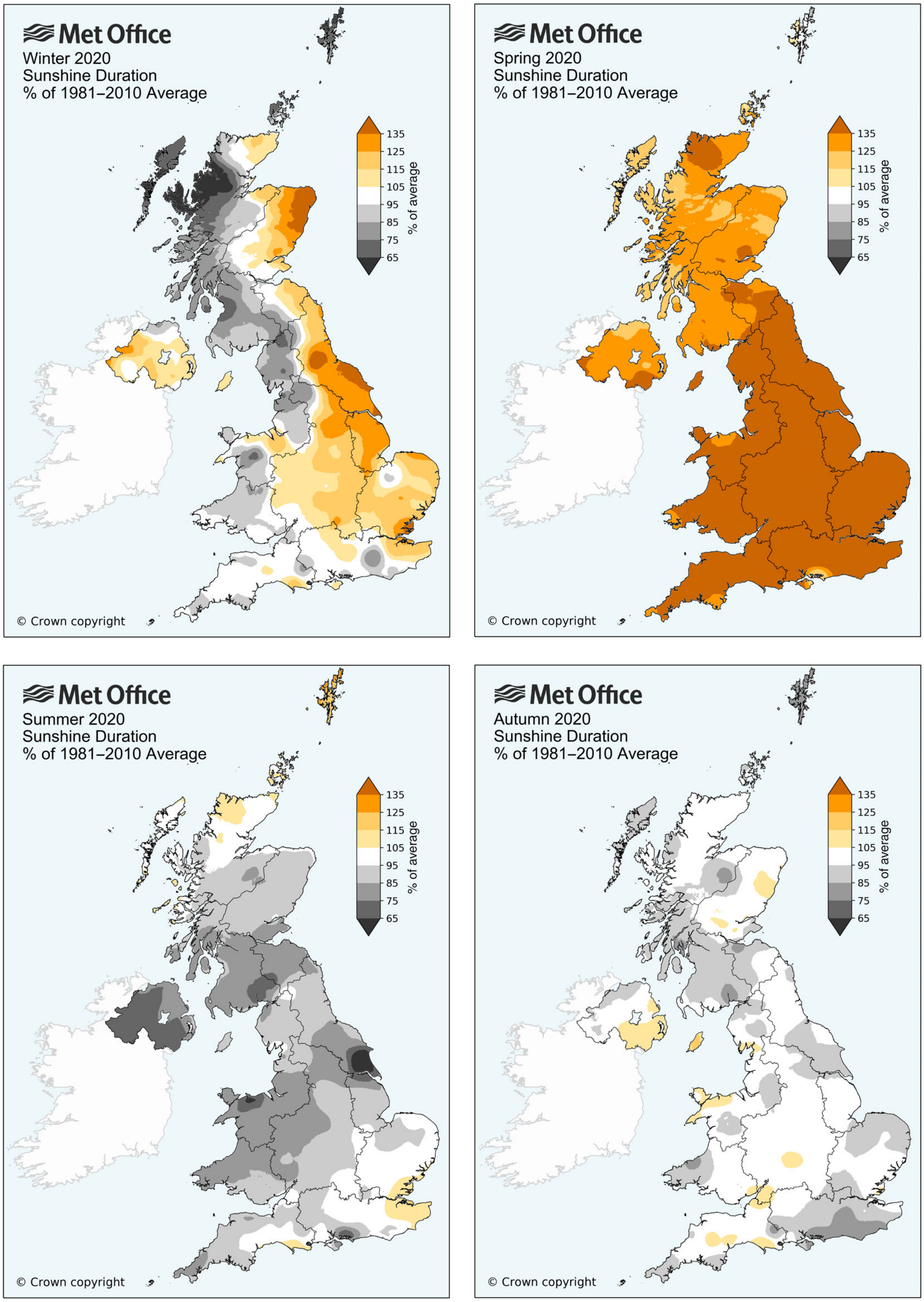


FIGURE 36 Sunshine anomalies (%) for seasons of 2020. Winter 2020 refers to the period December 2019 to February 2020

smoothed trend shows a slight increase in sunshine from a low during the 1960s–1980s to a sunnier period from 2000 onwards. The most recent decade (2011–2020) has had for the UK on average 8% more hours of bright sunshine than the 1961–1990 average and 4% more than the 1981–2010 average. This trend is apparent across all countries but is most prominent during the winter and spring, where the most recent decade is 13%/16% higher than 1961–1990. Figure 39 emphasizes the UK's exceptionally sunny spring of 2020

The sunshine network is relatively sparse, with the 2020 network comprising around 115 stations (Figure A1.4). This means that some parts of the UK such as Highland Scotland and central Wales have relatively

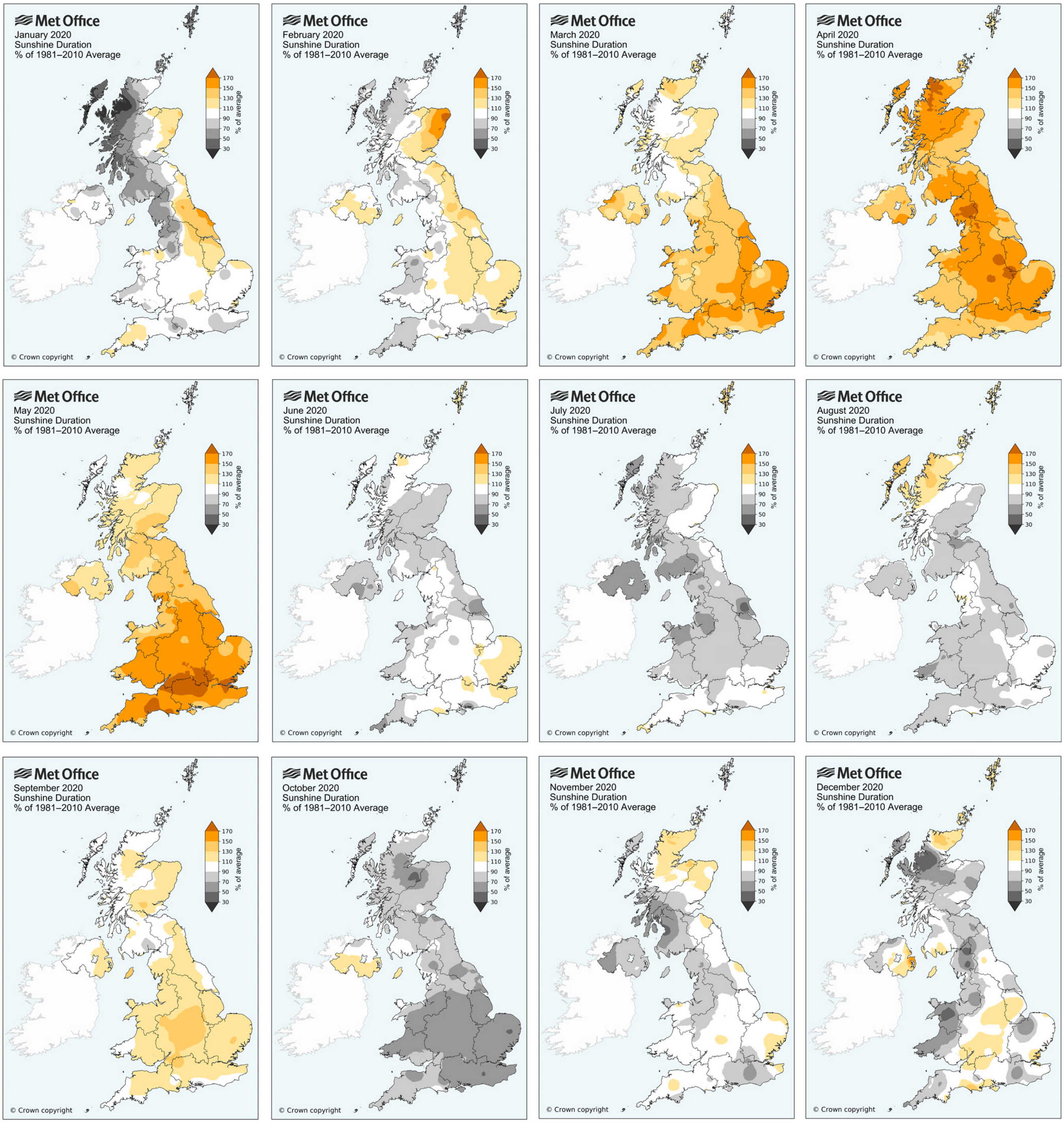
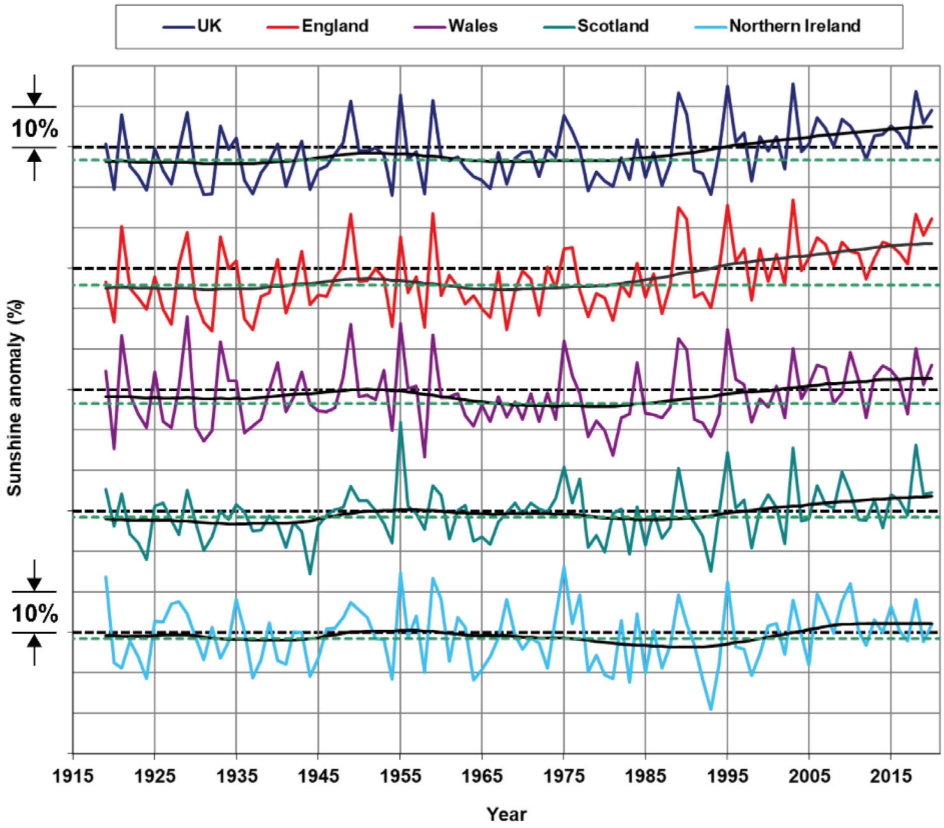


FIGURE 37 Sunshine anomalies (%) for months of 2020



Area	1961–1990 average	1981–2010 average	2011–2020 average	2020
UK	1,328	1,373	1,430	1,497
England	1,430	1,493	1,574	1,675
Wales	1,353	1,401	1,433	1,486
Scotland	1,166	1,184	1,214	1,239
Northern Ireland	1,239	1,259	1,275	1,284

FIGURE 38 Annual sunshine duration (hours) for UK and countries, 1919–2020, expressed as a percentage of 1981–2010 average. The hatched black line is the 1981–2010 long-term average. The lower hatched green line is the 1961–1990 long-term average. Light grey grid-lines represent anomalies of ±10%. The table provides average annual sunshine values (hours)

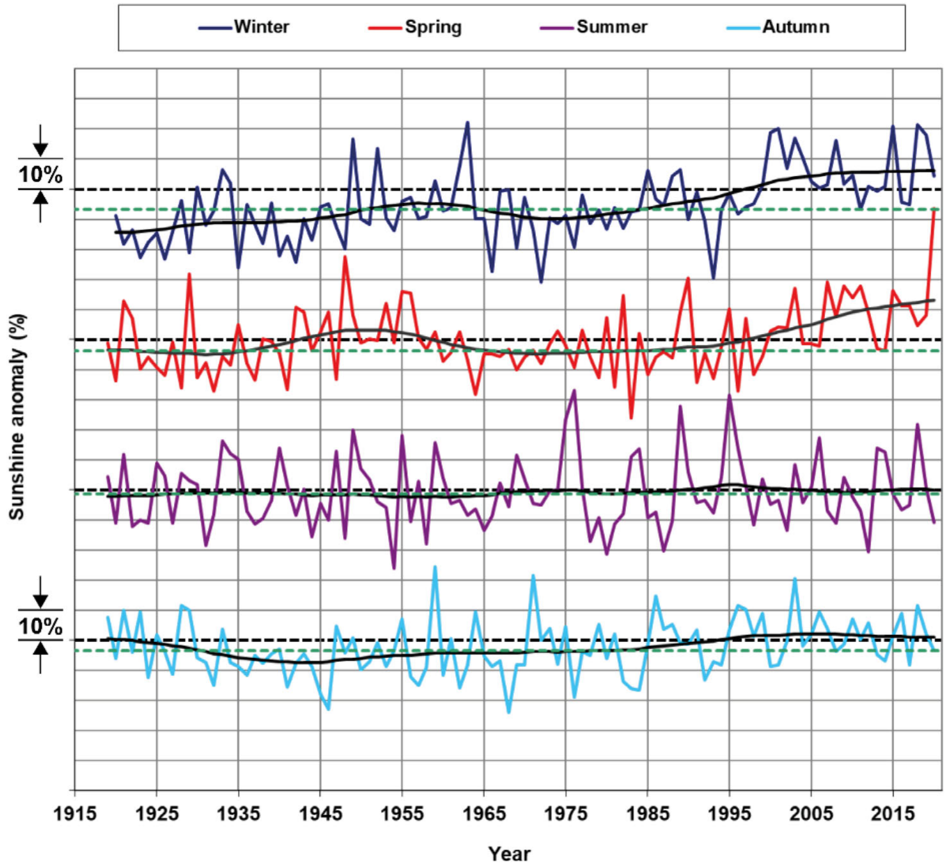
few observations. Sunshine stations may be affected by exposure issues, particularly in the winter months when the sun is at a low elevation and topographic shading may be important. The sunshine statistics throughout are presented to the nearest whole hour, but the uncertainties of the areal statistics relating to changes in the observing network over time can approach 2% (equivalent to approximately 5 min per day, on average). More details can be found in Annex 2.

5 | WIND

The windiest days of 2020 are listed in Table 4, and names storms listed in Table 5. Storms in 2020 were named as part of an initiative between the Met Office, Met Eireann and KNMI (the Dutch national weather service). Other European national meteorological agencies also apply names to storms. The naming of storms improves the communication of approaching severe weather through the media and government agencies by using a single authoritative system. Storms are named based on a combination of both the impact the weather may have, and the likelihood of those impacts occurring, taking into account wind, rain or snow. The number of named storms from year-to-year should not be used as a climate index in its own right because the criteria for naming storms have changed since the scheme was first introduced in autumn 2015.

Storm Brendan—a deep but fairly typical Atlantic winter storm system—brought strong winds to the UK in mid-January. Winds gusted at over 50 Kt (58 mph) across much of Wales, south-west England and Northern Ireland, reaching 60 Kt (69 mph) or more across exposed locations in west Wales, western and northern Scotland. The storm brought transport disruption, some fallen trees and reports of structural damage. Large waves battered exposed coastlines in Wales, Northern Ireland and Western Scotland. Schools in the Western Isles were closed.

FIGURE 39 Seasonal sunshine duration for the UK, 1919–2020 (note winter from 1920 to 2020; year is that in which January and February fall). The hatched black line is the 1981–2010 long-term average. The lower hatched green line is the 1961–1990 long-term average. Light grey grid-lines represent anomalies of ±10%. The table provides average seasonal sunshine values (hours)



Season	1961–1990 average	1981–2010 average	2011–2020 average	2020
Winter	147	158	166	165
Spring	419	436	486	626
Summer	498	505	504	451
Autumn	264	274	276	265

Storms Ciara and Dennis in early and mid-February brought significant wind impacts in addition to flooding problems. Ciara was a particularly powerful storm, and with winds gusting at over 60 Kt (69 mph) widely across England and Wales and this was the most severe wind storm of the year. Gusts of 60 Kt (69 mph) were recorded widely not just around the coast, but also at inland locations, notably North Wales, the south Pennines and parts of Lincolnshire and Norfolk, including 77 Kt (89 mph) at Capel Curig, Conwy, 75 Kt (86 mph) at Lake Vyrnwy, Powys, 67 Kt (77 mph) at Cranwell, Lincolnshire, and 65 Kt (75 mph) at Cardinham, Bodmin, Cornwall. In terms of widespread gust speeds across England and Wales exceeding 60 Kt, Ciara was the most significant storm since 12 February 2014.

Ciara caused widespread disruption throughout the UK. Hundreds of flights were cancelled, rail passengers advised not to travel, ferry services were cancelled and the Port of Dover was closed. The Humber Bridge was closed for only the second time in its history and the Dartford Crossing also closed. Part of the M11 was also closed due to the risk of a damaged aircraft hangar blowing onto the road, and tragically a man died in Hampshire when a tree fell on his car. Power cuts affected over 675,000 homes. Huge waves battered exposed coastlines with waves overtopping sea defences. Hastings lifeboat nearly capsized as it answered an emergency call at the height of the storm. Strong winds buckled a construction crane in north London and tore the sails off a historic windmill in Burgh Le Marsh, Lincolnshire. It took one flight three attempts to land at Gatwick before the aircraft diverted to Frankfurt. However, a British Airways flight was reported to have made the fastest subsonic New York to London journey—less than 5 hr—making use of powerful jet stream winds exceeding 250 mph.

Storm Dennis, a week later, also brought very strong winds, although the worst of the impacts were from the rain. Strong winds and large waves battered exposed coastlines, and in County Cork, Ireland, an abandoned "ghost" cargo ship was washed ashore. One feature of

TABLE 4 The windiest days of year 2020

Date	England (95)	Wales (11)	Scotland (34)	N. Ireland (15)	Total (155)	Named storm
07 January 2020	4	2	17	2	25	
11 January 2020	5	3	4	1	13	
13 January 2020	16	9	21	10	56	Brendan
14 January 2020	22	8	4		34	Brendan
15 January 2020	3		7	1	11	
16 January 2020	8	3	3		14	
08 February 2020	8	8	16	1	33	Ciara
09 February 2020	70	15	18	5	108	Ciara
10 February 2020	26	9	6	3	44	
11 February 2020	14	3	15	3	35	
15 February 2020	38	10	6		54	Dennis
16 February 2020	42	12	20	4	78	Dennis
17 February 2020	10	7	15		32	
21 February 2020	4	3	13		20	
22 February 2020	13	5	21	3	42	
29 February 2020	18	7	5	2	32	Jorge
01 March 2020	4	4	3	2	13	Jorge
11 March 2020	8	5	4		17	
12 March 2020	10	4	2	2	18	
22 May 2020		4	8	4	16	
20 August 2020	4	2	2	5	13	Ellen
21 August 2020	8	6			14	
25 August 2020	10	8		1	19	Francis
24 October 2020	3	2	5	1	11	
31 October 2020	7	5	22	5	39	Aiden
01 November 2020	4	8	8	1	21	
02 November 2020	7	5			12	
15 November 2020	8	4			12	
26 December 2020	21	11	6	2	40	Bella
27 December 2020	24	9			33	Bella

Note: The table lists dates where 10 or more stations across the UK recorded a maximum wind gust greater than or equal to 50 Kt (58 mph) on that day. The table also gives a count of affected stations by country. The number of wind observing sites in 2020 for each country (based on data availability) is also given in brackets.

Dennis was the persistence of the strong winds across the UK for several days, with the low pressure centre to the north-west slow to clear the UK, and winds of 50 Kt sustained for a period of around 2 days. Storm Jorge, named by the Spanish meteorological service, brought further very windy weather at the end of February but impacts were generally less than from Ciara and Dennis.

After this, wind related weather impacts were generally limited through the spring and much of the summer. Strong winds caused some disruption in Northern Ireland and northern England on 12th March, while on 21–22nd May fallen trees affected transport in Manchester and Cardiff. On 25th July a tornado in Northampton caused some damage to property.

Storms Ellen and Francis, separated by only a few days, brought significant wind impacts in late August. Ellen brought significant travel disruption, hundreds of homes were left without power in Wales and the M48 Severn Bridge was closed. Rail and ferry services in west Wales were cancelled, large waves battered exposed coastlines causing some coastal flooding and there were reports of fallen trees (with the ground saturated and trees in full leaf at this time of year). Francis caused further transport disruption to road and rail and further coastal flooding. Thousands of homes were without power, there were reports of fallen trees and the M48 Severn Bridge again closed. These were two of the most notable August storms in the UK in the last 50 years (for more details, see Section 8).

An area of low pressure brought stormy conditions to parts of eastern England on 25th September. Sand drifts up to 1.5 m high were reported in residents gardens in Norfolk, and the Port of Felixstowe was closed due to high winds. Fallen trees affected some roads and railway lines in parts of Norfolk, and Suffolk. Impacts were also reported on the roads, with damage to boats in harbours along the coast.

Strong winds from storm Alex brought some impacts to southern England on 2nd October before the storm moved south across France. Large waves affected parts of the south coast exposed to the east—for example, at Swanage (Dorset) and several areas experienced power cuts including the Isle of Wight, Portsmouth, Southampton, Devon, Cornwall, towns east of Reading and parts of west London. Storm Barbara on 21st October was named by the Spanish meteorological service but brought limited impacts to the UK. Storm Aiden on 31st October was part of a spell of turbulent, wet and very windy weather from late October to early November as a succession of deep Atlantic low pressure systems, associated with a powerful jet stream, crossed the UK. Large waves resulted in 33 shipping containers being lost overboard from a vessel in the Pentland Firth, while a yacht capsized off the Isles of Scilly.

Storm Bella was another large, deep area of low pressure with very strong winds sweeping across England and Wales overnight 26–27th December. The strongest winds from storm Bella were around the coastline of Wales, south-west and southern England, where wind gusts exceeded 60 Kt (69 mph). Needles Old Battery (Isle of Wight) recorded 92 Kt (106 mph), the UK's highest wind gust at a low level station since 2 November 2019, while Aberdaron, Llŷn Peninsula recorded 72 Kt (83 mph). Large waves affected coastlines of Wales and southern England.

As a measure of storminess Figure 40 counts the number of days each year on which at least 20 stations recorded gusts exceeding 40/50/60 Kt (46/58/69 mph). Most winter storms have widespread effects, so this metric will reasonably capture fairly widespread strong wind events. The metric will consider large-scale storm systems rather than localized convective gusts. There are no compelling trends in maximum gust speeds recorded by the UK wind network in the last five decades, particularly bearing in mind the year-to-year and decadal variations and relatively short length of this time series. There were 10 named storms during the year, and overall 2020 was a

TABLE 5 UK named storms of 2020

Name	Date of impact on UK and/or Ireland
Brendan	13–14 January 2020
Ciara	8–9 February 2020
Dennis	15–16 February 2020
Jorge	28 February–1 March 2020
Ellen	19–20 August 2020
Francis	25 August 2020
Alex	2–4 October 2020
Barbara	21 October 2020
Aiden	31 October 2020
Bella	26–27 December 2020

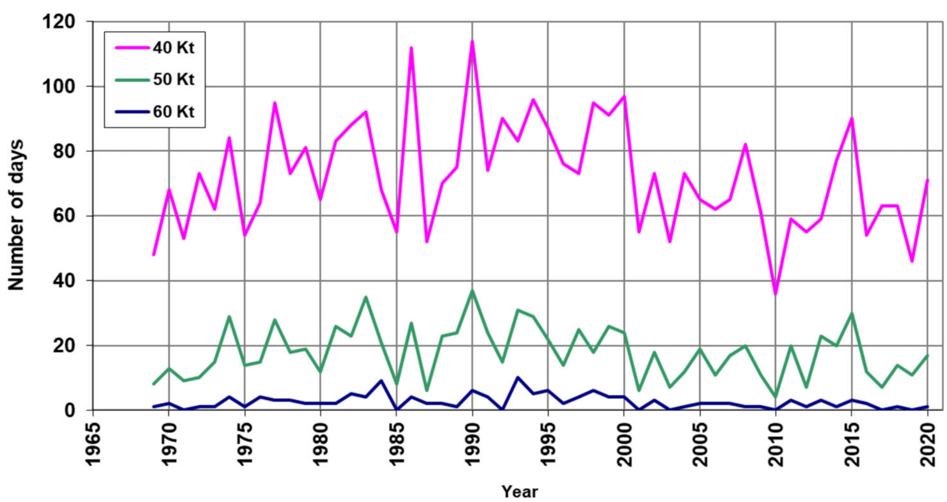


FIGURE 40 Count of the number of individual days each year during which a max gust speed ≥40, 50 and 60 Kt (46, 58, 69 mph; 74, 93, 111 kph) has been recorded by at least 20 or more UK stations, from 1969 to 2020. Stations above 500 m above sea level are excluded

fairly typical year for storminess when compared to previous decades. Nevertheless, for the 50 and 60 Kt metrics it was the stormiest year since 2015. However, there were many windier years than 2020, particularly in the 1980s and 1990s.

Note that higher 40 Kt counts from the mid-1980s through the 1990s as shown in Figure 40 is broadly consistent with a period of positive phase of the winter NAO as shown in Figure 2. This earlier period also included among the most severe storms experienced in the UK in the observational records including the ‘Burns Day Storm’ of 25 January 1990, the ‘Boxing Day Storm’ of 26 December 1998 and the ‘Great Storm’ of 16 October 1987, while in the last decade the most significant major winter storms have been on 5 December 2013, 3 January 2012 and 8 December 2011. None of the storms of 2020 compared with these earlier storms for overall severity across the UK.

Changes in instrument type, station network size, station exposure, and choice of metric used mean that interpreting trends in storminess from UK wind speed data is not straightforward due to the limitations of available data, and results should be treated with caution. The wind network on which Figure 40 is based comprises around 130 stations in the 1970s, 150 in the 1980s, 190 in the 1990s and 2000s and 160 in the 2010s. Figure 40 has not been adjusted to take into account this changing network but this may partly account for the higher station counts in 40 Kt gusts through the 1980s and 1990s. Although data from the land network as presented in this report show no compelling trends in maximum gust speeds in the UK, Matthews *et al*. (2014) notes an increase in cyclone intensity and wind speeds across the North Atlantic since the 1950s based on the NCEP reanalysis (Kalnay *et al*., 1996).

6 | SEA LEVEL

A UK sea level index for the period since 1901 provides the rate of 1.5 ± 0.1 mm·year^{-1} for sea level rise, when excluding the effect of vertical land movement (Woodworth *et al*., 2009a), resulting in a sea level rise of 16.5 cm (Figure 41). This is close to the global sea level rise estimate of 16 cm (likely range 12–21 cm) for the period 1902–2015 (Oppenheimer *et al*., 2019). When vertical land movement is included, the net rate of sea level rise is slightly higher in the south of England and slightly lower in some parts of Scotland.

However, UK sea level change is not a simple linear increase, but also includes variations on annual and decadal timescales. Using the UK sea level index, we have estimated the changes in the rate for sea level rise for different time periods (Figure 42). For the period 1958–2018 the rate of sea level rise has increased to 1.8 ± 0.3 mm·year^{-1}, which is in agreement with recently published results for the rate of sea level rise of 2.4 ± 0.3 mm·year^{-1} in the UK using a different approach and different data sets (Hogarth *et al*., 2020), allowing for the large error bars on both estimates. The rate for the period 1993–2019 has increased further to 3.6 ± 1.0 mm·year^{-1}, which is comparable to the global estimate of sea level rise of 3.2 ± 0.4 mm·year^{-1} for this same period based on satellite altimetry (Baringer *et al*., 2020).

The evolution of the trend over time (Figure 42) provides scientific evidence that rate of sea level rise is increasing, confirmed by acceleration of 0.034 ± 0.019 mm·year^{-2} estimated by the conventional approach, where the acceleration is defined as the second derivative of sea level in time. Calculated acceleration for the UK sea level rise by Hogarth *et al*., 2020 is larger (0.058 ± 0.030 mm·year^{-2}), however, the error bars in both estimates are quite large, demonstrating the challenge in estimating the trend and acceleration

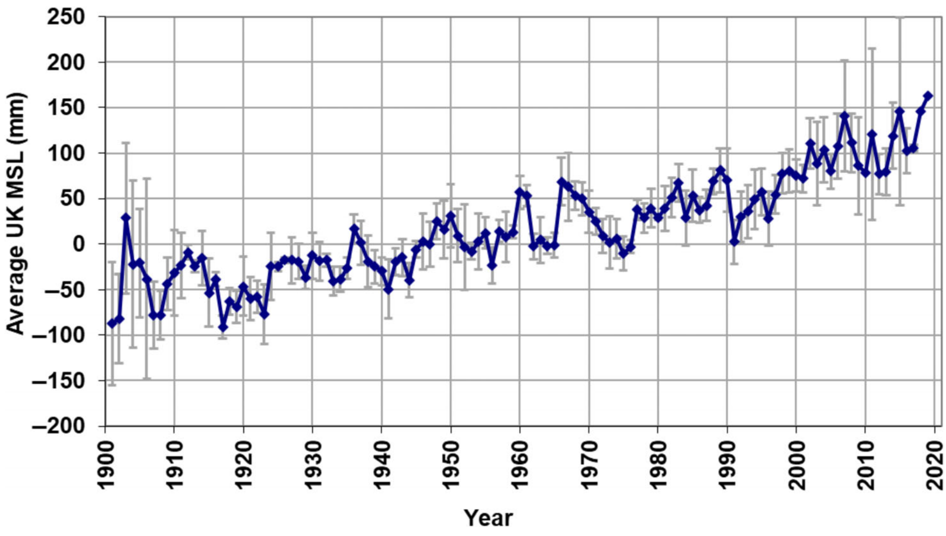


FIGURE 41 UK sea level index for the period since 1901 computed from sea level data from five stations (Aberdeen, North Shields, Sheerness, Newlyn and Liverpool) from Woodworth *et al*. (2009). Error bars shown in the UK index indicate uncertainty (one standard deviation) in values for individual years

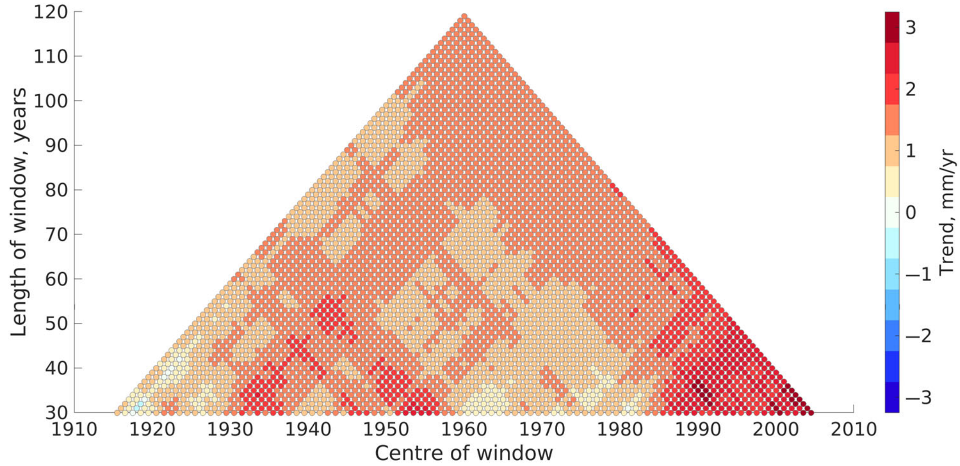


FIGURE 42 Trends in the UK sea level index fitted over all possible windows at least 30 years long between 1901 and 2019. Each point represents one window, with the value on the horizontal axis representing the centre of the window, the value on the vertical axis representing the length of the window, and the colour of the point encoding the value of the trend. So, for example, the point at (1960, 61) represents the trend over the period 1930–1990

in time series with large variability in different scales (Douglas, 1992; Jevrejeva *et al.*, 2008; Woodworth *et al.*, 2009b) and the number of large-scale atmospheric and ocean processes that contribute to non-uniform sea-level rise around the coast of the UK (Woodworth *et al.*, 2009b; Hogarth *et al.*, 2020).

The UK index is based on five long-running stations dating back to the beginning of the 20th century. Due to ongoing issues with data quality, there was unfortunately not enough data to update the UK sea level index with a value for 2020. The 2019 and 2018 values are based on only one of these stations (Newlyn) due to missing data at the others at various times during the year. Uncertainties in the UK sea level index for several recent years, notably 2007, 2011 and 2015, are large; it is suspected that these relate to data quality issues at the Liverpool gauge. The method for calculating uncertainties does not currently take into account missing stations. The 2010, 2018 and 2019 values are based on only one gauge so error bars are not available. Given issues with data availability in the network a review of the method used to calculate the UK index may be required to derive an index based on the complete network of stations, rather than restricting this to long-running stations only.

7 | EXTREMES FOR YEAR 2020

Table 6 shows the UK weather extremes for year 2020. The highest temperature of the year, 37.8°C at Heathrow on 31st July made this the UK's third warmest day on record. The highest daily minimum temperature of the year, 22.3°C at Langdon Bay, Kent on 8th August occurred during a major heatwave across southern England (for more details of both extremes, see Section 8).

The lowest maximum, minimum and grass minimum temperatures occurred in mid-February and at the end of December. These were fairly typical for the lowest values of the year—the lowest minima occurring under clear skies and light winds with lying snow. The greatest snow depth of 24th February occurred in the north Pennines; depths elsewhere in the north Pennines were more typically 5–15 cm.

The highest daily rainfall total of 239.9 mm at East Wretham, Norfolk on 16th August, was due to a highly localized rainfall event, and was subject to extensive quality control before acceptance (for more details, see Section 8). This value set a new UK August record, and it was the second daily rainfall total of over 200 mm observed during 2020, with 212.8 mm at Honister Pass, Cumbria on 28th June. While daily totals of over 200 mm are exceptional for the UK, there has been a marked recent increase in the number of such observations, with 200 mm recorded in 2008, 2009, 2012, 2015 (two dates), 2017 and 2020 (two dates). All such recent totals, with the sole exception of East Wretham, have occurred in the English Lake District. The highest gust speed of 92 Kt (106 mph) at Needles Old Battery was due to storm Bella. This station has a uniquely exposed location on the western end of the Isle of Wight.

8 | SIGNIFICANT WEATHER EVENTS OF 2020

This section describes notable weather events which occurred during 2020. The choice of event is determined by the National Climate Information Centre based on our experience of monitoring the UK's climate through the year, broadly taking into account a combination of spatial extent, severity and duration and any associated impacts. It does not represent a comprehensive list of all impactful weather affecting the UK during the year, which may be mentioned elsewhere in the report. A discussion of notable and named storms for 2020 is also included in the wind section of this report.

8.1 | Exceptionally wet February including storms Ciara and Dennis

Storms Ciara and Dennis were part of an exceptionally wet February for the UK, leading to major flooding of national significance, with the flooding at least as severe as that in November 2019 (Kendon *et al*., 2020); these events brought, by far, the most severe weather impacts of the year.

Ciara, a major winter storm, swept across the UK on 8th February (Figure 43). Bands of intense convective rainfall were embedded in the fronts sweeping across the UK (Figure 44). Around 100–150 mm of rain fell across the Lake District fells, while across Snowdonia and the Pennines totals exceeded 75 mm fairly widely with a few locations here also exceeding 100 mm (Figure 45a). Around 50–75% or more of the February long-term average rain fell widely, with parts of the south Pennines, notably West Yorkshire, receiving a whole month's average (Figure 45b). Several long-running stations recorded their wettest February day, including Eskdalemuir, Dumfriesshire (79.4 mm, 109 years), Newton Rigg, Cumbria (50.2 mm, 98 years), Auchincruive, Ayrshire (39.4 mm, 81 years) and Edinburgh Royal Botanic Garden (34.4 mm, 78 years).

Ciara alone brought major flood impacts but the situation was made much worse by storm Dennis, arriving only a week later. Dennis was an exceptionally deep Atlantic depression (Figure 46), bringing widespread persistent rain—again with some intense embedded convective bands (Figure 47). Western upland parts of the UK received a further 50–100 mm or more of rain falling on saturated ground—with around the whole month's average rain falling across the west and north Midlands (Figure 48a,b).

Figure 49 shows UK area-average daily rainfall totals for December 2019–February 2020. UK area-average rainfall totals exceeded 20 mm from Ciara (8th) and Dennis (15th)—among only 41 out of more than 47,000 days in the UK daily series from 1891 with totals over 20 mm. Totals reached or exceeded 10 mm on 8 days of the month and 5 mm on 18 days, indicating both the exceptional nature of the rainfall from Ciara and Dennis combined with the persistent wet weather throughout much of the month—also including storm Jorge.

Most of the UK received more than twice the February long-term average rainfall, with 300% quite widely in the north and west, and over 400% in parts of

TABLE 6 Annual extremes for the UK for year 2020

Extreme	Observation	Date	Station
Highest daily maximum temperature (09–09 GMT)	37.8°C	31 July	Heathrow, Greater London, 25 masl
Lowest daily minimum temperature (09–09 GMT)	−10.2°C	13 February 30 December	Braemar, Aberdeenshire, 327 masl Dalwhinnie, Inverness-shire, 351 masl
Lowest daily maximum temperature (09–09 GMT)	−1.9°C	30 December	Carlisle, Cumbria, 28 masl
Highest daily minimum temperature (09–09 GMT)	22.3°C	8 August	Langdon Bay, Kent, 117 masl
Lowest grass minimum temperature (09–09 GMT)	−12.7°C	31 December	Aboyne, Aberdeenshire, 140 masl
Highest daily rainfall (09–09 GMT)	239.9 mm	16 August	East Wretham, Norfolk, 32 masl
Greatest snow depth (09 GMT)	23 cm	24 February	Copley, County Durham, 253 masl
Highest daily sunshine	16.8 hr	16 June	Fair Isle, Shetland, 57 masl
Highest gust speed	92 Kt, 106 mph	27 December	Needles Old Battery, Isle of Wight, 80 masl
Highest gust speed (mountain)	115 Kt, 132 mph	3 February	Cairngorm Summit, Inverness-shire 1,237 masl

Note: Stations above 500 m above mean sea level (masl) are considered as mountain stations and therefore not representative of low-level areas. They are excluded from the table with the exception of the highest mountain gust. Channel Island values are also quoted if these exceed UK values.

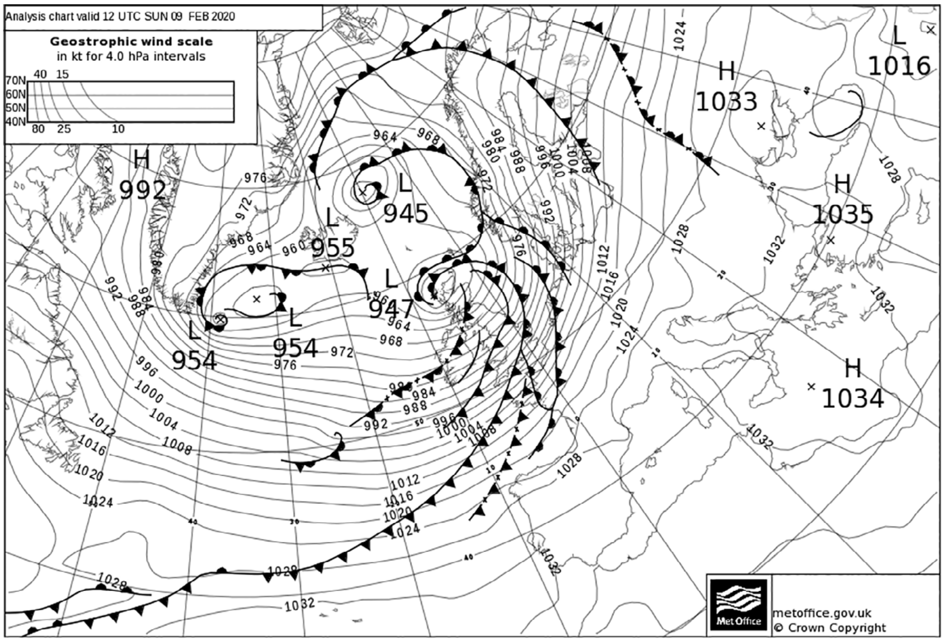


FIGURE 43 Analysis chart at 1200 UTC 9 February 2020

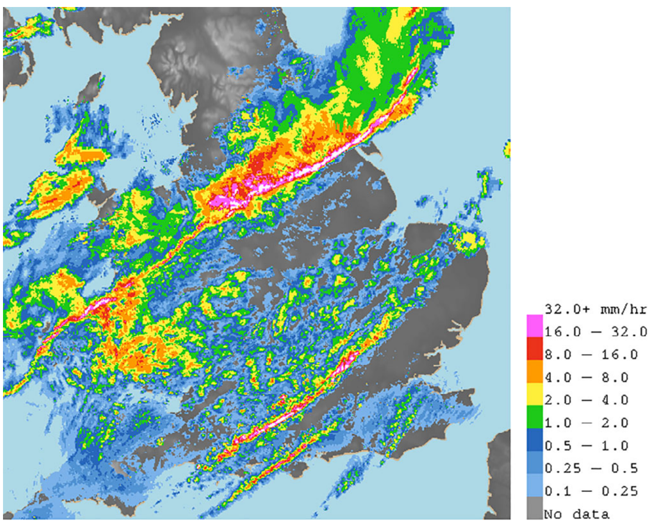


FIGURE 44 UK rain-radar image at 1200 UTC 9 February 2020

the Pennines (Figure 50). This was, by a wide margin, the UK's wettest February on record (Figure 51)—a notable outlier compared to other wet Februarys in the series. Table 7 lists the UK's top-10 wettest calendar months, ranked both as actual totals and as anomalies relative to the monthly long-term average. February 2020 was the UK's fifth wettest calendar month on record, but in addition, with 242% of the 1981–2010 long-term average this was the highest rainfall anomaly of any calendar month in the UK series from 1862. Four out of the top-10 wettest months in both lists (actuals and anomalies) have occurred since 2000—with five of the top-10 wettest months by anomaly falling in February. Davies *et al.*, 2021, describes winter 2019/2020—including February 2020—in more detail, including meteorological drivers, predictability and attribution to climate change.

8.2 | Dry and sunny spring

Figure 52 shows area-average daily rainfall totals for England for the first half of 2020. After persistent rainfall through February until mid-March, there was little rainfall across England from 19th March until 2nd June—although with some much needed rain across central southern England on 17th April and the last 4 days of the month. After the prolonged wet weather, the dry conditions were initially welcome, but the dry spring subsequently made conditions difficult for farmers and growers, limiting growth of grass and crops. Much of north-east England received 5–10 mm or less rain during April, and central and southern England received less than 5 mm during May; a few locations received less than 1 mm (Figure 53). England had its driest May on record in a series from 1862, and the driest calendar month since August 1995.

It was also an exceptionally sunny spring, with long periods of unbroken sunshine, particularly across England and Wales. Figure 54 shows spring sunshine totals recorded across the network. Totals across southern England and around the coast exceeded 700 hr quite widely, with three stations recording over 800 hr (more

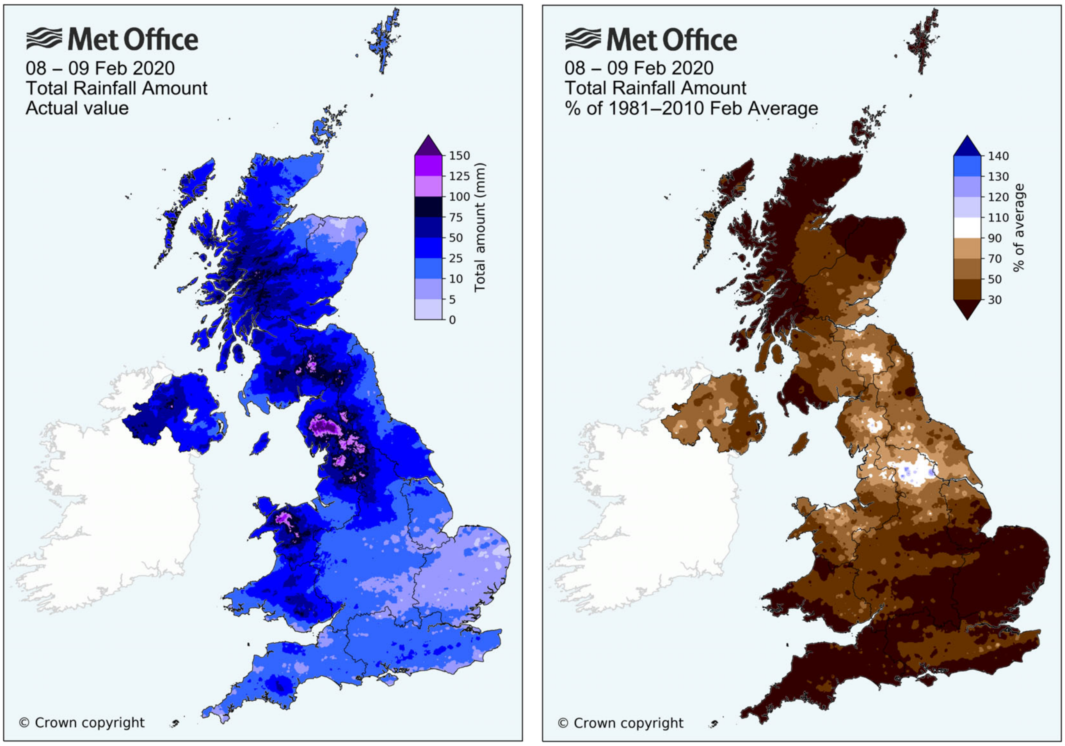


FIGURE 45 UK rainfall totals from storm Ciara, 8–9th February 2020 (a) actuals and (b) as a percentage of the 1981–2010 February whole-month average. Raindays are 09–09 UTC

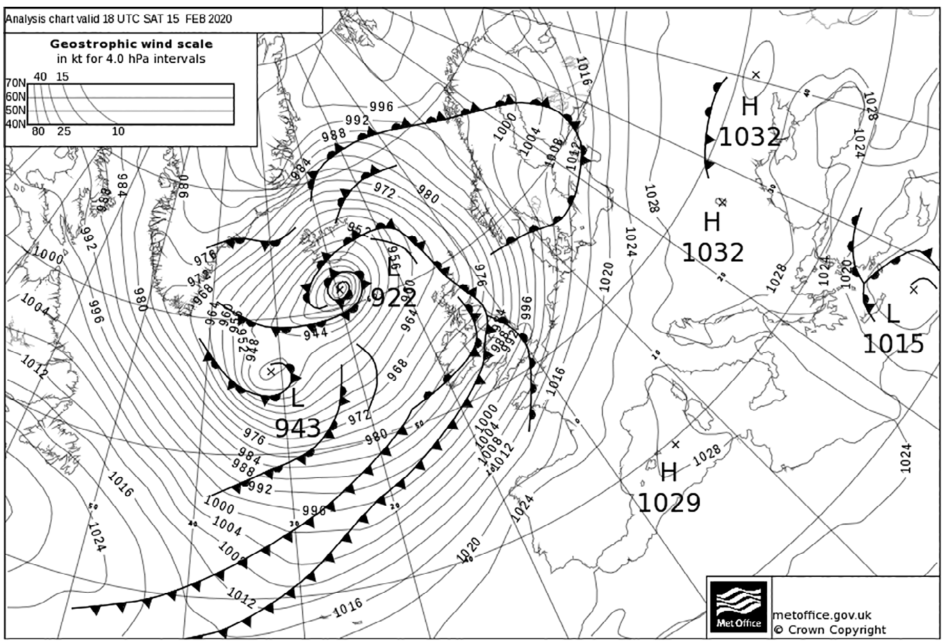


FIGURE 46 Analysis chart at 1800 UTC 15 February 2020

than 8.5 hr per day on average). Remarkably, totals across the UK were typically 100 hr or more in excess of what might be expected during an average UK summer; many stations across central and southern England recording more than 150% of average spring sunshine. The combination of dry, warm and sunny conditions resulted in a sharp reduction in soil moisture to record breaking-lows. By the end of the spring river flows were far below normal, with new record minima in some locations, and reservoir stocks were depleted.

8.3 | Hot day, 31 July

On 31 July 2020 the temperature reached 37.8°C at Heathrow, Greater London, making this the UK's third hottest day on record. The analysis chart at 1200 UTC 31st July 2020 shows an area of low pressure to the west drawing a flow of hot air from the continent across southern and central parts of the UK (Figure 55). Temperatures across central southern England widely exceeded 34–35°C. 36°C was recorded in and around Greater London, and also in Oxfordshire, Warwickshire and Northamptonshire. Kew Gardens reached 37.3°C (Figure 56).

Figure 57 compares daily maximum temperature anomalies on the UK's three hottest days: July 25, 2019, when a new UK record of 38.7°C was set at Cambridge Botanic Garden); 10 August 2003 (the previous UK record of 38.5°C at Faversham, Kent); and 31 July 2020. On 31 July 2020, temperatures across central England were widely 12°C or more above the July 1981–2010 long term average, but the heat was not quite so extreme as 25 July 2019 or 10 August 2003.

This was only the fourth occasion where temperatures in the UK have exceeded 37°C. The UK all-time record of 36.7°C (98 °F) at Raunds, Northamptonshire, Canterbury, Kent and Epsom, Surrey stood for nearly 80 years until 37.1°C on 3 August 1990 at Cheltenham, Gloucestershire; before the record was broken in 2003 and then 2019. Of the six occasions when temperatures have exceeded 36.7°C (98 °F) in the UK, three have occurred in the last 6 years (Table 8).

Crowds descended on beaches along the south coast at Poole, Bournemouth and Brighton causing gridlock on

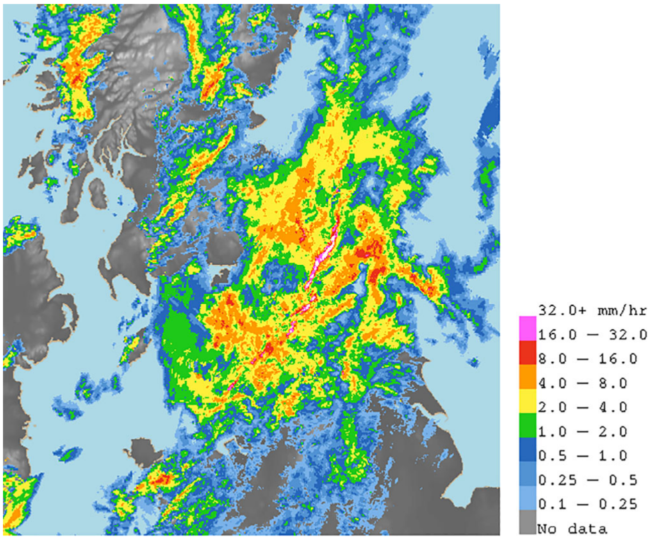


FIGURE 47 UK rain-radar image at 1800 UTC 15 February 2020

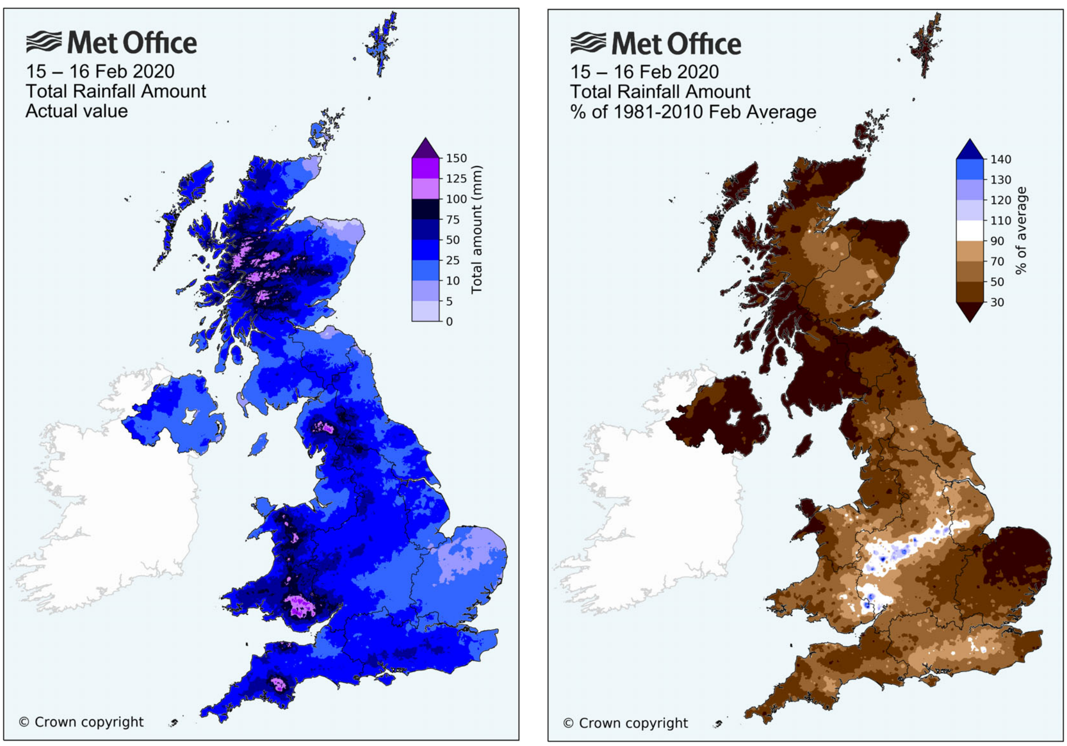


FIGURE 48 UK rainfall totals from storm Dennis, 15–16 February 2020 (a) actuals and (b) as a percentage of the 1981–2010 February whole-month average. Raindays are 09–09 UTC

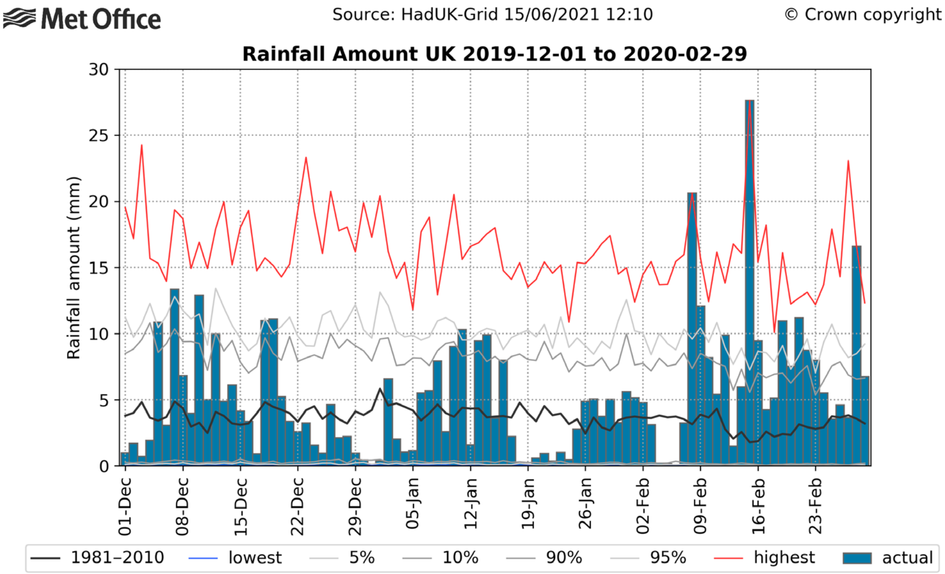


FIGURE 49 UK daily area-average rainfall totals for winter 2020 (December 2019–February 2020)

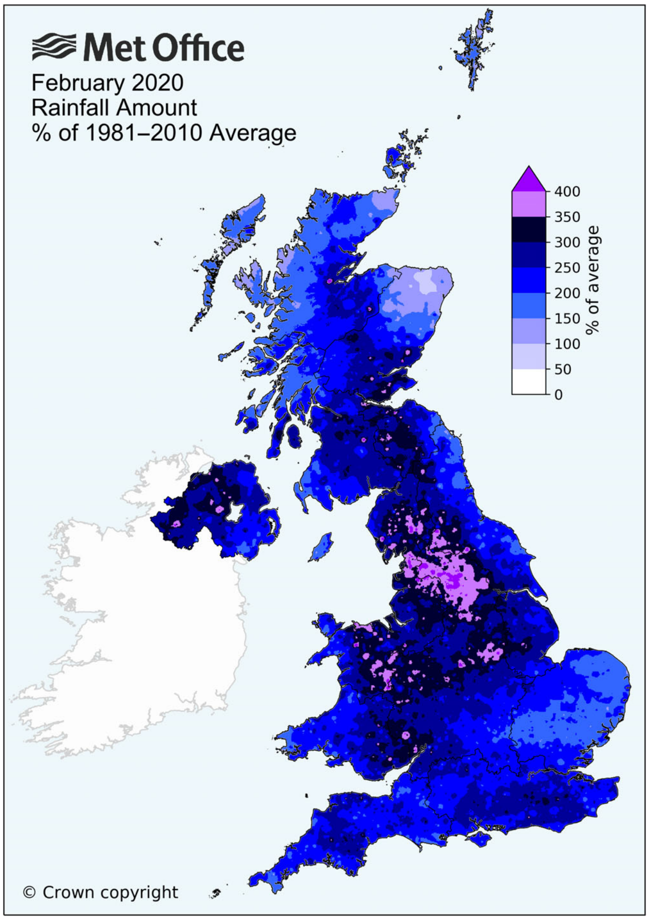


FIGURE 50 UK rainfall for February as a percentage of the 1981–2010 average

roads; trains were also very crowded. Fortunately this was an isolated day of extreme heat, with daily maximum temperatures in the mid to high 20s on 30th July and 1st August.

8.4 | Southern England heatwave, August

Southern England experienced one of the most significant heatwaves of the last 60 years during early August 2020 as hot, humid air moved north from the near continent. The analysis chart at 12 UTC 8 August 2020 shows a slack airflow over the UK with south-east England in a hot, humid air-mass extending from the near-continent, separated by a front from cooler, fresher conditions to the north (Figure 58). Temperatures exceeded 30°C widely across south-east and parts of central England—and locally 34°C—for six consecutive days, with 35°C reached on 7, 10, 11 and 12th and 36°C on 7 and 11th (Figure 59). The highest temperature was 36.4°C on 7th August at Heathrow and Kew Gardens, with 36.2 also reached at Charlwood, Surrey on 11th. Although 31 July 2020 was hotter with 37.8°C at Heathrow, this was a single day in isolation, rather than a sequence of hot days lasting almost a week.

The heatwave also included a succession of uncomfortably mild and humid nights with temperatures held up above 18°C, including five ‘tropical nights’ on 8, 10, 11, 12 and 13th where temperatures locally remained above 20°C (Figure 60). The highest daily minimum temperatures were generally in London (strongly influenced by the urban heat-island effect) but also around the coastline of the south-east from Suffolk to Hampshire due to the increased humidity from the maritime influence. The highest daily minimum temperature was 22.3°C at Langdon Bay (Kent) on 8th, while London St James's Park also recorded a minimum of 22.0°C on 12th.

Figure 61 shows hourly air temperature at London St James's Park and Wisley, Surrey through the heatwave.

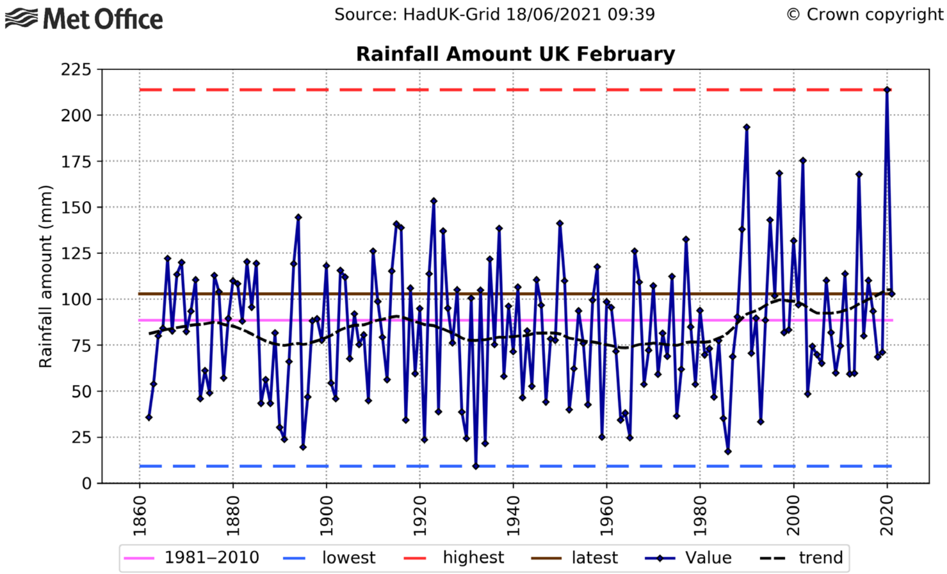


FIGURE 51 UK rainfall for February, series from 1862

TABLE 7 The UK's top-10 wettest calendar months—ranked both as actuals (left) and as anomalies (right)

Rank	Month	Total (mm)	Month	% of 1981–2010 monthly average
1	October 1903	226.1	**February 2020**	242
2	**December 2015**	216.9	February 1990	219
3	**November 2009**	215.0	**June-2012**	203
4	**February 2020**	213.6	**February 2002**	199
5	December 1929	213.4	July 1988	193
6	January 1928	205.1	February 1997	191
7	December 1914	202.7	**February 2014**	190
8	**October 2000**	199.6	May 1967	189
9	October 1967	196.8	September 1918	189
10	December 1999	195.5	August 1912	188

Dates in bold are since 2000.

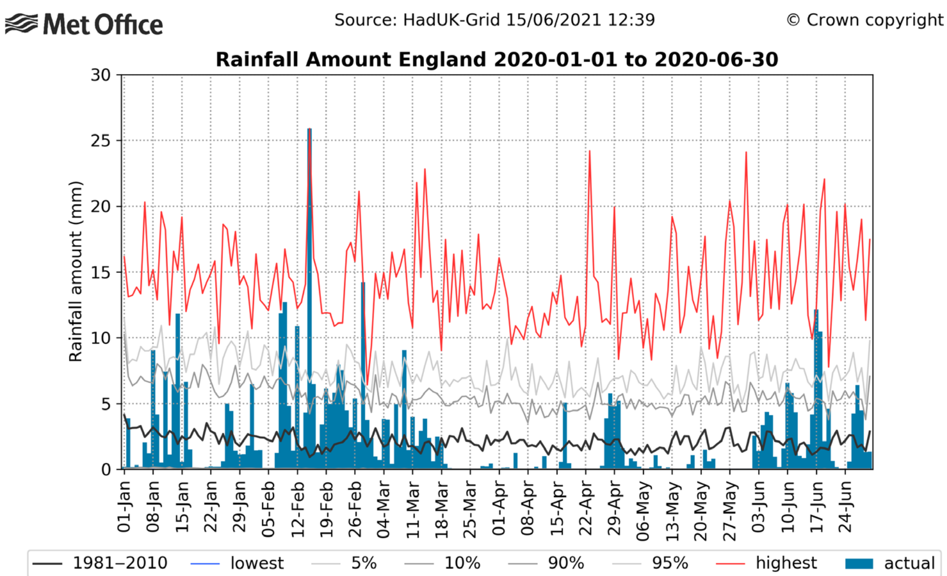


FIGURE 52 England area-average daily rainfall from January to June 2020

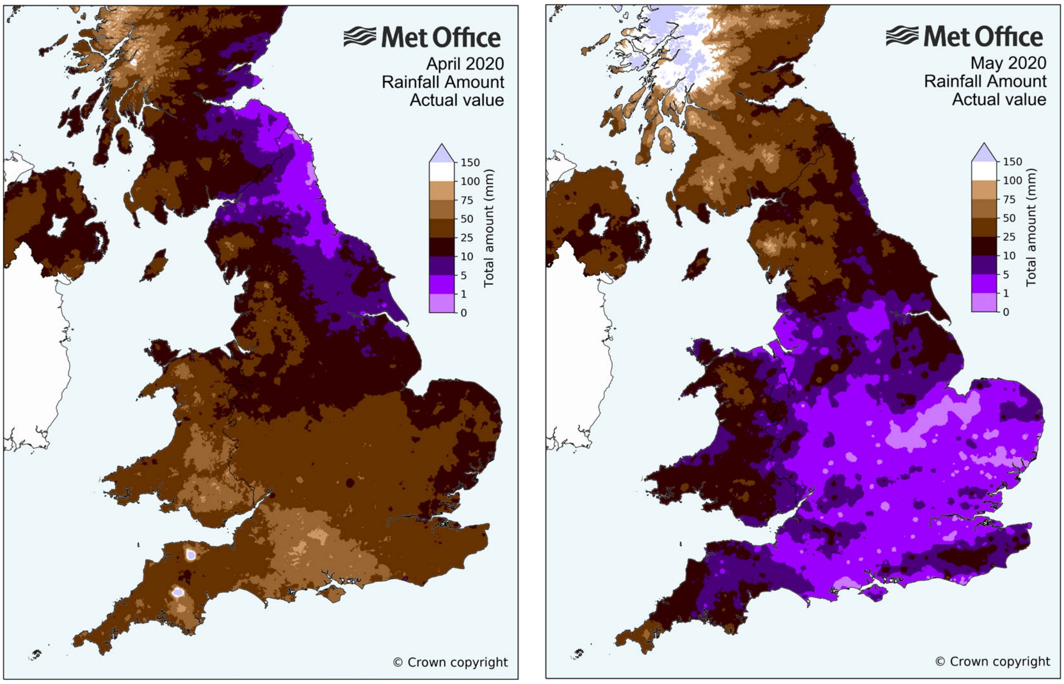


FIGURE 53 Rainfall totals (mm) during April and May 2020 across England

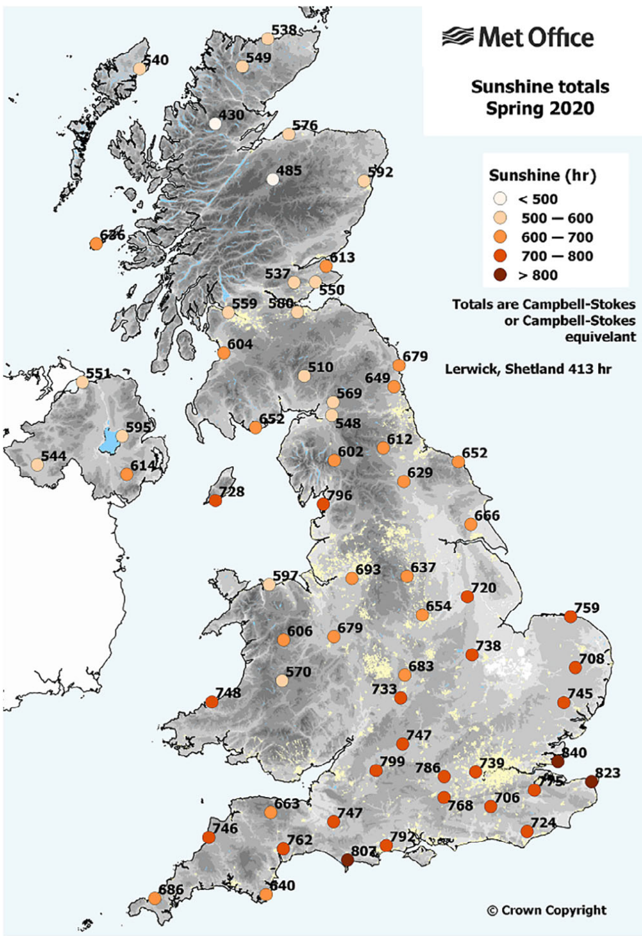


FIGURE 54 Sunshine totals (hours) for spring 2020 across the UK

Daily maximum temperatures at both stations reached the low- to mid-30s for six consecutive days 7–12 August and were broadly comparable at both locations. However, daily minimum temperatures were several degrees higher on 8, 11 and 12th at St James's Park compared to Wisley—A rural station approximately 40 km from central London, clearly showing the urban heat-island influence on St James's Park retaining higher temperatures at night

Heatwave comparisons are complex if they are to consider severity, duration and spatial extent. The August 2020 heatwave saw a combination of both unusually high temperatures and sustained duration for approximately a week, although the highest temperatures were mostly confined to London and the south-east. At least 20 stations recorded temperatures of 32°C or higher for six consecutive days during August 2020; the last time this occurred was from 1–6 July 1976. It was also the only occasion in at least the last 60 years with 34°C recorded somewhere in the UK for six consecutive days.

34°C has been recorded in the UK during seven out of the last 10 years 2011–2020, compared to seven out of the previous 50 years 1961–2010, suggesting that temperatures of 34°C or higher occurring at some point during the summer are becoming much more common. A further indication of the changing nature of the UK's climate is the number of 'tropical nights'—that is, days where the daily minimum temperature has remained above 20°C. A tropical night has been recorded in all but

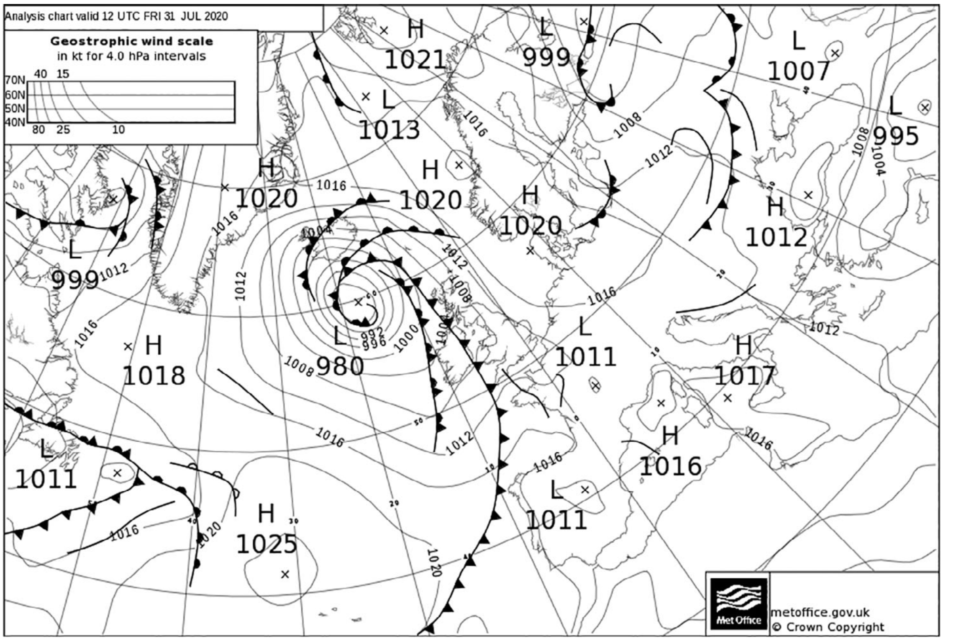


FIGURE 55 Analysis chart at 1200 UTC 31 July 2020

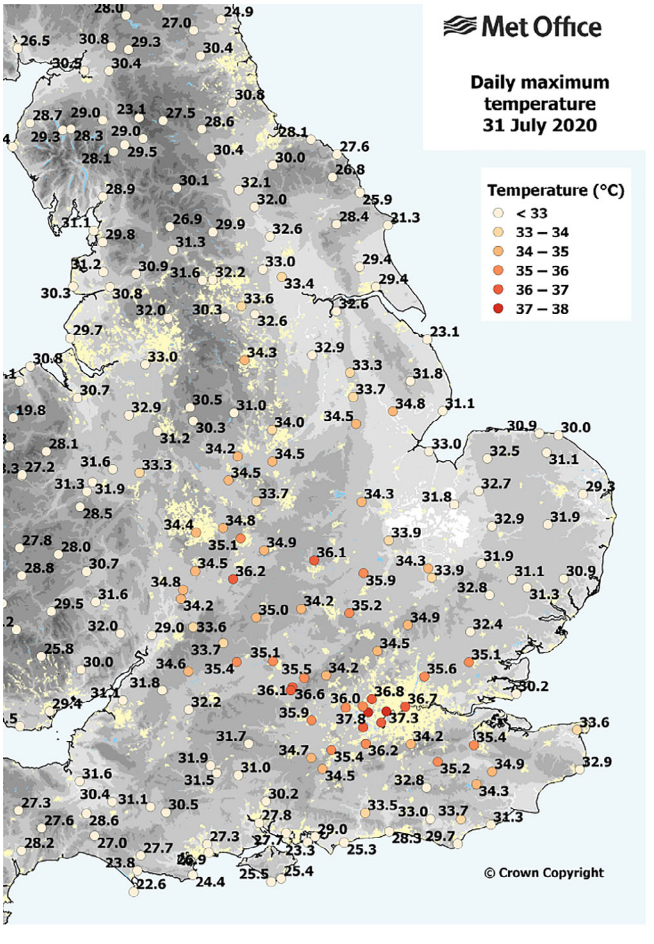


FIGURE 56 Daily maximum temperatures on 31 July 2020

three of the last 20 years 2001–2020, compared to only half of the years from 1961 to 2000 (20 out of 40 years).

The hot weather made conditions difficult for the elderly and vulnerable; Public Health England estimated more than 1,700 excess deaths from this heatwave across England. Many beaches became exceptionally busy—for example, in Sussex and Dorset. Firefighters tackled a large heathland fire in Surrey. The hot weather also saw the development of some impactful thunderstorms. Part of the M25 was closed due to flash-flooding and a train in Kent was evacuated after a landslide. A wooden pavilion in Hampshire caught fire after a suspected lightning strike and there were reports of large hailstones falling.

8.5 | Extreme Norfolk rainfall, 16th August

Thunderstorms affected parts of East Anglia on 16th August. Figure 62 shows some intense downpours across East Anglia with localized rainfall rates exceeding 32 mm per hour. Around 50–100 mm of rain fell locally in an area of Norfolk between Thetford and Norwich, with a rain-gauge in East Wretham recording a remarkable daily total of 239.9 mm. Four unofficial rain-gauges on adjacent farms within a 5 km radius recorded 180 mm or more, while two other rain-gauges in the registered

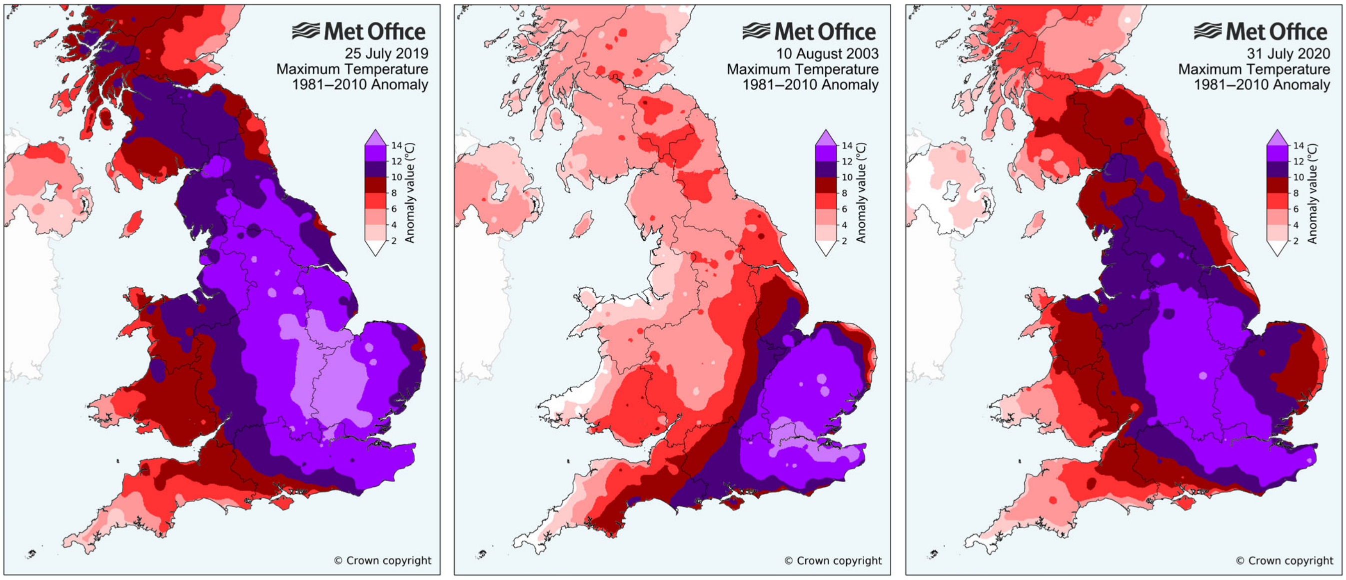


FIGURE 57 Daily maximum temperature anomalies relative to the 1981–2010 July average for the UK's three hottest days on record: 25 July 2019, 10 August 2003 and 31 July 2020

TABLE 8 The UK's six hottest days on record

Date	Daily maximum temperature (°C)	Location
25 July 2019	38.7	Cambridge Botanic Garden
10 August 2003	38.5	Faversham, Kent
31 July 2020	37.8	Heathrow, Greater London
3 August 1990	37.1	Cheltenham, Gloucestershire
1 July 2015	36.7	Heathrow, Greater London
9 August 1911	36.7	Raunds, Northamptonshire, Epsom, Surrey, and Canterbury, Kent

network at Watton and Saham Toney 10 km to the north of East Wretham recorded 147.0 and 139.7 mm, respectively (Figure 63).

The East Wretham rainfall total of 239.9 mm set a new UK August daily rainfall record, exceeding 200.4 mm at Otterham, Cornwall on 16 August 2004 during the extreme Boscastle flooding event. The torrential rainfall caused localized flash-flooding in Watton with several properties affected, and there were other flooding problems more widely across Norfolk from thunderstorms and torrential downpours. However, flood impacts overall from this event were relatively modest and likely to relate to the localized nature of the extreme rainfall, the rural nature of the area and the low-lying topography.

Daily rainfall totals exceeding 200 mm remain relatively rare in the UK and the majority have occurred across upland areas of western Britain—the English Lake District in particular—from prolonged frontal rainfall events in the autumn and winter months. However, it is notable that of around 20 such observations since 1961, almost half have occurred in the most recent decade. Historically, one of the most severe flooding events to affect Norfolk occurred in August 1912, when 180 square miles of East Anglia from the Broads to Wymondham (Norfolk) received more than 175 mm of rain in 48 hr. The 160.3 mm that fell at Norwich on 26 August was reported at the time as the largest amount on record for a rainfall day in eastern England. This event caused widespread flooding and damage across East Anglia (Meteorological Office, 1912; Kendon and Prior, 2011).

8.6 | Storms Ellen and Francis, August

Storms Ellen and Francis in late August were separated by only a few days. They each brought wind gusts of 40–50 Kt across inland areas and 50–60 Kt across exposed coastal locations—particularly affecting Wales and south-west England. Met Eireann issued a red warning for damaging winds across south-west Ireland from storm Ellen. Wind speeds reached 69 Kt (79 mph) at Capel Curig, Conwy during Ellen and 70 Kt (81 mph) at Needles Old Battery (Isle of Wight) from Francis. The analysis charts

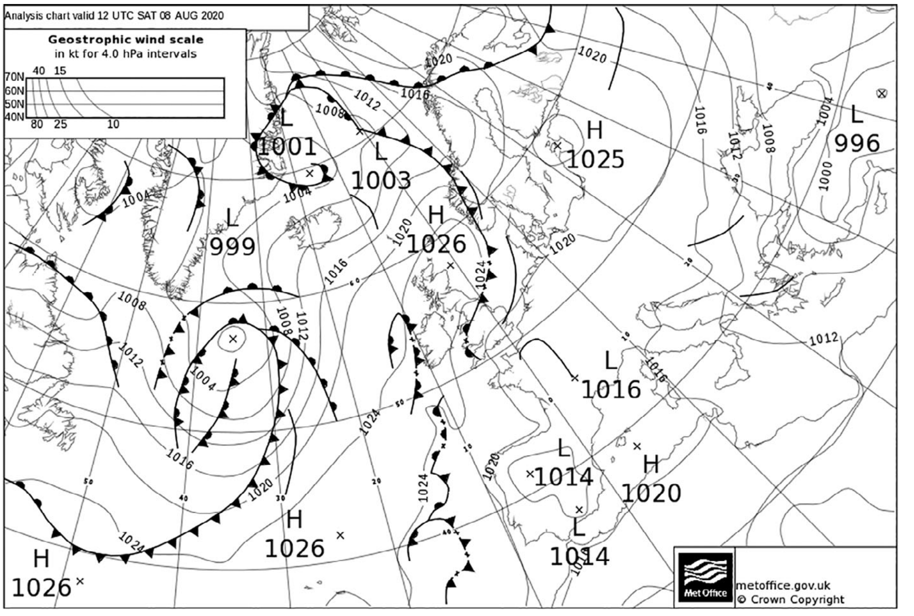


FIGURE 58 Analysis chart at 1200 UTC 8 August 2020

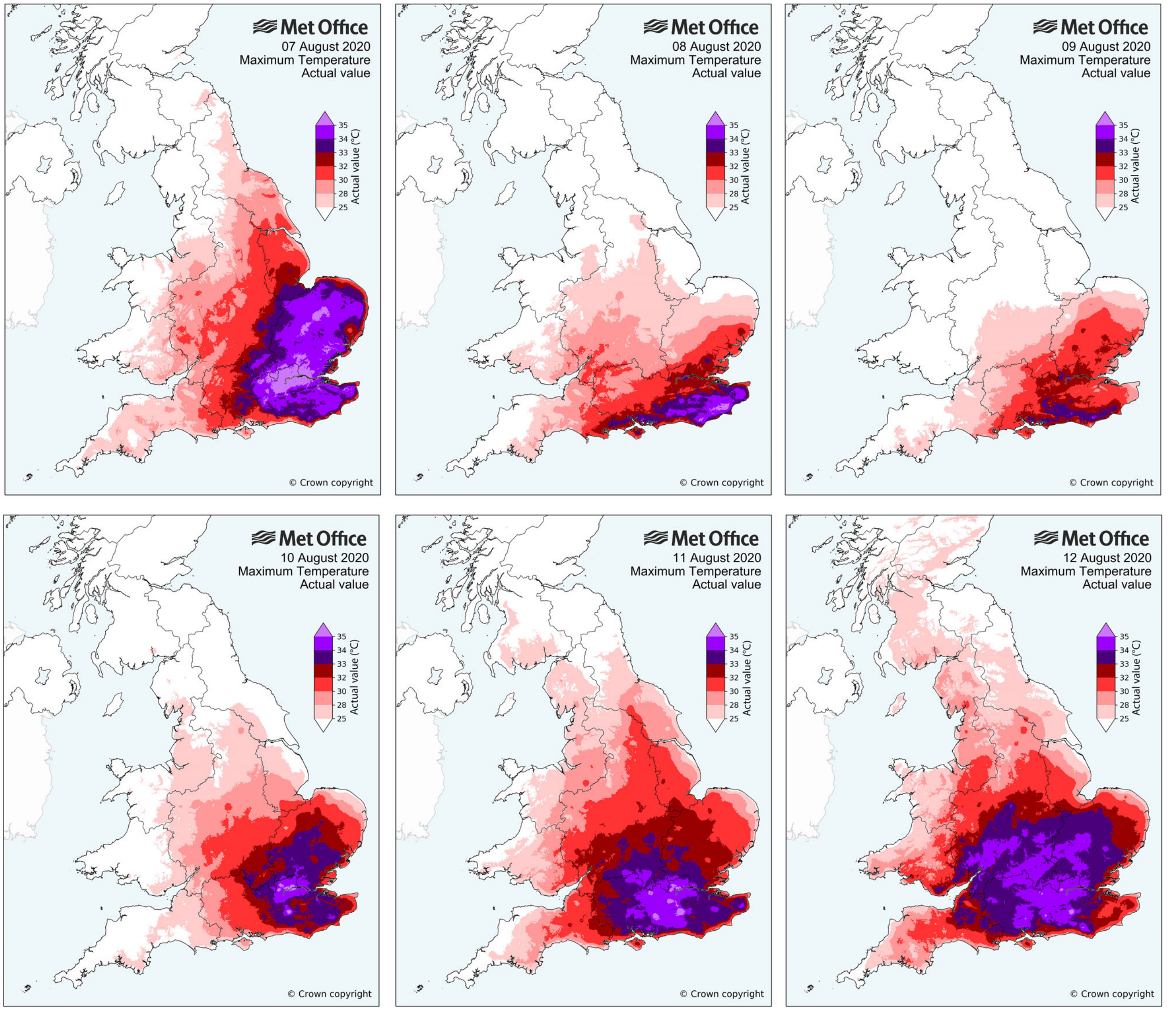


FIGURE 59 Daily maximum temperatures, 7–12 August 2020

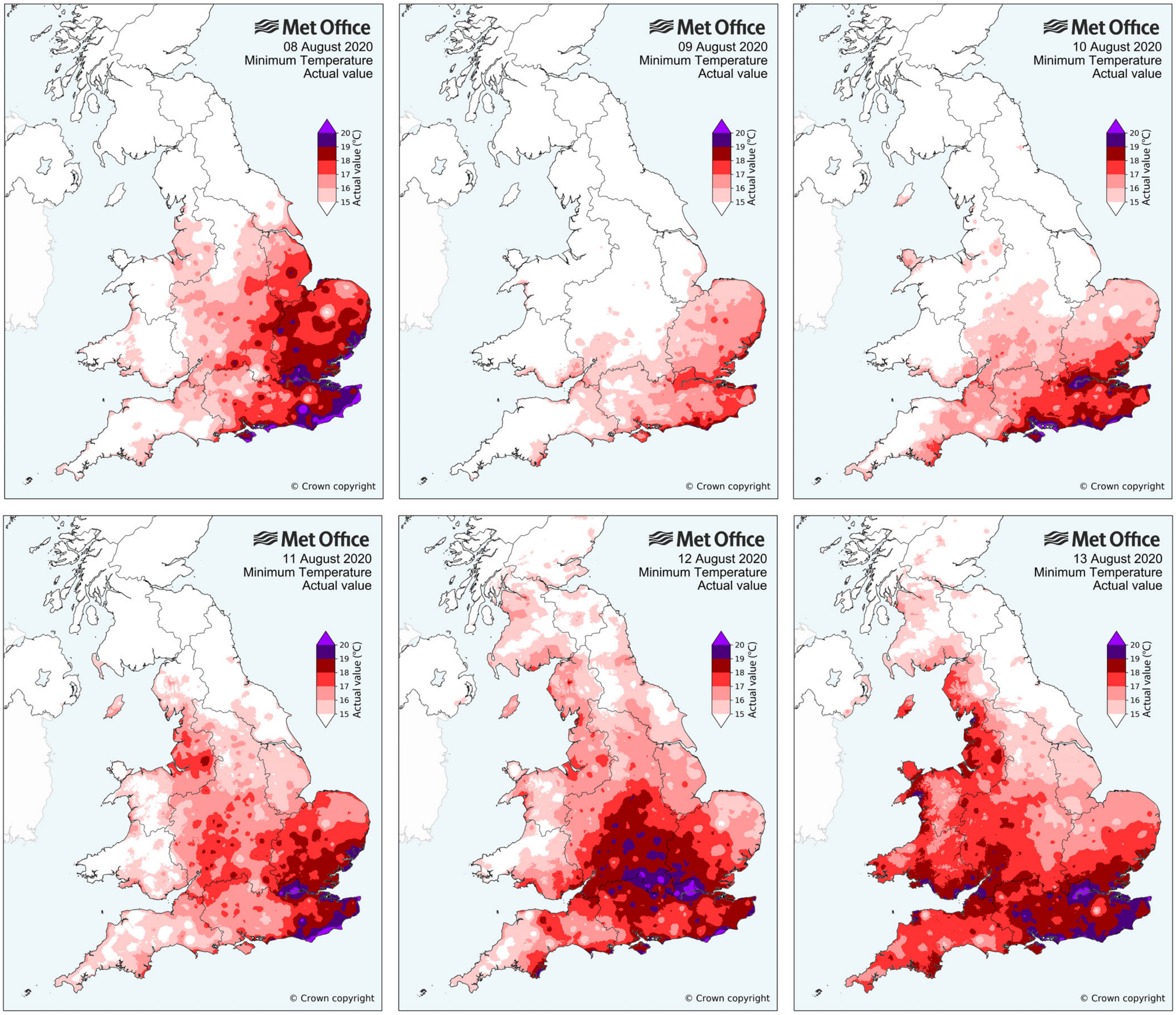


FIGURE 60 Daily minimum temperatures, 8–13 August 2020. The 'patchy' nature of these maps reflects the influence of individual station exposure—particularly the local topography—on minimum temperatures

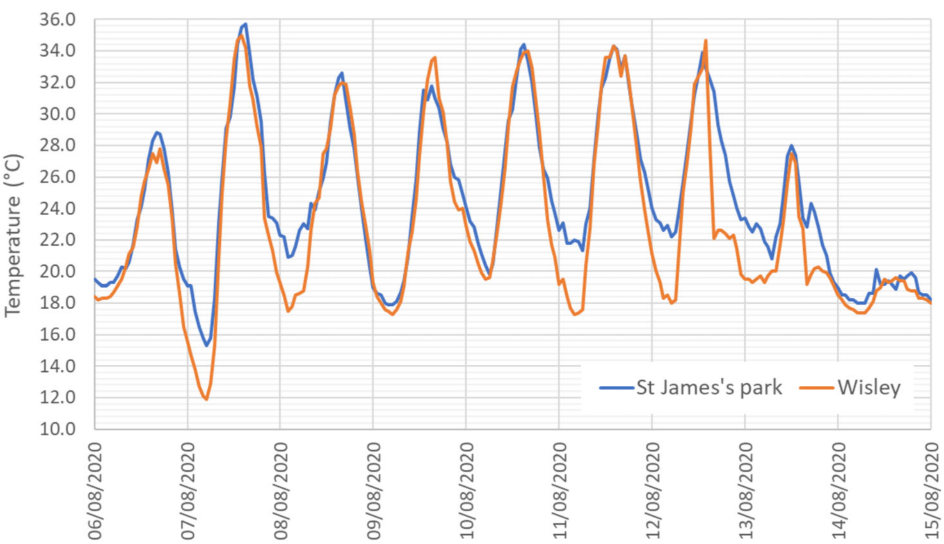


FIGURE 61 Hourly air temperatures at London St James's Park and Wisley, Surrey from 6 to 15 August 2020

for both storms show tightly packed isobars bringing some very strong winds (Figures 64 and 65).

Figure 66 shows hourly maximum gust speeds at three exposed coastal locations, Aberdaron (Lleyn Peninsula), Pembrey Sands (Carmarthenshire) and Needles Old Battery (Isle of Wight). In all three locations gusts of 50–60 Kt or more were recorded during these storms. The spike in wind gusts at around 0000 UTC August 20, 2020 coincided with the red warning across Ireland, ahead of the main passage of Ellen across the UK

Figure 67 lists August storms of the last 50 years, ranked by the number of stations recording gusts exceeding 50 Kt. By this metric, storms Ellen and Francis were ranked in the top 10 most notable August storms of the last 50 years although note that as with Figure 40, the counts have not been adjusted to take into account the changing network size. The most severe of these August storms, the Fastnet Storm occurred on 14 August 1979. Fifteen sailors died in the Fastnet yacht race and there were several other fatalities at sea and on land. Wind gusts reached 65 Kt (75 mph) at Milford Haven, Pembrokeshire and even Northolt, London recorded 52 Kt (60 mph). Another significant storm at this time of year was from the remnants of Hurricane Charley on 25–26 August 1986. This storm did not make landfall over the US but tracked eastwards across the Atlantic towards the UK where strong winds caused damage in addition to exceptionally wet weather across England and Wales. A storm on 30 August 1992 occurred a few days after Hurricane Andrew in the US, with trees brought down in central London and six fatalities. Storms of this severity tend to be more frequent further into autumn, a recent example being storm Ali on 19 September 2018 (Kendon *et al*., 2019)

8.7 | Exceptionally wet day, 3rd October, 2020

Heavy rain from storm Alex affected parts of southern England on 1st October, and more widely on 2nd October before the storm moved south into continental Europe. The following day, 3rd October, was exceptionally wet with another area of low pressure across the UK. Thirty to fifty millimetre fell very widely, significantly more than this in some areas—it is highly unusual for rainfall totals as high as this to be recorded on the same day across such a large spatial extent of the country. The UK recorded 30.0 mm of rain, on average, across the entire UK and this was widely reported in the media at the time as enough rainwater to fill Loch Ness (7.6 cubic kilometres).

A large number of weather stations recorded their wettest October day on record, including several with 100+ year records, and scattered widely across the UK

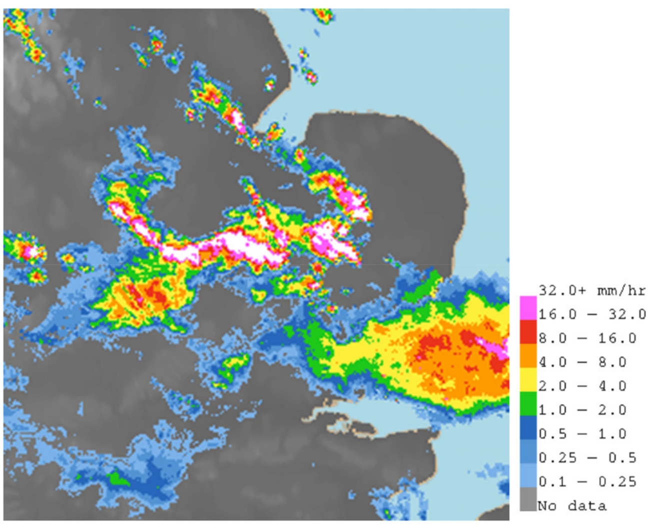


FIGURE 62 UK rain-radar image at 1530 UTC 16 August 2020

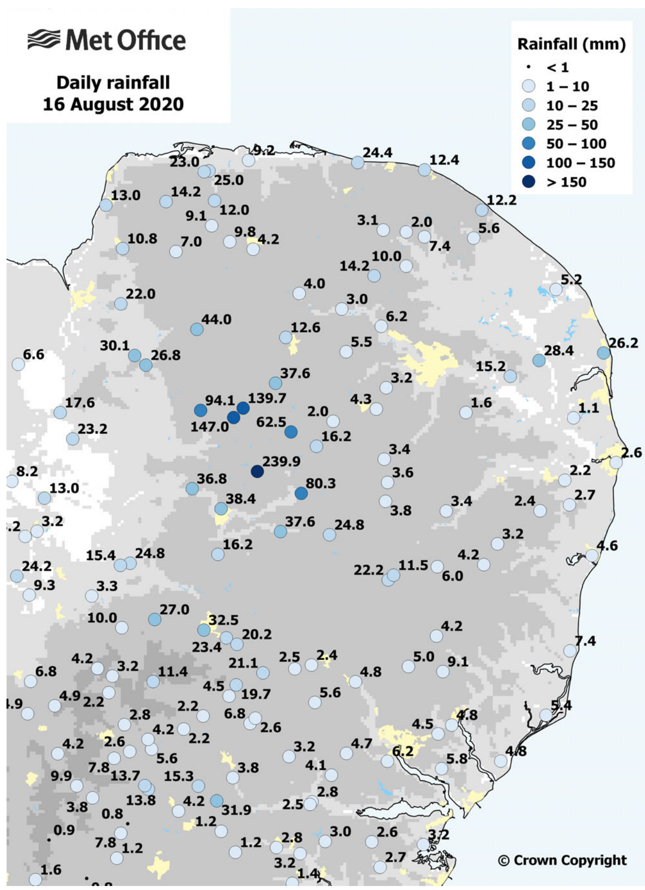


FIGURE 63 Daily rainfall totals 16th August 2020 (09–09 UTC)

from London to the west Midlands to Lancashire to Aberdeenshire (Table 9). At Oxford, 60.0 mm on 3 October made this Oxford's sixth wettest day in almost 200 years daily record (1828), and its wettest day for 47 years (since 67 mm on 27 June 1973). More details of the Oxford series are available in a book on the Oxford weather station (Burt and Burt, 2019).

Year 2020 included two of the three wettest days on record UK-wide (Figure 68). On 25 August 1986—ironically a late-summer bank holiday—there was unusually widespread and heavy rainfall across England and Wales associated with the remnants of Hurricane Charley. In contrast, 15 February 2020—storm Dennis—and 3 October 2020 were both wet, or very wet, across the vast majority of the UK (Kendon and McCarthy, 2021). Remarkably, of the 41 days in the UK area-average daily rainfall series from 1891 where the total has exceeded 20 mm, four have occurred in 2020, also including storm Ciara (8th February) and storm Bella (26th December). Figure 69 shows UK daily rainfall totals for year 2020, including these four dates, with a further high rainfall total from storm Jorge in late February. The two notably wet days in late August 2020 were due to storms Ellen and Francis. Of the 47,000+ days in this series, six

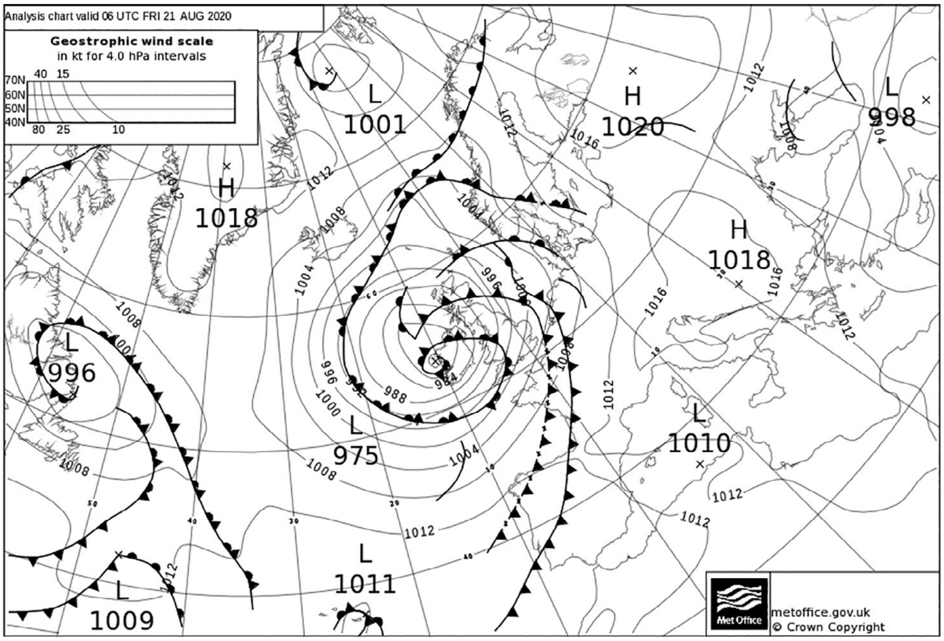


FIGURE 64 Analysis chart at 0600 UTC 21 August 2020

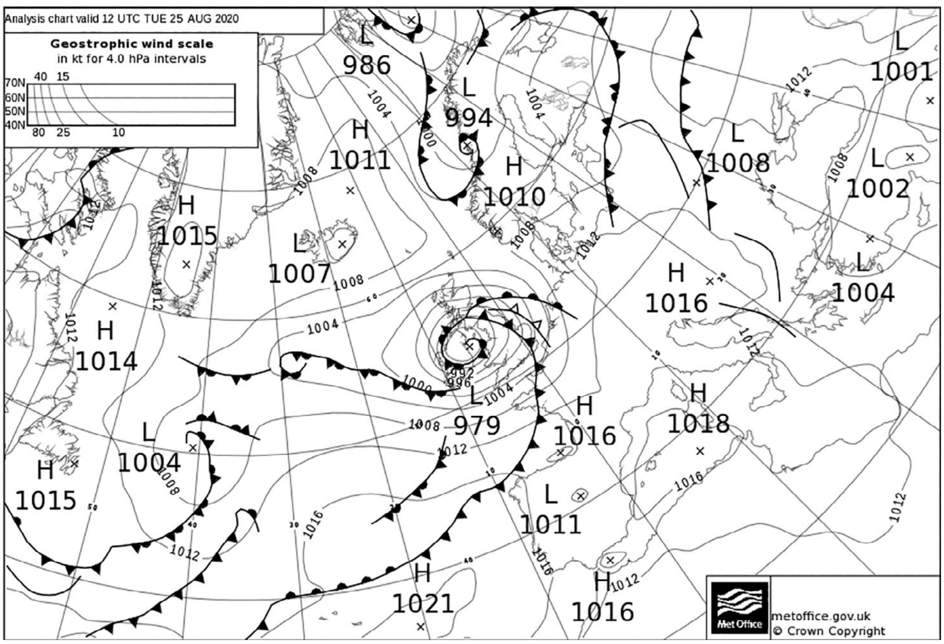


FIGURE 65 Analysis chart at 1200 UTC 25 August 2020

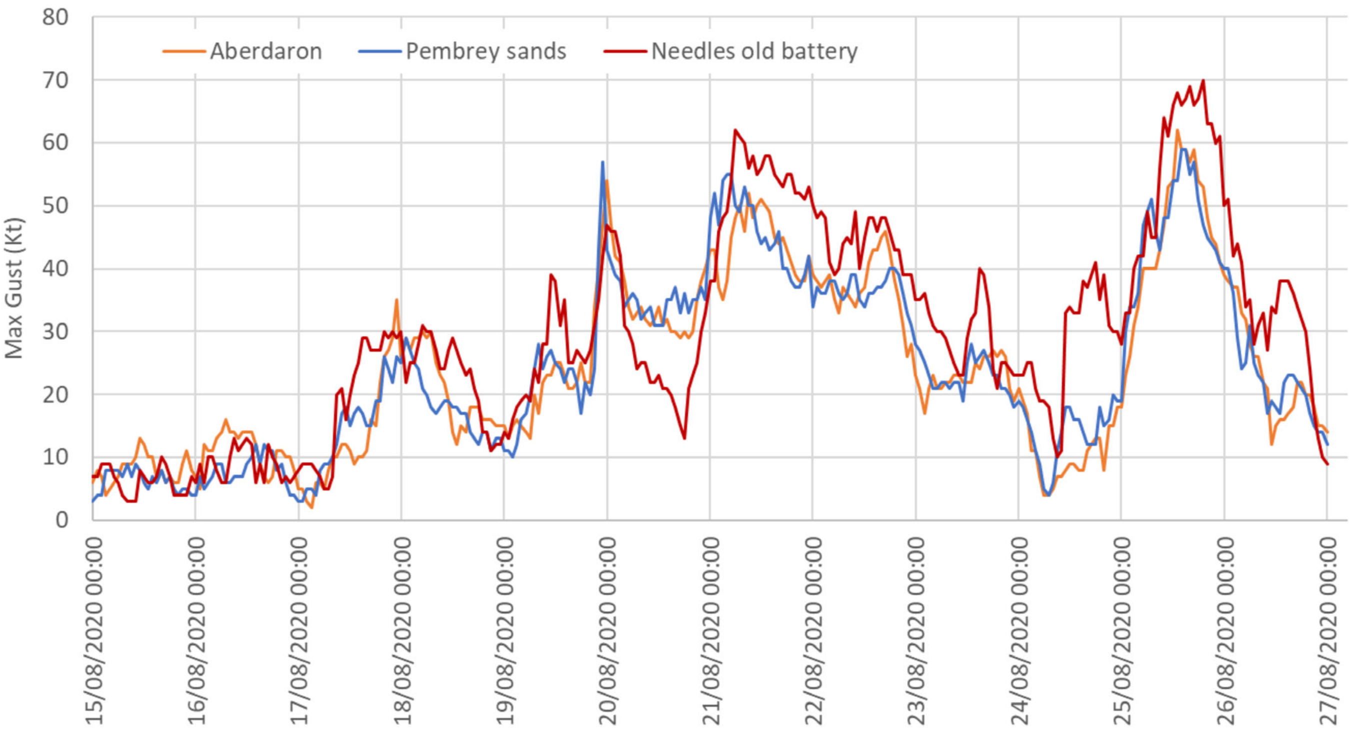
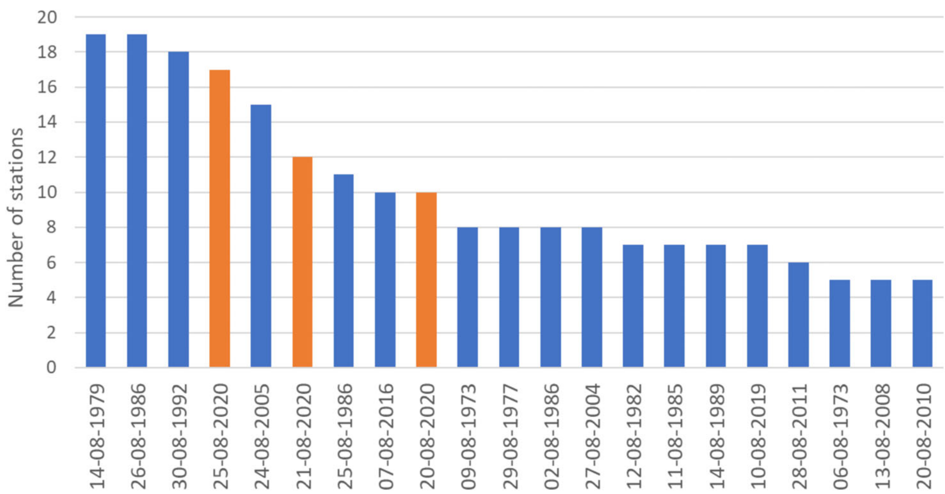


FIGURE 66 Hourly maximum gust speeds at three exposed coastal locations, Aberdaron (Lleyn Peninsula), Pembrey Sands (Carmarthenshire) and Needles Old Battery (Isle of Wight)

FIGURE 67 Count of the number of UK stations by date in August recording gusts ≥50 Kt, based on station data from 1970. The 2020 dates are shown in orange



out of the 20 wettest days, and 25 of the 100 wettest days, have occurred since 2000.

Christidis *et al.* (2021) investigated the role of anthropogenic forcing in influencing the UK's wettest day of the year, with the record rainfall of the wettest day in year 2020 (3 October 2020) estimated to have become about 2.5 times more likely because of human influence on the climate system. However, while they used the full HadUK-Grid daily rainfall series from 1891, they acknowledged the limitations of earlier years in the series due to the much smaller network prior to 1961 (Figure A1.2).

9 | PRELIMINARY 1991–2020 LONG TERM AVERAGES

Year 2020 was the last year of the World Meteorological Organization (WMO) Climatological reference standard normal for the period 1991–2020 (WMO, 2017). Next year's report (2021) will use the official averages for this new 1991–2020 period as the most up-to-date 30-year reference period, replacing 1981–2010. Normals for the period 1961–1990 will be retained for ongoing comparison. The calculation of UK climate long-term averages is

TABLE 9 Daily rainfall totals October 3, 2020 for selected stations

Station	Daily rainfall 3rd October 2020 (mm)	Previous wettest October day (mm)	Date	Record length
Oxford	60.0	49.3	09 October 1875	165
Rothamsted (Hertfordshire)	59.8	55.2	12 October 1993	105
Balmoral (Aberdeenshire)	66.6	53.9	15 October 1976	105
Leuchars (Fife)	60.6	51.2	11 October 2012	98
Wellesbourne (Warwickshire)	48.6	47.4	15 October 2002	65
Benson (Oxfordshire)	43.6	38.8	29 October 2000	65
Preston, Moor Park (Lancashire)	51.6	50.6	27 October 1980	63
London St James's Park	52.4	41.6	15 October 1980	56

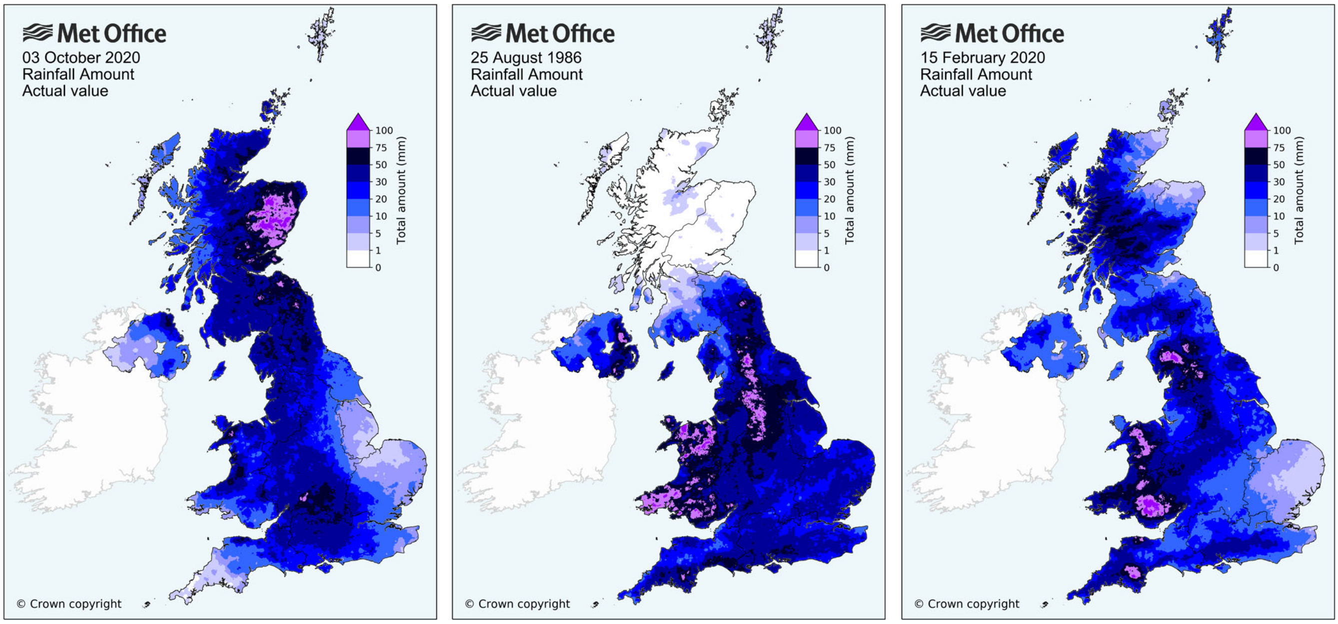


FIGURE 68 UK rainfall totals on 3 October 2020 (30.0 mm), 25 August 1986 (29.9 mm) and 15 February 2020 (27.6 mm). Raindays are 09–09 UTC. Figures in brackets are the UK daily area-average rainfall

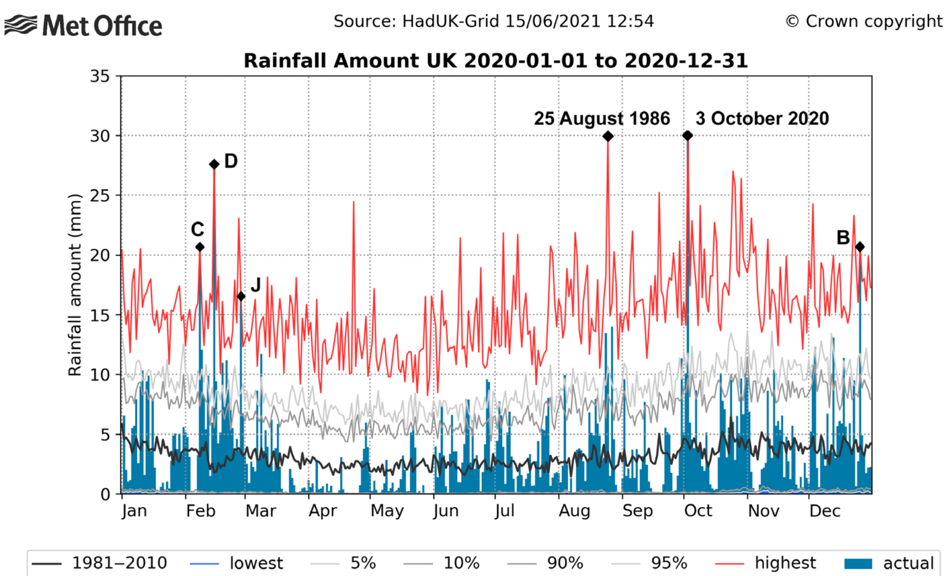


FIGURE 69 UK area-average daily rainfall during 2020. The wettest days are labelled: C—storm Ciara, D—storm Dennis, J—storm Jorge, B—storm Bella, and 3 October 2020. For reference 25 August 25 1986 is also shown

TABLE 10 Preliminary monthly, seasonal and annual T_{mean} 1991–2020 long term averages difference (°C) from 1961–1990 and 1981–2010 for the UK and countries

Period	Difference from 1961–1990 (°C) UK	England	Wales	Scotland	N. Ireland	Difference from 1981–2020 (°C) UK	England	Wales	Scotland	N. Ireland
January	1.0	1.0	0.9	0.9	0.8	0.3	0.3	0.3	0.3	0.2
February	1.2	1.3	1.2	1.2	1.0	0.5	0.5	0.5	0.4	0.4
March	1.1	1.2	1.0	0.9	0.8	0.2	0.2	0.2	0.3	0.1
April	1.2	1.3	1.2	1.1	0.9	0.5	0.5	0.5	0.4	0.3
May	0.9	1.0	1.0	0.8	0.9	0.3	0.3	0.3	0.3	0.3
June	0.7	0.8	0.8	0.5	0.6	0.3	0.3	0.3	0.3	0.3
July	0.9	1.0	0.7	0.9	0.7	0.2	0.2	0.1	0.1	0.1
August	0.9	1.0	0.8	0.8	0.7	0.2	0.2	0.2	0.2	0.2
September	0.8	0.7	0.7	0.8	0.7	0.3	0.2	0.2	0.4	0.2
October	0.3	0.4	0.4	0.2	0.1	0.3	0.3	0.3	0.3	0.2
November	1.0	1.0	0.9	1.0	0.9	0.3	0.3	0.3	0.3	0.2
December	0.4	0.5	0.5	0.3	0.2	0.3	0.4	0.4	0.3	0.2
Winter	0.8	0.9	0.9	0.8	0.7	0.4	0.4	0.4	0.4	0.3
Spring	1.0	1.1	1.1	0.9	0.9	0.3	0.3	0.3	0.3	0.3
Summer	0.8	0.9	0.8	0.7	0.7	0.2	0.2	0.2	0.2	0.2
Autumn	0.7	0.7	0.7	0.7	0.6	0.3	0.3	0.3	0.3	0.2
Year	0.9	0.9	0.8	0.8	0.7	0.3	0.3	0.3	0.3	0.2

Colour key				
	X >0.95°C	0.95°C > X > 0.45°C	0.45°C > X > 0.25°C	X <0.25°C

Note: Differences are calculated based on unrounded values, before rounding is applied.

a multi-step process requiring all station data to be received and quality controlled for 2020 before averages are calculated by gridding these station long term average data.

Tables 10 and 11 present the difference between the 1991 and 2020 preliminary long-term averages against 1961–1990 and 1981–2010 for Tmean and rainfall and Figures 70 and 71 show the mapped differences in annual averages. These preliminary averages are calculated as an average of the 30 monthly, seasonal and annual area-average values for the UK and countries. These preliminary averages allow key changes from the earlier baseline reference periods to be identified, since any differences between the preliminary and final long-term average values are likely to be small.

The averaging period 1991–2020 is entirely independent of the earlier period 1961–1990, whereas it is not independent of 1981–2010 since it shares two decades in common—1991–2010—with 1981–1990 being dropped and 2011–2020 added. Consequently the difference between 1991–2020 and 1981–2010 will be very much less than the difference between 1991–2020 and 1961–1990. Changes in the long-term averages between these reference periods, particularly 1981–2010, reflect the variability of the UK's climate—that is, annual and decadal variability and whether extreme months, seasons or years happen to be dropped or added. However, they also provide a clear indication of the changing nature of the UK's climate, especially for temperature, where the trend is much more apparent compared to this variability, than it is for rainfall.

The UK's annual mean temperature has increased by 0.9°C when comparing 1991–2020 against 1961–1990. All months and seasons have seen an increase across all countries. The greatest increases of over 1.0°C have been in the spring months across England and Wales. The smallest increases have been in October and December (the latter e.g., influenced by the exceptionally cold December 2010). The UK annual mean temperature has increased by 0.3°C when comparing 1991–2020 against 1981–2010. This is broadly consistent since 0.9°C over 30 years represents approximately 0.3°C per decade, that is, the relatively rapid rate at which the UK's climate has warmed over this period. Again, all months and seasons

TABLE 11 Preliminary monthly, seasonal and annual rainfall 1991–2020 long term averages percentage difference from 1961–1990 to 1981–2010 for the UK and countries

	Difference from 1961 to 1990 (%)					Difference from 1981 to 2020 (%)				
Period	**UK**	**England**	**Wales**	**Scotland**	**N. Ireland**	**UK**	**England**	**Wales**	**Scotland**	**N. Ireland**
January	8	3	3	15	−1	0	0	−1	1	−1
February	22	14	14	33	13	9	10	8	9	9
March	−8	−13	−9	−3	−5	−10	−9	−12	−11	−9
April	7	0	3	15	11	−1	−4	−2	3	−1
May	−1	−4	0	3	1	2	−2	1	6	2
June	8	7	10	8	11	5	5	7	5	7
July	12	13	18	8	25	6	6	6	5	10
August	3	4	1	2	4	5	8	4	3	2
September	−10	−4	−9	−14	−13	−5	−2	−5	−9	−4
October	10	17	9	6	−1	−3	−1	−7	−4	−4
November	9	12	7	5	14	2	5	0	0	9
December	10	9	7	12	10	6	6	6	7	6
Winter	12	7	7	18	6	5	4	3	5	4
Spring	−1	−6	−3	4	2	−4	−5	−5	−3	−3
Summer	7	8	9	6	12	5	6	6	4	6
Autumn	3	9	3	−1	1	−2	1	−4	−4	0
Year	6	5	4	7	5	1	2	0	1	2

Colour key					
	$X > 9.5\%$	$9.5\% > X > 4.5\%$	$4.5\% > X > -4.5\%$	$-4.5\% > X > -9.5\%$	$X < -9.5\%$

Note: Percentages are based on unrounded values, before rounding is applied.

have seen an increase across all countries, with the largest increase in February and April across England and Wales. The greatest warming in annual mean temperature relative to 1961–1990 has been by more than 1°C across the east Midlands and East Anglia, with the least warming around western coastal fringes and parts of Northern Ireland and Scotland. Warming has been relatively uniform relative to 1981–2010 across the UK; but slightly lower across south-west England and Northern Ireland.

The UK's annual average rainfall has increased by 6% when comparing 1991–2020 against 1961–1990. The periods October to February and June/July have increased—resulting in an increase in winter (12%) and summer (7%)—whereas March and September have decreased by around 10%—with little change in spring and autumn overall. Individual extreme months—such as December 2015, June 2012 or February 2020 are likely to have had a significant influence on these statistics. Remarkably, Scotland's average February rainfall has increased by a third from 1961–1990 to 1991–2020—although it is possible that this may reflect difficulties in accurately observing precipitation falling as snow (which would have been a more common occurrence for the earlier period). The overall increase in UK annual rainfall may reflect long-term trends in the UK's rainfall, however, there is a large decadal variability in the UK series and the period 1961–1990 is relatively dry (Figure 25). In contrast, the UK's annual average rainfall has only seen a very small increase compared to 1981–2010. Rainfall has increased in February, June to August and December but decreased in March and September.

The largest increases in annual average rainfall of more than 10% compared to 1961–1990 have mostly been across Scotland, although most of the UK has become wetter. The difference from 1981–2010 is generally much less—with some slight reductions in a few locations, such as parts of northern Scotland. The relatively speckled characteristic of the maps may be related to the different order of the calculation for the preliminary 1991–2020 averages. (These preliminary averages are calculated from the 30 monthly, seasonal or annual area-average

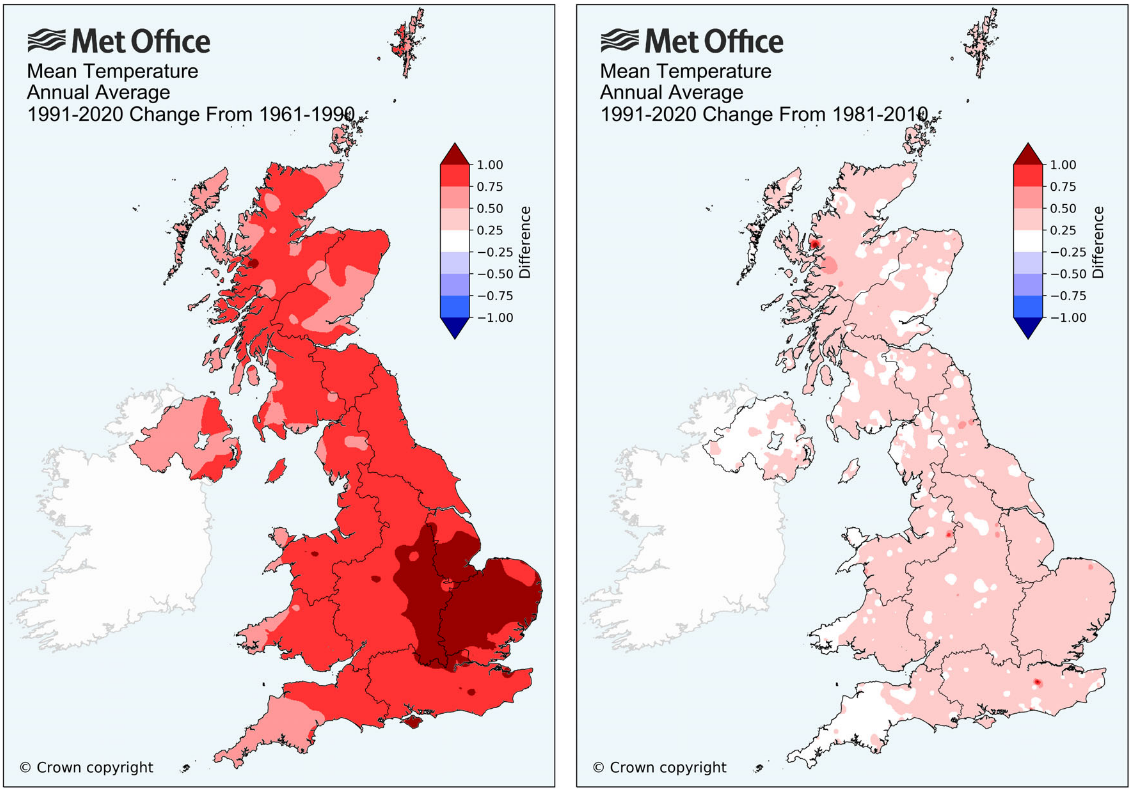


FIGURE 70 Difference (°C) between preliminary 1991–2020 annual average T_{mean} and earlier periods 1961–1990 and 1981–2010

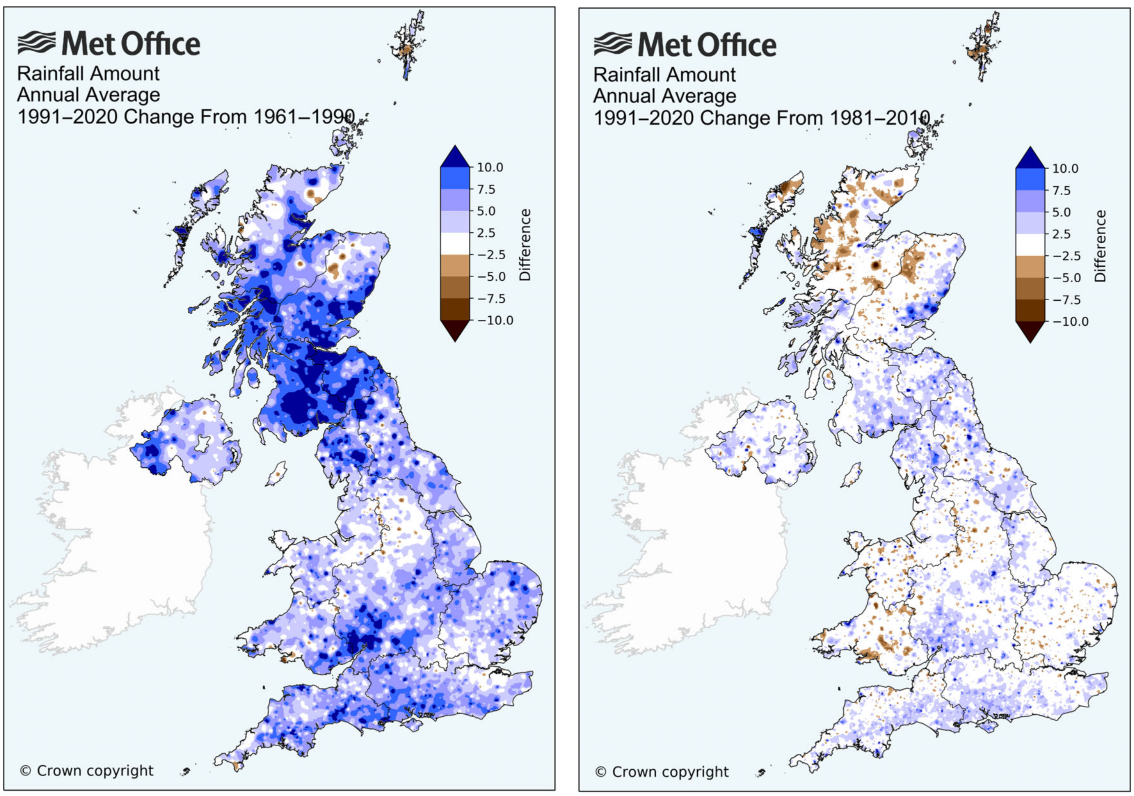


FIGURE 71 Difference (%) between preliminary 1991–2020 annual average rainfall and earlier periods 1961–1990 and 1981–2010

values whereas final averages will be calculated as area-average values from long-term average grids). However, the varying network of stations through the period may also be a factor, since over this duration, even relatively small factors affecting exposure of individual stations may have an influence. Fundamentally, a degree of noise is inevitable in these maps as rainfall has a much greater spatial variability than temperature.

In summary, the UK has been wetter through the period 1991–2020 compared to 1961–1990, but there is little difference from 1981–2010 for the year overall—but with considerable variation through the months and seasons and some small-scale local variations.

10 | PHENOLOGY

Changes in phenology (recurring events in nature and their relationships with climate) provide a wide range of information about the health and functioning of plants and ecosystems, and their responses to climate. Sparks and Collinson (2008) provided a brief history of phenological recording in the UK. Here, we present average UK changes in two phenological indicators—first leaf and bare tree dates. These provide an indication of changes in the timing of nature's response to spring and autumn, and therefore also the length of the growing season. Elder and Hawthorn are typically the earliest to unfold their leaves (in mid- to late-March), followed, about 1 month later, by Silver Birch and Oak. In comparison, bare tree dates for these species are more condensed, typically occurring between mid-to late-November. There is a weak positive correlation between national growing degree day estimates (Section 2.2) and the first leaf to bare tree interval for oak. This, and the potential for a link with national growing season length estimates, merits further investigation, although the national-scale statistics presented in this report will inevitably mask the complexity of factors affecting the phenological data presented in this report.

2020 was a year of notably early first leaf dates and also earlier bare tree dates across the UK of four common shrub/tree species: Elder, Hawthorn, Silver Birch and Pedunculate Oak, relative to the 1999–2019 baseline period (Figure 72, Table 12). Elder first leaf was the earliest in its series (15.9 days earlier than the baseline) and actually occurred in late February. Oak first leaf was also the earliest in its series (8.9 days earlier than the baseline). The early first leaf dates were associated with generally mild conditions through January and February and some notable warmth and sunshine in April. Bare tree dates were 3–5 days earlier than the baseline, but overall

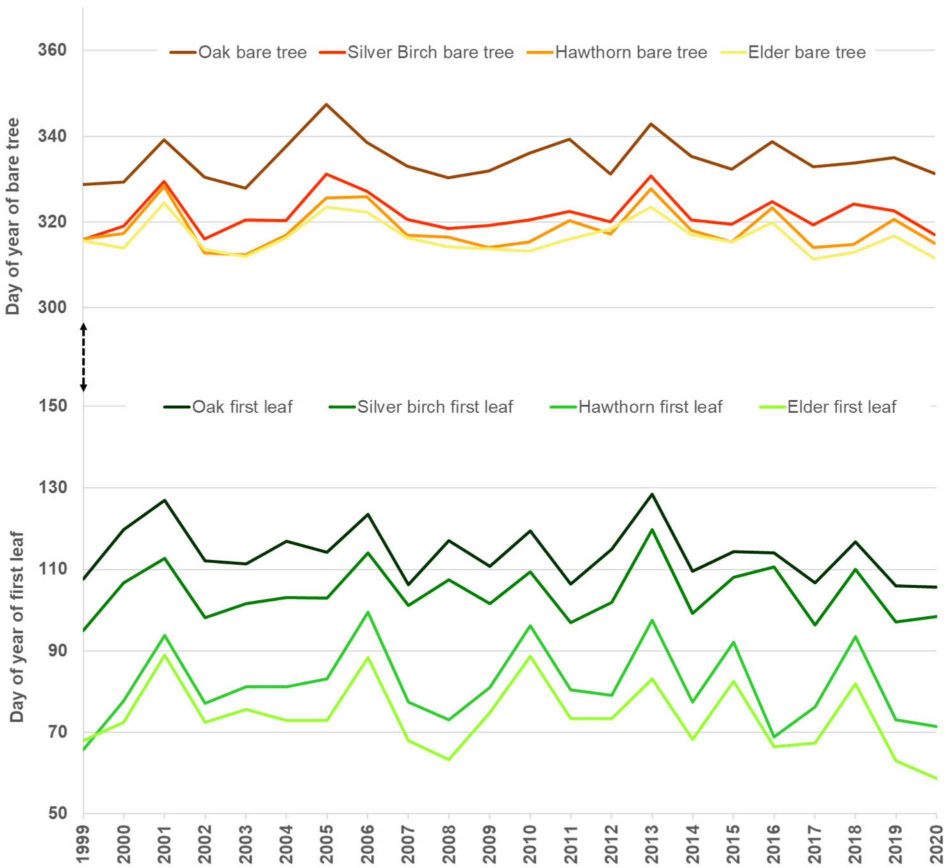


FIGURE 72 Mean day of year of first leaf and bare tree phenology indicators for four common shrub or tree species: Elder, Hawthorn, Silver Birch and Oak, derived from UK observations contributed to Nature's Calendar from 1999 to 2020

TABLE 12 Mean date of first leaf and bare tree phenology indicators for four common shrub or tree species: Elder, Hawthorn, Silver Birch and Oak, derived from UK observations contributed to Nature's Calendar from 1999 to 2020

	Elder	Hawthorn	Silver Birch	Oak
Mean first leaf date 1999–2019	15 March	23 March	14 April	24 April
2020 mean first leaf relative to 1999–2019	−15.9	−10.8	−6.1	−8.9
Mean first leaf response to a 1°C increase in <month below>	−6.4	−6.4	−6.0	−5.9
Month(s)	January/February	February/March	March/April	March/April
Mean bare tree date 1999–2019	12 November	14 November	18 November	30 November
2020 mean bare tree date relative to 1999–2019	−5.0	−3.5	−5.0	−3.5
Mean bare tree response to a 1°C increase in <month below>	+2.0	+2.6	+2.3	+2.8
Month(s)	October	October	October	October

Note: Columns show the mean dates for the 1999–2019 period, the anomaly in days for 2020 relative to 1999–2019, the temperature response (days change per °C: −ve earlier, +ve later) and months of maximum temperature sensitivity.

the leaf-on season was about 6 days longer than the baseline because of the greater advance in spring. First leaf responses to temperature for the four species were around 6 days earlier for every 1°C increase in mean temperature of the 2 months prior to the month of mean first leaf. In contrast, tree bare dates in autumn typically showed a response of about 2–3 days later for every 1°C increase in October temperature.

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APPENDIX: APPENDICES—STATE OF THE UK CLIMATE 2020

These appendices provide information about the underlying datasets used in this report. Much of the content is repeated from previous reports, with only minor updates, but the appendices are included here in full for reference. Brief sections on sea surface temperature and wind have been added.

ANNEX 1: DATASETS 1

NAO index

The Winter North Atlantic Oscillation (WNAO) index is traditionally defined as the normalized pressure difference between the Azores and Iceland. This represents the principal mode of spatial variability of atmospheric pressure patterns in the North Atlantic. The WNAO index presented in this report is an extended version of this index based on a series maintained by the University of East Anglia Climatic Research Unit, using data from stations in Gibraltar and south-west Iceland (Jones *et al.*, 1997). These two sites are located close to the centres of action that comprise the WNAO. Data from these stations have been used to create homogeneous pressure series at the two locations which extend back to 1821. The WNAO index in this report is based on these data and presented back to 1850, with winter defined as December to February, to provide consistency with winter statistics presented elsewhere in this report.

For the UK, a positive WNAO index tends to be associated with higher temperatures and higher rainfall (R^2 values of .56 for winter mean temperature and 0.30 for winter rainfall based on years 1885–2020 and 1863–2020, respectively, see Annex 2). This means that over half of the annual variability for UK winter mean temperature and almost a third for rainfall may be associated with the WNAO. Importantly, however, it also implies that the WNAO is unable to fully explain the variability of UK winters because the complexity of weather types and associated temperature and rainfall patterns through the season cannot be fully accounted for by this single index. This is because other modes of spatial variability in atmospheric pressure patterns also affect the UK's weather. For example, the East Atlantic (EA) and Scandinavian (SCA) patterns—the second and third modes of spatial variability represented in their positive phases by low pressure to the west of Ireland and high pressure over Scandinavia, respectively—also exert an influence (Hall and Hanna, 2018). The influence of WNAO may also differ regionally across the UK, for example, for rainfall across the north-west compared to the south-east, which overall UK rainfall statistics will tend to smooth out (West *et al.*, 2018).

The centres of action that define the summer NAO (SNAO) correspond to grid-point pairs 60N, 5E and 80N, 50W—corresponding to locations to the east of the Shetland Islands and in north-west Greenland, respectively These locations reflect the smaller spatial scale and a more northerly location of the summer Atlantic storm track (Folland *et al.*, 2009). Due to the location of these points a station-based SNAO series cannot be used. Instead, the SNAO index has been calculated from the Met Office Hadley Centre's sea-level pressure dataset, HadSLP2 (Allan and Ansell, 2006) and extended to the present day using the NCEP reanalysis (Kalnay *et al.*, 1996). The index is calculated as the difference in seasonal mean sea-level pressure between these grid-point pairs for each year from 1850 to 2020 inclusive. Summer is defined as June, July and August to provide consistency with summer statistics presented elsewhere in the report. Note this SNAO definition differs from Folland *et al.* (2009) which uses July and August only. For the UK, a positive SNAO tends to be associated with higher temperatures and lower rainfall (R^2 values of .27 for summer mean temperature and 0.45 for summer rainfall based on years 1884–2020 and 1862–2020, respectively).

HadSLP2 is a global dataset of monthly mean sea-level pressure on a 5° latitude–longitude grid from 1850 to date. The dataset is derived from a combination of marine observations from ICOADS (International Comprehensive Ocean-Atmosphere Data Set) and land (terrestrial and island) observations from over 2000 stations around the globe. The dataset has a step change in variance in the mid-2000s, with an increased variance after this relating to when real-time updates from the NCEP reanalysis fields started.

Monthly, daily and annual grids

The principal source of data in this report is the HadUK-Grid dataset, comprising monthly and daily gridded data covering the UK (Hollis *et al.*, 2019). The primary purpose of these data are to facilitate monitoring of UK climate and research into climate change, impacts and adaptation. All gridded data are at 1 km resolution. The grids are based on the GB national grid, extended to cover Northern Ireland and the Isle of Man, but excluding the Channel Islands. This dataset is updated annually. This report uses version 1.0.3.0 of the dataset. The previous version 1.0.2.0 was used in the State of the UK Climate 2019 report (Kendon *et al.*, 2020), with version 1.0.2.1 released in November 2019.

Table A1.1 shows the monthly and daily grids from HadUK-Grid used for this report, including the year from

TABLE A1.1 Monthly and daily variables presented in this report, gridded over the UK at 1 km resolution

Climate variable	Definition	First year available	Gridding time-scale
Max air temperature	Monthly average of daily max air temperatures °C	1884	Monthly
Min air temperature	Monthly average of daily min air temperatures °C	1884	Monthly
Mean air temperature	Monthly average of mean daily max and mean daily min air temperatures °C	1884	Monthly
Days of air frost	Count of days when the min air temperature is below 0°C	1960	Monthly[a]
Days of ground frost	Count of days when the grass min air temperature is below 0°C	1961	Monthly
Heating degree days	Day-by-day sum of number of degrees by which the mean temperature is less than 15.5°C	1960	Annual[b]
Cooling degree days	Day-by-day sum of number of degrees by which the mean temperature is more than 22°C	1960	Annual[b]
Growing degree days	Day-by-day sum of number of degrees by which the mean temperature is more than 5.5°C	1960	Annual[b]
Precipitation	Total monthly precipitation amount (mm)	1862	Monthly
Days of rain ≥1 mm	Number of days with ≥1 mm precipitation	1891	Monthly[a]
Days of rain ≥10 mm	Number of days with ≥10 mm precipitation	1891	Monthly[a]
Rainfall intensity	Total precipitation on days with ≥1 mm divided by the count of days with ≥1 mm during the year	1891	Annual[b]
Sunshine	Total hours of bright sunshine during the month based on the Campbell–Stokes recorder	1919	Monthly
Max air temperature	Daily max air temperatures °C	1960	Daily
Min air temperature	Daily min air temperatures °C	1960	Daily
Precipitation	Daily precipitation amount (mm)	1891	Daily

Note: The table also includes monthly and annual grids derived from daily grids.
[a]Monthly grids derived from daily grids.
[b]Annual grids derived from daily grids.

which variables are available. Derived annual grids are also included. The 1 km resolution provides a level of detail that can reasonably represent smaller-scale local features of the UK's climate—although inevitably this will always be constrained by the limitations of the underlying station network data and so micro-climate effects may not necessarily be captured. The 1 km resolution can also be used to explore uncertainties in the gridding methods, and facilitates re-gridding to new high-resolution climate model resolutions.

The principal source of UK station data is the Met Office Integrated Data Archive System (MIDAS) Land and Marine Surface Stations Database, but this has been supplemented by further recently digitized historic data from multiple sources including British Rainfall and Met Office Monthly and Daily Weather Reports; in total several million additional daily and monthly observations of temperature, rainfall and sunshine from up to 190 stations. These additional historical data have allowed monthly temperature to extend back to 1884, monthly rainfall back to 1862, monthly sunshine back to 1919, and daily rainfall back to 1891. The extension of these gridded datasets back to the late 19th century provides an invaluable longer-term context for the interpretation of the time-series and variability of the UK's climate.

The HadUK-Grid data extraction and gridding process has been carried out in a single batch process. Generating the entire dataset in this way using a single process through a managed code base in a consistent manner eliminates the possibility of inhomogeneities being inadvertently introduced by changes in the processing chain over a period of several decades, potentially introducing non-climatic changes to the resulting dataset.

Daily maxtemp, mintemp and rainfall grids of the UK have also been generated. Daily temperature has been gridded back to 1960, with daily rainfall back to 1891 as described above. With daily data there is often a weaker link between the data and the geographical factors which shape the average over a longer time-scale. Metrics in this report based on the daily rainfall grids are only presented from 1961, even though these grids extend back to 1891. This is because of the step-change in station network density in 1961 (Figure A1.2). The smaller number of stations before this date means that further work is needed to determine the extent to which any trends in metrics in earlier years are influenced by the relatively low station network density.

Several of the monthly climate variables (days of air frost, days of rain ≥1 mm and days of rain ≥10 mm) have been derived from the daily grids (daily mintemp and daily rainfall, respectively) rather than gridded from monthly station values directly. This approach has the advantage of ensuring that these monthly variables are consistent with the daily grids on which they are based (which would not be the case if they were gridded from station data). Because the gridding is at a daily timescale, we also anticipate that there will be a better overall representation of spatial variation in these monthly derived variables, although this is subject to ongoing research. Annual degree-day and rainfall intensity grids have also been derived from daily temperature and daily rainfall grids, respectively. In contrast, monthly temperature and rainfall grids are gridded separately from station data, rather than being derived from daily temperature and rainfall grids. This means that they are not exactly consistent (indeed observations from monthly rain-gauges can only go into the monthly rainfall grids)—but in general differences are small.

The network used for gridding for each variable changes each month. A key aim of the gridding process is to remove the impact of these changes in the distribution of stations on the climate monitoring statistics. This could be overcome by only using stations with a complete record, but the sparseness of such stations would introduce much greater uncertainty due to the spatial interpolation required. Instead, all stations believed to have a good record in any month are used, and every effort made to compensate for missing stations during the gridding process reducing uncertainty by maximizing the number of observations used.

Figures A1.1–A1.3 show the number of stations used for creating monthly and daily grids for each of the variables. For monthly temperature, the number of stations varies from fewer than 100 for the period 1884–1900, increasing to between 200 and 400 from the 1910s to 1950s and reaching a peak of over 500 stations from the 1960s to 1990s, followed by a subsequent decline to below 400 stations in the most recent decade. The number of stations recording monthly days of ground frost (i.e., with a grass minimum thermometer) is typically around 100 fewer than air temperature from the 1960s onwards. The number of monthly sunshine stations rises from around 150 to almost 400 from the 1920s to 1970, followed by a steady decline to around 100 stations in the most recent decade (Figure A1.1). The number of stations for rainfall shows a fairly steady increase from fewer than 100 in the 1860s to over 800 in the late 1950s (Figure A1.2a), followed by a step-change to over 4,000 stations from 1961 and a peak of over 5,500 stations in the mid-1970s, with a subsequent steady decline to fewer than 3,000 in the most recent decade (Figure A1.2b).

As would be expected the number of stations for daily temperature over the period 1960–2020 matches that for monthly temperature (Figure A1.3). However, the number of daily rainfall stations is significantly fewer than for monthly rainfall. This may be partly accounted for where some rainfall data has only been digitized at monthly timescales (e.g., from the British Rainfall publications), and in addition due to the presence of some monthly rain-gauges in the network, principally across upland areas of the UK (Figure A1.2).

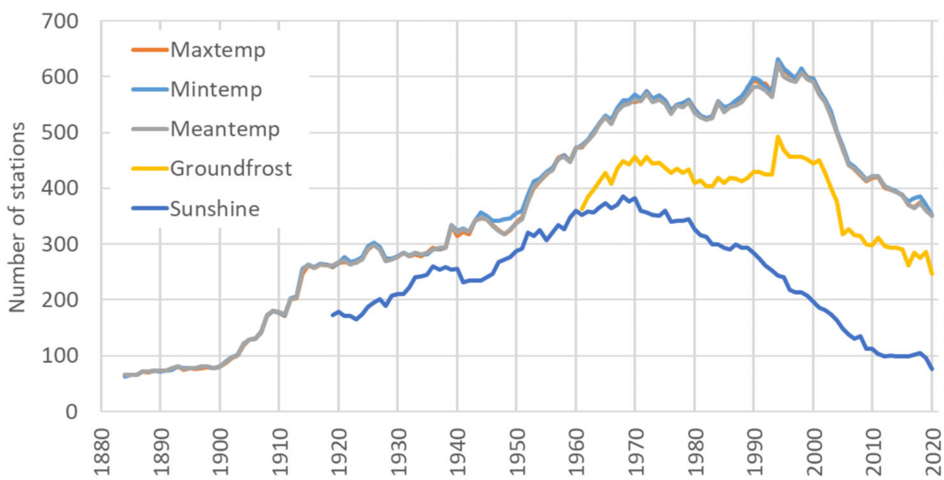


FIGURE A1.1 Number of stations used for gridding—Monthly maxtemp, mintemp, meantemp (1884–2020), days of ground frost (1961–2020) and monthly sunshine (1919–2020)

FIGURE A1.2 Number of stations used for monthly/daily rainfall (a) 1862/1891–2020 and (b) 1862/1891–1960, with the step change from <1,000 stations to >4,000 stations occurring in 1961

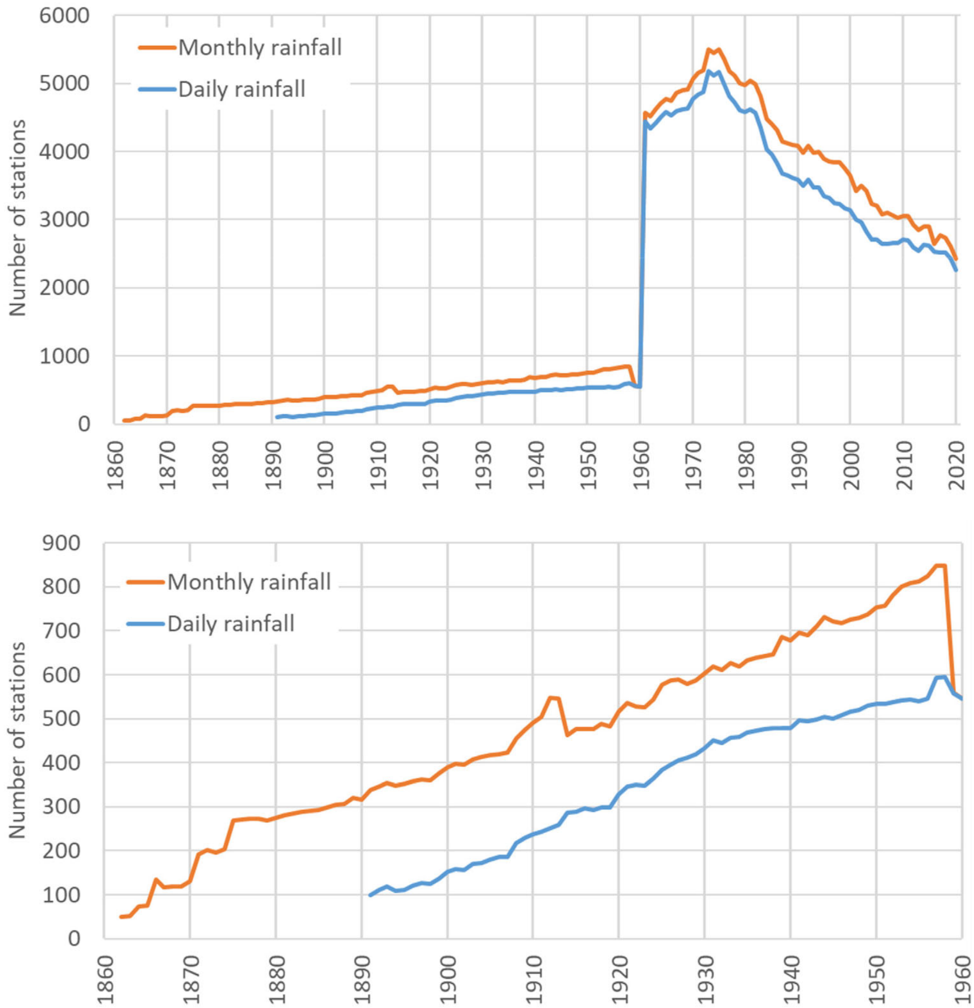
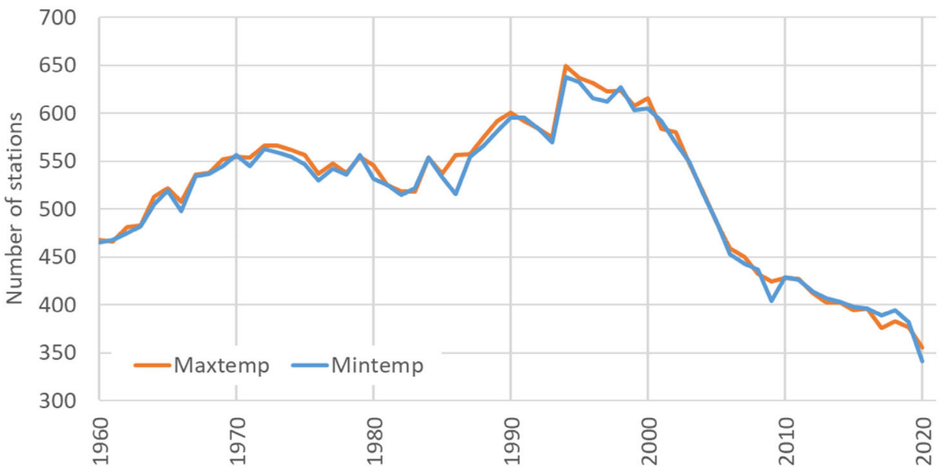


FIGURE A1.3 Number of stations used for daily temperature 1960–2020. The number of stations is very similar to monthly maxtemp and monthly mintemp as shown in Figure A1.1



Overall, figures A1.1–A1.3 also emphasize the scope for further data recovery/digitization work, since the increase in station numbers in 1961 reflects an increase in digitized data since this date, but not an increase in the underlying observation network; many records held in paper archives are yet to be recovered. Major Citizen Science data recovery projects such as the University of Reading Rainfall Rescue Project have highlighted the potential to contribute large improvements in station network coverage in earlier years in the series. This is

TABLE A1.2 Approximate total number of observations used for each variable

Climate variable	Number of years	Number of grids	Average number of stations values per grid	Total number of station values
Monthly maxtemp	137	1,644	358	590,000
Monthly rainfall	159	1,908	1819	3,470,000
Monthly groundfrost	60	720	392	280,000
Monthly sunshine	102	1,224	249	300,000
Daily maxtemp	61	22,280	519	11,560,000
Daily rainfall	130	47,483	1,889	89,700,000

ongoing work and such data will continue to feed into future versions of this report.

The approximate total number of station values used to generate the grids for each variable is given in Table A1.2. In total well over 100 million station values have been used to generate the HadUK-Grid dataset, with more than 90% of these accounted for by daily temperature and daily rainfall. Note however, that for monthly variables (e.g., monthly mean maximum temperature), the majority of the monthly station values will have themselves been derived from daily station values (e.g., daily maximum temperature). So in practice the number of *station values* used to generate the grids will differ from the number of *station observations* extracted from the MIDAS database or the other recently digitized data sources.

Figure A1.4 shows the state of the UK's observing network in 2020. The networks are designed and maintained to achieve a good spatial coverage with stations representative of all areas of the UK. Due to the high spatial variation in rainfall, the network is much denser than for other variables, but even so highly localized events may still be missed. While the majority of the UK is reasonably well covered, some areas, notably western Scotland, are more data-sparse than others, but these also tend to correspond to areas with a smaller population. Coverage for some variables (notably sunshine) may considerably reduce if data for an individual station is missing, and where surrounding stations struggle to cover the gap—there is limited redundancy in the network. Overall however, even though the current number of stations may be fewer than in earlier decades (e.g., the 1970s), the spatial distribution of stations is more even, and so there is an improvement in the overall network's ability to capture the spatial characteristics of climate variables over that day, month, season or year.

Long-term average grids

Areal averages for the WMO standard 30-year climatological reference periods 1961–1990 and 1981–2010 presented in this report have been calculated from long-term average monthly gridded datasets at 1 km resolution covering the UK (Hollis *et al*., 2019). The process for producing these grids is outlined as follows: For the majority of variables, long-term averages for each station are calculated from monthly station data. Gaps in individual months at stations are filled with estimates obtained via regression relationships with a number of well-correlated neighbours, and long-term averages are then calculated for each site. Gridded datasets of long-term averages are created by regression against latitude, longitude, elevation, terrain shape, proximity to coast and urban extent, followed by inverse-distance weighted interpolation of residuals from the regressions. The estimation of missing values allows a dense network of stations to be used, and this along with the range of independent variables used in the regression, allows detailed and accurate long-term average datasets to be produced. These are then used to constrain the gridded analyses for individual years, seasons, months and days via the geographical interpolation of deviations from, or ratios of, the long-term average.

However, this method does not work well for a number of variables, including days of air frost and ground frost, and an alternative approach is used. Here, the gridded long-term average datasets are obtained by averaging the monthly grids.

Table A1.3 shows the approximate number of stations used to generate the HadUK-Grid long-term average grids for the period 1981–2010, compared to the average number of stations per monthly grid over the same period. For monthly maxtemp, rainfall and sunshine there are typically two to three times more stations used for the long-term average grids than for the monthly grids for these variables.

Because the long-term average grids are obtained by gridding long-term average station data directly ('average then grid') rather than calculated from the monthly grids ('grid then average') the long-term averages are not exactly consistent with the monthly analyses. This is both because the order of the calculation differs, and because

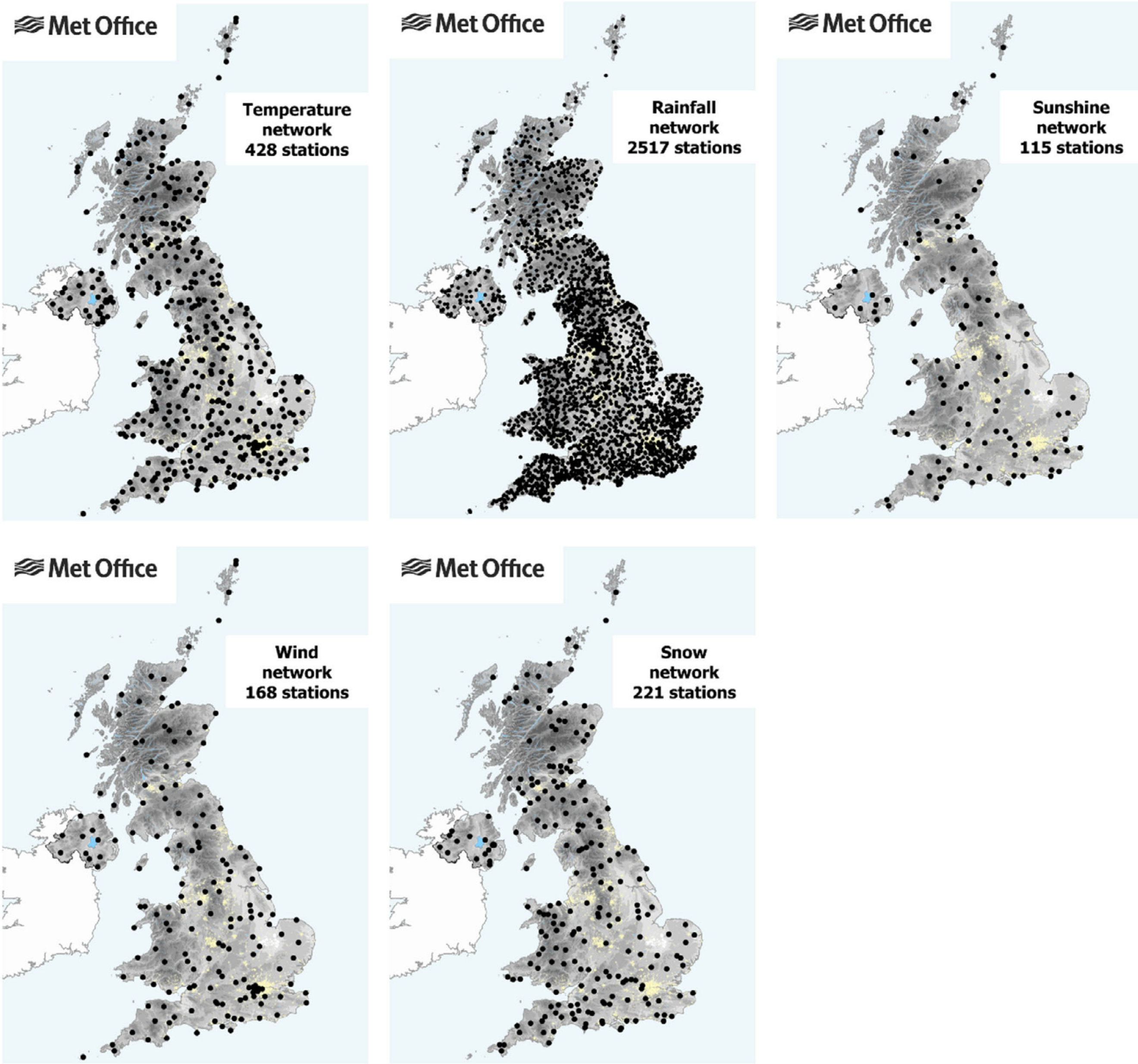


FIGURE A1.4 State of the UK observing network in 2020. The number of observations is indicative as these may vary on a daily basis due to data availability

TABLE A1.3 Number of stations used to generate long-term average grids

Climate variable	Number of station values per monthly long-term average grid (1981–2010)	Average number of station values per monthly grid over period 1981–2010
Air temp	1,202	538
Rainfall	9,657	3,847
Sunshine	617	226

the station network will be very much denser for the long-term average grids than the monthly grids due to the infilling process used when calculating station long-term averages. Table A1.4 compares 1981–2010 long-term average annual mean temperature and rainfall as derived from 1 km long-term average grids, and from the 360 individual monthly 1 km grids. For temperature, the difference of 0.02°C for the UK overall is much smaller than the difference of 0.6°C between 1961–1990 and 1981–2010 1 km long-term averages. For rainfall, the difference

TABLE A1.4 Comparison of 1981–2010 long-term average annual mean temperature and rainfall as derived from 1 km long-term average grids and individual monthly grids

Area	Temperature—Long-term average (°C)	Temperature—Long-term average derived from monthly grids	Difference (°C)	Rainfall—Long-term average (mm)	Rainfall—Long-term average derived from monthly grids	Difference (%)
UK	8.84	8.86	0.02	1,150	1,142	−0.6
England	9.65	9.65	−0.01	853	850	−0.4
Wales	9.12	9.14	0.02	1,463	1,446	−1.2
Scotland	7.39	7.45	0.06	1,563	1,551	−0.8
Northern Ireland	8.91	8.91	0.00	1,136	1,132	−0.3

Note: Differences are calculated from unrounded values.

of 0.6% is also much smaller than the difference of 5% between the 1961–1990 and 1981–2010 1 km long-term averages. These "order of operation" differences are generally small because the long-term average and individual monthly grids are at the same resolution (both 1 km), so, although the values are not exactly equal, the dataset is reasonably self-consistent.

Annual degree days

Degree-day datasets were generated from the daily temperature grids, as indicated in Table A1.1, using formulae given in Tables A1.5 and A1.6. The daily mean temperature T_{mean} is calculated from the daily maximum temperature T_{max} and the daily minimum temperature T_{min} as $(T_{max} + T_{min})/2$. The degree-day value is estimated differently depending on which of T_{max}, Tmean or T_{min} are above (for Cooling Degree Days and Growing Degree Days) or below (for Heating Degree Days) the defined threshold.

Consistency and quality control

Quality control of station observations held in the Met Office Integrated Data Archive System (MIDAS) database is the responsibility of the Met Office Observations Quality Management (OBQM) team. This team runs a suite of both automated and manual quality control checks on MIDAS, which is the source of the majority of the station data used in HadUK-Grid. The other digitized data sources have also had quality checks at time of digitization where possible. For example, tables of monthly rainfall published in British Rainfall also include annual totals, so the latter can be used as a "closure check" on the monthly totals. Development of the HadUK-Grid dataset and improvement in quality control processes to remove as much suspect data as possible, whilst avoiding the removal of good data, remains an active area of research and development and will feed into future versions. Further details are beyond the scope of this report.

The HadUK-Grid dataset uses open-source ancillary files for terrain elevation, proximity to coast and urban land use that are used within the interpolation scheme, which provides traceability. The dataset is also version controlled—including a version-controlled numbering system, so State of the UK Climate publications can all be linked to a specific version of the dataset. This report uses version 1.0.3.0 of the HadUK-Grid dataset. Details

TABLE A1.5 Formulae used for calculating cooling or growing degree days above thresholds of 22 and 5.5°C

Condition: daily T_{max} T_{min} and T_{mean} above or below $T_{threshold}$	Degree-day value
$T_{max} \le T_{threshold}$	0
$T_{min} \ge T_{threshold}$	$T_{mean} - T_{threshold}$
$T_{mean} \ge T_{threshold}$ and $T_{min} < T_{threshold}$	$0.5\,(T_{max} - T_{threshold}) - 0.25\,(T_{threshold} - T_{min})$
$T_{mean} < T_{threshold}$ and $T_{max} > T_{threshold}$	$0.25\,(T_{max} - T_{threshold})$

TABLE A1.6 Formulae used for calculating heating degree-days below a threshold of 15.5°C

Condition: Daily T_{max} T_{min} and T_{mean} above or below $T_{threshold}$	Degree-day value
$T_{min} \ge T_{threshold}$	0
$T_{max} \le T_{threshold}$	$T_{threshold} - T_{mean}$
$T_{mean} \le T_{threshold}$ and $T_{max} > T_{threshold}$	$0.5\,(T_{threshold} - T_{min}) - 0.25\,(T_{max} - T_{threshold})$
$T_{mean} > T_{threshold}$ & $T_{min} < T_{threshold}$	$0.25\,(T_{threshold} - T_{min})$

of the HadUK-Grid dataset are provided in Hollis *et al*. (2019).

Areal series

The monthly series for the UK and countries are calculated as area-averages derived from the 1 km monthly gridded datasets. Each monthly value is an average of all the individual 1 km grid point values which fall within the UK or country. The seasonal and annual series in turn are calculated from the monthly areal series. This approach enables a single statistic to be produced for each area (UK or country) from each grid, despite the fact that the UK's climate has a very high degree of spatial variation (e.g., with elevation). These statistics are self-consistent through time. In the same way, long-term averages are calculated as an average of all the individual 1 km long-term average grid points which fall within the UK or country. Daily area-averages have similarly been calculated from the 1 km daily gridded datasets.

Statistics for the UK and countries are useful for monitoring annual variability, trends and extremes but inevitably may mask considerable spatial variation across the area as shown in the anomaly maps.

Central England Temperature

The Central England Temperature (CET) monthly series, beginning in 1659, is the longest continuous temperature record in the world (Manley, 1974). It comprises the mean of three observing stations covering a roughly triangular area of England from Bristol to London to Lancashire; the current stations used for this series are Pershore College (Worcestershire), Rothamsted (Hertfordshire) and Stonyhurst (Lancashire) although the stations used in this series have changed in the past. A CET daily series is also available from 1772 (Parker *et al*., 1992).

Following each station change the data are adjusted to ensure consistency with the historical series by analysing periods of overlap between stations, and since 1974 the data have been adjusted to allow for any artificial warming effects due to the expansion of local built-up areas. Parker and Horton (2005) and Parker (2010) have investigated uncertainties in the CET series.

Global surface temperature

HadCRUT5 is a gridded dataset of global historical surface temperature anomalies relative to a 1961–1990 reference period. Data are available for each month from January 1850 (Morice *et al*., 2021). The HadCRUT5 dataset of global surface temperature comprises a blend of the CRUTEM5 land-surface air temperature dataset

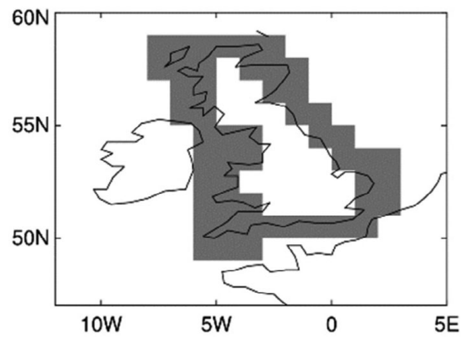


FIGURE A1.5 1° grid cells from HadISST1 used to calculate UK near-coast SST

(Osborn *et al*., 2021) and the HadSST4 sea-surface temperature dataset (Kennedy *et al*., 2019). CRUTEM5 anomaly fields are based on a compilation of monthly-mean temperature records from a global network of several thousand weather stations. HadSST is produced by taking in situ measurements of SST from ships, moored and drifting buoys, stored in the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). The HadCRUT5 global average values are calculated as the 'best estimate' mean of 200 ensemble member realizations. HadCRUT5 is one of several global surface temperature datasets, with others produced by NOAA, NASA and Berkeley Earth.

Sea-surface temperature data

The Met Office Hadley Centre's sea ice and sea surface temperature (SST) data set, HadISST1 is a global dataset of monthly SST and sea ice concentration on a 1° latitude–longitude grid from 1870 to date (Rayner *et al*., 2003). The dataset is derived from a combination of fixed and drifting buoys, ship bucket and engine room intake thermometers and hull sensors; and satellite data. The UK near-coast SST series in this report comprises the average of all 1° latitude–longitude grid cells adjacent to the coast of Great Britain (approximately 50 grid cells). These grid cells were selected to ensure that all the main UK landmass falls within this area (Figure A1.5).

England and Wales precipitation series

The England and Wales precipitation series (EWP) has monthly data back to 1766, and is the longest instrumental series of this kind in the world. The daily EWP series begins in 1931. The series incorporates a selection of long-running rainfall stations to provide a homogeneity-adjusted series of areal-averaged precipitation. EWP totals are based on daily weighted totals from a network of stations within each of five England and Wales regions.

The extent to which seasonal trends apparent in the EWP series are influenced by homogeneity issues (e.g., the number of stations used historically to compile the EWP series, how well the network has historically captured orographically enhanced rainfall across high ground, how well the network has historically captured precipitation which has fallen as snow) remains an area of investigation, and trends in the series should be treated with caution (Murphy *et al*., 2020). Various articles detail the development of the EWP series (Wigley *et al*., 1984; Alexander and Jones, 2001; Simpson and Jones, 2012).

Rain gauge and snow depth data

Daily rainfall data presented in this report are 0900–0900 UTC totals from either daily or tipping-bucket rain-gauges registered with the Met Office. The rain-gauge network has diminished from over 4,000 rain-gauges across the UK in the 1960s to between 2,500 and 3,000 in the 2010s. The gauges are owned and maintained by several organizations: the Met Office, the Environment Agency, Natural Resources Wales, SEPA and Northern Ireland Water. The spatial distribution of the network has changed with time but nevertheless the high network density ensures that all but the most localized convective events are captured at a daily time-scale.

Snow depth data are recorded at 0900 UTC. These are either spot observations from automatic snow depth sensors or manual observations of representative level depth in a location free from drifting or scour by wind; ideally the average of three measurements would be recorded. The network comprised over 400 stations from 1960 to 2000 but has subsequently reduced to around 200 stations in 2020.

Sunshine data

The UK's sunshine network in 2020 comprises two instrument types: approximately 40% Campbell–Stokes (CS) sunshine recorders which are read manually; the remainder Kipp & Zonen CSD-1 (KZ) automatic sunshine recorders. An upwards adjustment of KZ totals is made to give a monthly ‘CS equivalent sunshine’. This ensures that the full sunshine network (automatic and manual) is used while maintaining consistency between the two instrument types. Legg (2014a) and references therein provide further details.

Wind data

Wind speeds are measured by cup anemometers located on a standard 10m height mast. The rate of rotation is proportional to the speed of the wind. At mountain stations, wind speeds are measured by heated sonic anemometers which have no moving parts and avoid potential problems with icing.

Sea level data

Sea-level changes around the British Isles are monitored by the UK national network of tide gauges; for 2020 this network comprised 42 stations. For more than 100 years tide gauges have provided measurements of sea-level change relative to the Earth's crust. However, tide gauges are attached to the land, which can move vertically thus creating an apparent sea level change. A UK sea level index for the period since 1901 computed from sea level data from five of these stations (Aberdeen, North Shields, Sheerness, Newlyn and Liverpool) provides the current best estimate for UK sea level rise, excluding the effect of this vertical land movement. The records from each station are combined after removing the long-term trend from each to account for varying vertical land movement rates across the country. After aggregating the records, the calculated country-wide average rate of 1.4 mm·year^{-1} is reintroduced (Woodworth *et al*., 2009a; Bradley *et al*., 2011). Trends in the index are calculated using the CATS (Create and Analyse Time Series) package described in Williams, 2008, which produces realistic estimates of uncertainty by accounting for autocorrelation in the series.

For comparison, recent work (Hogarth *et al*., 2020) has produced a ‘Final Common Mode’ UK sea level index based on an expanded set of 48 tide gauge records, and using extra metadata and records of maintenance recovered from archives to extend existing sea level records. The two indices are complementary, however, not strictly comparable as the Hogarth *et al*. series also removes the effects of seasonal cycles, tides, and storm surges. Nevertheless, the fitted trend of 2.4 ± 0.3 mm·year^{-1} in the Hogarth *et al*. index is in broad agreement with the 1.8 ± 0.3 mm·year^{-1} of the index described here over the period 1958–2018. Similarly, the Hogarth index shows higher acceleration over the same period of 0.058 ± 0.030 mm·year^{-2}, compared to 0.034 ± 0.019 mm·year^{-2} here, but again, results agree within the margin of errors.

As mentioned in Woodworth *et al*. (2009a), the network of 42 stations falls under the responsibility of the Environment Agency (it is no longer operated by the Proudman Oceanographic Laboratory). Only five sites date back to the beginning of the 20th century: the others did not begin until the 1950s. In creating the long-term index, we follow Woodworth's approach, which only uses data from the long-term series. Woodworth *et al*. (2009a), which is based on data from up to 2006, notes that throughout the course of the record, at least three of the five stations are present for all years apart from three, the last of which was 1915. Unfortunately, from 2007 onwards, there have been more gaps in observations for the five stations. We are unable to add a value for 2020 as the five stations were either damaged or not producing climate quality data for sustained periods throughout the year. A UK national report in 2019 for the biannual Global Sea Level Observing System (GLOSS) meeting provides more information about issues with the network, available at https://www.jcomm.info/index.php?option=com_oe&task=viewDocumentRecord&docID=24144

Phenology data

Nature's Calendar, run by the Woodland Trust, has been collating information on the timing of the seasons for over 20 years. Furthermore, it has built up a considerable database of older data, derived from a number of sources. Current data, recorded by citizen scientists across the UK, identify dates on which particular phenological events are observed. Here, we show UK mean dates for the first unfolded leaf ('first leaf') in spring and first bare tree ('bare tree') in autumn for four common shrub or tree species: Elder (*Sambucus nigra*); Hawthorn (*Crataegus monogyna*); Pedunculate Oak (*Quercus robur*); Silver Birch (*Betula pendula*).

First leaf and bare tree dates for the baseline period, 1999–2019, derived from annual means, are compared with those for 2020. To assess the relationships with temperature, we have compared the 1999–2020 annual mean dates for first leafing to monthly CET for the month incorporating the mean date and the preceding 2 months. We report the response to a 1°C increase in the months that were significantly associated with first leafing date. We also compare 1999–2020 annual means of bare tree dates to October mean CET, since experience has shown that the influential window for autumn events is much shorter. CET provides a reasonable representation of the inter-annual temperature variations across the UK, for comparison with the UK-wide phenology indicators.

ANNEX 2: TIME-SERIES, TRENDS AND UNCERTAINTY 2

Time-series and trends shown in this report

The time-series in this report are plotted on either actual or anomaly scales. The plots with anomaly scales often show several different areas, seasons or variables which are offset for clarity and ease of comparison; the offsets do not reflect absolute differences between the time-series.

The time-series shown throughout are plotted showing the annual series and a smooth trend. This means that both annual variability and longer-term trends (removing this short-term variability) can be viewed simultaneously. Importantly, we note that for some series there may be few individual years that fall close to this long-term trend; and many or even most years may fall well above or well below. Most time-series plots also include the 1981–2010 and 1961–1990 long-term averages.

The smooth trend-lines are constructed using a weighted kernel filter of triangular shape, with 14 terms either side of each target point. The kernel defines how much weighting the terms either side of a point in the series have in estimating the smoothed average at that point; in this case the triangular shape using 14 data points either side means that data points further away have less influence. The effect is to smooth out the year-to-year variations and estimate any longer-term variations in the data. The kernel is reflected at the ends of the time series so the trend lines cover the full length of the series. However, this process of reflection will tend to damp any trends at the ends of the time series, so the trend line for the first and last decade of each series should be interpreted cautiously. The method of creating smoothed trend-lines using a 'non-parametric regression' is described in Mudelsee, 2019, who describes the advantages and disadvantages of various possible statistical approaches in trend analysis of climate time-series.

Climate records at individual stations may be influenced by a variety of non-climatic factors such as changes in station exposure, instrumentation and observing practices. Issues of changing instrumentation and observing practices will tend to be of greater importance early in the series, particularly before the 20th Century. In contrast, station exposure issues related to urbanization, which may for example, affect temperature-related variables, may be of greater importance in the late part of the series from the mid-20th Century, although this is likely to vary on a station by station basis—for example, whether a station is located in the centre of a large city or nearer the periphery, the latter being more likely to have changed over time. Identifying and correcting for such factors in climate monitoring is referred to as homogenisation. Some homogenisation has been undertaken for some series presented in this report, such as the CET record, and the adjustment of sunshine records described in Annex 1. For most variables however, the individual station data in this report have not been explicitly homogenized to account for these non-climatic factors.

We note that the 1961–1990 and 1981–2010 averages presented are not exactly consistent with the average of the yearly data through the same period (see Annex 1 discussion on long-term averages and Table A1.4), although in practice any differences are small. We use averages derived from 1961–1990 and 1981–2010 gridded data because they contain the most comprehensive set of stations, and thus represent our best estimate of these climatologies.

Uncertainty estimates

Earlier studies have considered uncertainties in the gridded data and areal-averages based on a 5 km 'legacy' gridded dataset previously used for UK climate monitoring (Legg, 2011; Legg, 2015). The HadUKGrid 1 km gridded dataset, while at a different resolution, uses the same method of interpolation, and a key source of uncertainty in both datasets is associated with spatial sampling—that is, the density of the observation network, which is the same in both cases. We therefore anticipate the uncertainty estimates for HadUK-Grid associated with spatial sampling to be similar to those of the 5 km gridded dataset. The uncertainty estimates in these studies have been adjusted upwards to acknowledge other sources of error, for example, observational errors such as random errors in instrument readings, calibration errors or structural uncertainty (the latter implying that alternative methods of analysis may produce slightly different results). Legg (2015) published uncertainty ranges for areal-averages of monthly mean temperature, rainfall and sunshine; these increase in the past as the network density reduces.

Table A2.1 lists 1σ uncertainty (standard error) ranges for annual mean temperature, rainfall and sunshine for different periods in the legacy 5 km gridded dataset. Indicative date periods are presented here. These correspond to: the earliest years in the 5 km dataset where the availability of station data was generally lowest and uncertainty highest; a period in the dataset around the 1960s which for rainfall corresponds to a step increase in availability of station data and corresponding decrease in uncertainty; and a relatively recent period in the dataset indicating current uncertainty. More comprehensive tables covering the full date range can be found in Legg (2015). We have applied a conservative reduction factor of √2 to convert monthly uncertainty ranges to annual. Uncertainty associated with individual months of the year cannot be considered independent but it is reasonable to assume that winter half-year biases are likely to be different in nature from summer half-year biases (Parker, 2010). Seasonal uncertainty ranges are likely to be similar to monthly uncertainty ranges presented in Legg (2015). Uncertainties in the CET and EWP series have also been investigated elsewhere (Parker and Horton, 2005; Parker, 2010; Simpson and Jones, 2012).

Uncertainties in areal rainfall statistics may potentially be large for small (county-sized) areas early in the series due to the relatively small number of stations pre-1900. Rainfall will be affected to a much greater extent than temperature due to the much greater spatial variation, whereas temperature tends to be a much smoother varying field. This means that ranking of years (e.g., the wettest autumn in the series for county X) may change if more observations were added to the dataset in the future. Further work is required on the HadUK-Grid dataset to assess the uncertainties in areal-average statistics relative to station network density and area size.

The summary rainfall statistics for the UK and countries presented in this report are based on an areal average of the rainfall total in mm, rather than an areal average of the rainfall anomaly field as a percentage. This is judged to be the simpler and more readily

Temperature (°C)					
Year range	**UK**	**England**	**Wales**	**Scotland**	**Northern Ireland**
1910–1919	0.04	0.04	0.06	0.06	0.08
1961–1965	0.03	0.03	0.04	0.03	0.04
2006–2012	0.03	0.03	0.04	0.04	0.04
Rainfall (%)					
Year range	**UK**	**England**	**Wales**	**Scotland**	**Northern Ireland**
1910–1919	1.2	1.2	3.0	2.8	3.7
1961–1965	0.3	0.3	0.6	0.5	0.8
2006–2012	0.4	0.4	0.9	0.7	1.6
Sunshine (%)					
Year range	**UK**	**England**	**Wales**	**Scotland**	**Northern Ireland**
1929–1935	0.7	0.8	1.0	1.0	1.6
1959–1964	0.6	0.8	0.9	0.8	1.4
2005–2012	0.7	0.9	1.1	1.1	1.8

TABLE A2.1 1σ uncertainty (standard error) ranges for annual T_{mean}, rainfall and sunshine comprehensible statistic for the majority of users and is directly proportional to the total volume of rainfall across the country. However, it means that climatologically wetter areas of the UK have a greater influence on the overall UK summary statistic than the drier areas, rather than all equal-sized areas having equal influence (as would be the case using an areal average of the rainfall anomaly field). This introduces uncertainty because the rank of each year relative to the others may vary depending on which of these two metrics is chosen (Kendon and Hollis, 2014). It may also influence any trend in overall UK rainfall if this varies spatially between climatologically wetter and drier parts of the UK.

A further source of uncertainty in the rainfall data is introduced by measurement of precipitation which has fallen as snow. At manually read rain gauges the observer will measure precipitation equivalent of fresh snow fallen at 0900 UTC, whereas at automatic rain gauges any snow collected will be recorded when it subsequently melts; quality control of these data may then re-apportion this precipitation to previous days. However, inevitably snow measurement can be problematic, for example, if wind eddies may carry snow over or blow it into or out of the gauge, in many situations estimation of precipitation from snow may be either underestimated or overestimated. However, this now tends to be usually less of a problem than during colder, snowier years of earlier decades.

Coefficient of determination

The coefficient of determination, R^2, is the square of the correlation coefficient, R, between a predictor variable and a dependent variable based on linear least-squares regression. The R^2 value is a statistical measure of how closely the dependent variable can be predicted from the predictor variable. An R^2 value of 1 would indicate a perfect correlation, in which the dependent variable can be predicted without error from the predictor variable. An R^2 value of 0 would mean the predictor variable has no predictive value for the dependent variable. An R^2 value of .5 would mean that 50% of the variance in the dependent variable can be explained by variations in the predictor variable. R^2 values exceeding .9 for time-series in this report would indicate that they are very highly correlated.

Rounding

Values quoted in tables throughout this report are rounded, but where the difference between two such values is quoted in the text (e.g., comparing the most recent decade with 1981–2010), this difference is calculated from the original unrounded values.

ANNEX 3: USEFUL RESOURCES 3

Met Office

Annual State of the UK climate publications from 2014 http://www.metoffice.gov.uk/climate/uk/about/state-of-climate

UK climate information http://www.metoffice.gov.uk/climate

HadUK-Grid information https://www.metoffice.gov.uk/climate/uk/data/haduk-grid/haduk-grid

The CET dataset is maintained by the Met Office Hadley Centre and can be downloaded at http://www.metoffice.gov.uk/hadobs/hadcet/

The EWP dataset is maintained by the Met Office Hadley Centre and can be downloaded at http://www.metoffice.gov.uk/hadobs/hadukp/

The HadISST1 dataset is maintained by the Met Office Hadley Centre and can be downloaded at http://www.metoffice.gov.uk/hadobs/hadisst/

The HadSLP2 dataset is maintained by the Met Office Hadley Centre and can be downloaded at https://www.metoffice.gov.uk/hadobs/hadslp2/

The HadCRUT5 dataset is maintained by the Met Office Hadley Centre and can be downloaded at https://www.metoffice.gov.uk/hadobs/hadcrut5/

Met Office DataPoint (for application developers) https://www.metoffice.gov.uk/datapoint

Met Office UK Storm Centre Name our Storms project https://www.metoffice.gov.uk/weather/warnings-and-advice/uk-storm-centre/index

Further information on data products available from the Met Office may be obtained by contacting the Customer Centre http://www.metoffice.gov.uk/about-us/contact

External links

The Met Office is not responsible for the content of external internet sites

Access to HadUK-Grid dataset (open access) https://catalogue.ceda.ac.uk/uuid/4dc8450d889a491ebb20e724debe2dfb

Access to a copy of the Met Office Midas database is available to researchers on registration at http://catalogue.ceda.ac.uk/uuid/220a65615218d5c9cc9e4785a3234bd0

Bulletin of the American Meteorological Society (BAMS) State of the Climate Report https://www.ncdc.noaa.gov/bams

WMO Annual Bulletin on the Climate in region VI (Europe and Middle East) https://www.dwd.de/EN/ourservices/ravibulletinjahr/ravibulletinjahr.html

Centre for Ecology and Hydrology, National Hydrological Monitoring Programme, Monthly Hydrological

Summaries for the UK http://nrfa.ceh.ac.uk/monthly-hydrological-summary-uk

Copernicus Climate Change Service (C3S) (2017): ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate . Copernicus Climate Change Service Climate Data Store (CDS), *date of access*. https://cds.climate.copernicus.eu/cdsapp#!/home

Environment Agency Water Situation Reports for England https://www.gov.uk/government/collections/water-situation-reports-for-england

Marine Climate Change Impact report cards http://www.mccip.org.uk/impacts-report-cards/full-report-cards/

National Tidal and Sea Level Facility UK National Tide Gauge Network (owned and operated by the Environment Agency) http://www.ntslf.org/data/uk-network-real-time

Natural Resources Wales Water Situation Reports for Wales https://naturalresources.wales/about-us/what-we-do/water/resources/water-situation-report-2019/?lang=en

Public Health England heatwave mortality monitoring reports https://www.gov.uk/government/publications/phe-heatwave-mortality-monitoring

Scottish Avalanche Information Service annual reports of the winter season http://www.sais.gov.uk/sais-annual-reports/

University of East Anglia Climatic Research Unit North Atlantic Oscillation (NAO) data https://crudata.uea.ac.uk/cru/data/nao/

University of Reading Rainfall Rescue Project https://www.zooniverse.org/projects/edh/rainfall-rescue

Weather at Oxford in 2020 https://www.geog.ox.ac.uk/research/climate/rms/report20.pdf

WMO guide to climatological practices https://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.php